Diagenesis and Reservoir Quality of the Oligocene Vedder Sandstones, of the Rio Bravo Oil Field, Kern County, California

By

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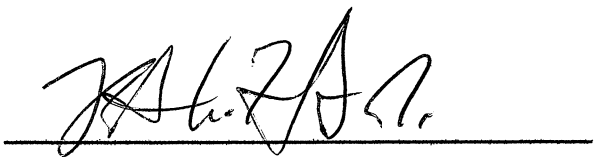

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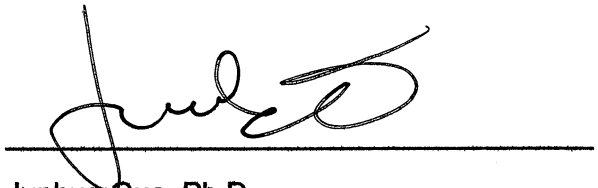

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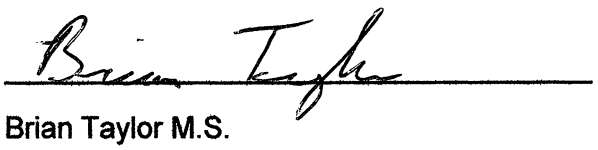

Brian Taylor M.S.

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ABSTRACT

The Rio Bravo oil field is located about fifteen miles northwest of Bakersfield, California. The zone of importance is the Vedder Sandstone, which is about 1,250 ft (380 m) in thickness. The thin (<100 ft, 30 m) Miocene Rio Bravo sandstone, which unconformably overlies the Vedder Sandstone, is included in the main Vedder reservoir. Burial depths range from approximately 10,750 ft (3,277 m) to 12,450 ft (3795 m), with reservoir temperature at 248°F (120°C). These sandstones are presumed to be at or very near their deepest burial depths based upon temperature and burial comparisons of similar oil fields located on the east side of the San Joaquin basin. The mineralogy and lithology of Oligocene sandstones of the Rio Bravo oil field were examined using a petrographic microscope and a scanning electron microscope equipped with an energy dispersive x-ray spectrometer (SEM-EDS) and a cathode luminescence imaging system (SEM-CL).

The Vedder Sandstones are medium-to fine-grain, subangular to subround, very poorly to well-sorted arkosic to lithic arenites deposited as shallow marine sandstones. Accessory minerals of the Vedder Formation include biotite, muscovite, zircon, hornblende, rutile, garnet, epidote, and magnetite/titanomagnetite. The diagenetic features affecting reservoir quality of the Vedder Sandstones include compaction, cementation, deformation, dissolution, recrystallization, and replacement of minerals.

Porosity within the Vedder Sandstones is controlled mainly by compaction and dissolution of framework-grains. Compaction decreased porosity through ductile deformation of shale clasts, micas, and volcanics, which commonly were squeezed into adjacent pores to form pseudomatrix. Rotation and slippage of grains and fracturing of brittle grains were also widespread. Dissolution of framework-grains and carbonate cements created oversized and elongate pores and altered quartz:feldspar:rock fragments, and quartz:feldspar:lithics ratios.

Albitization occurred extensively along fractures in plagioclase and potassium feldspar grains. Precipitation of potassium feldspars occurred as overgrowths on and in fractures within detrital feldspar grains. Plagioclase shows varying degrees of alteration to clay or sericite. Biotite has been altered to chlorite and pyrite. Cements include: clays (kaolinite, chlorite, and mixed-layer illite/smectite or illite/chlorite), and carbonates. Kaolinite occurs as pore-filling cement, commonly associated with feldspar dissolution. Carbonates include calcite and dolomite. Calcite cement occurs within some through going fractures. Both late-stage calcite and dolomite have partially to completely replaced framework-grains.

Textural relationships of the Vedder Sandstones diagenetic minerals delineate the following paragenetic sequence: (1) glauconite; (2) phosphate; (3) burial and alteration of detrital biotite, feldspars, and volcanics; (4) early pyrite cement; (5) biotite altering to chlorite; (6) early grain dissolution; (7) precipitation of rutile; (8) early pore-lining clays coatings; (9) early dolomite cement; (10) anhydrite cement; (11) early calcite cement; (12) compaction; (13) fracturing; (14) grain/cement dissolution; (15) albitization; (16) late pore-lining and pore-filling clays; (17) potassium feldspar overgrowths; (18) quartz overgrowths; (19) zeolite cement; (20) precipitation of barite; (21) hydrocarbon migration; (19) late pyrite cement.

INTRODUCTION

The ability to accurately predict reservoir quality in sandstones (as controlled by porosity and permeability) is one of the most important responsibilities facing a petroleum geologist during hydrocarbon exploration and production. Often, reservoir quality is largely controlled by diagenesis-the chemical, physical, and biological processes that occur subsequent to deposition (Ali, 1981; Pettijohn et al., 1987; Boggs, 1992). Diagenetic processes include compaction, cementation, deformation, dissolution, recrystallization, and replacement of minerals (Hayes, 1979). These processes can significantly alter the reservoir quality by reducing porosity through compaction and cementation or enhancing porosity through dissolution. Understanding the diagenetic history of a reservoir is important because it can reduce the risks when searching for new hydrocarbons and it can also facilitate in the success of enhanced-recovery methods (Ali, 1981; Taylor, 2007).

The Rio Bravo oil field, located about fifteen miles northwest of the city of Bakersfield, California and three miles south of the town of Shafter (Figure 1), has been producing hydrocarbons since their discovery in 1937. Production comes mainly from the Oligocene Vedder Sandstones. Burial depths of the Vedder Sandstones range from approximately 10,750 ft (3,276 m) to 12,450 ft (3,794 m).

The Vedder Sandstones of the Rio Bravo oil field have been identified for potential carbon capture and sequestration (CCS) (Gillespie, 2011). Before CCS can occur the mineralogy and reservoir properties must be evaluated. To date there have been no detailed studies published about the mineralogy, lithology or porosity/permeability of the Vedder Sandstones at the Rio Bravo oil field. This research sets out to determine the mineralogy and lithology of Oligocene Vedder Sandstones of the Rio Bravo oil field, and to interpret the diagenetic processes that have affected reservoir quality by altering porosity and permeability (Pettijohn et al., 1987; Boggs, 1992; Horton et al., 2009). Such information will be crucial in

evaluating enhanced-recovery methods for continuing future oil production. It will also be essential for determining the feasibility for subsurface CO_2 sequestration in these strata (Gillespie, 2011).

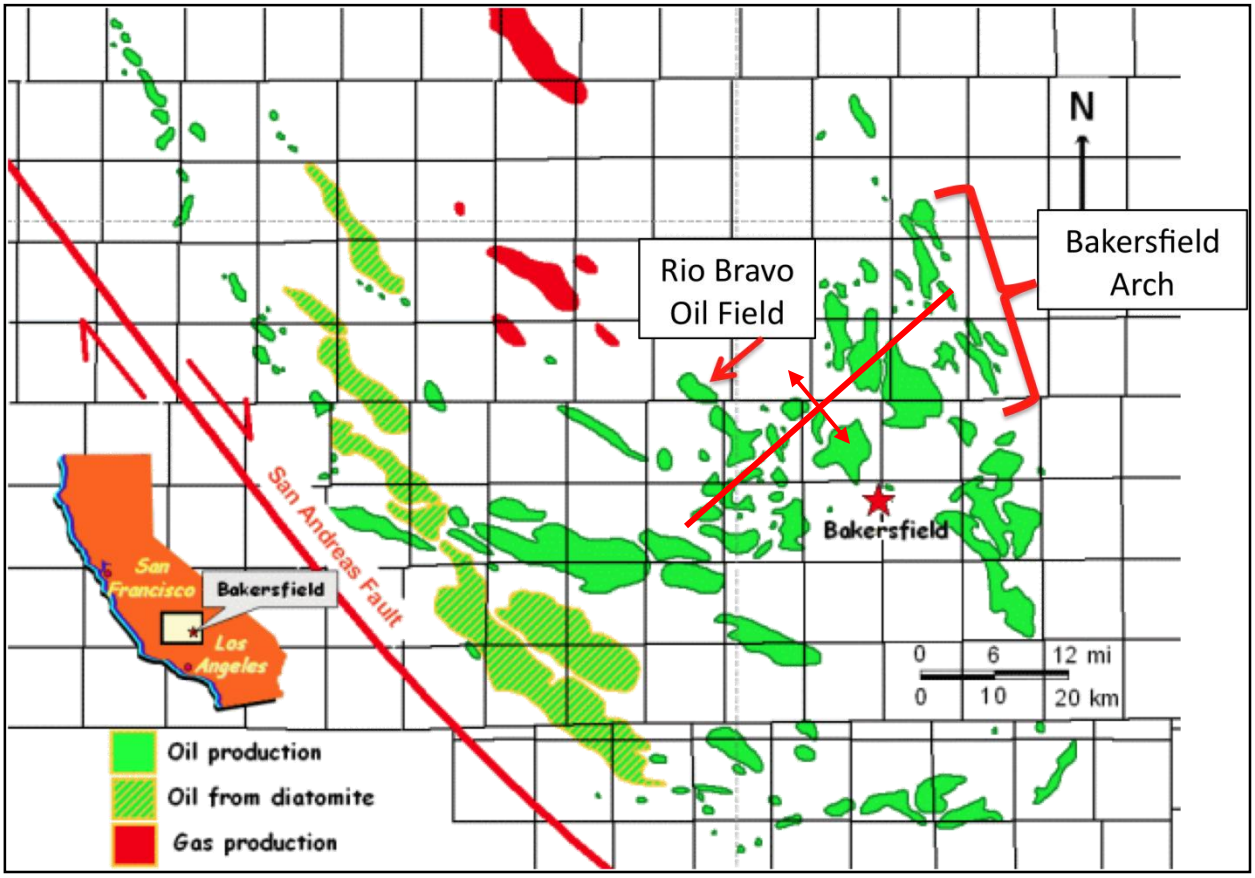


Figure 1: General location map showing the study area within the San Joaquin basin. Modified from sjvgeology.org.

GEOLOGIC AND TECTONIC SETTING

The San Joaquin basin is an asymmetric, sediment-filled (upper Mesozoic and Cenozoic sediments) forearc basin in the central portion of California (Bartow, 1991; Moxon,1988). The basin is bound by the California Coast Ranges (Diablo and Temblor Ranges) to the west, the Sierra Nevada plutonic complex to the east, and the Transverse Ranges (San Emigdio-Tehachapi Ranges) to the south (Figure 2) (Fischer & Surdam, 1988). The Stockton arch to the north separates the San Joaquin basin from the Sacramento basin. The Bakersfield arch (Figures 1, 3), a NE-SW trending anticline, divides the basin into two sub-basins: the Tejon sub-basin (Figure 3) to the south, and the Buttonwillow sub-basin (Figure 3) to the north (Fischer & Surdam, 1988).

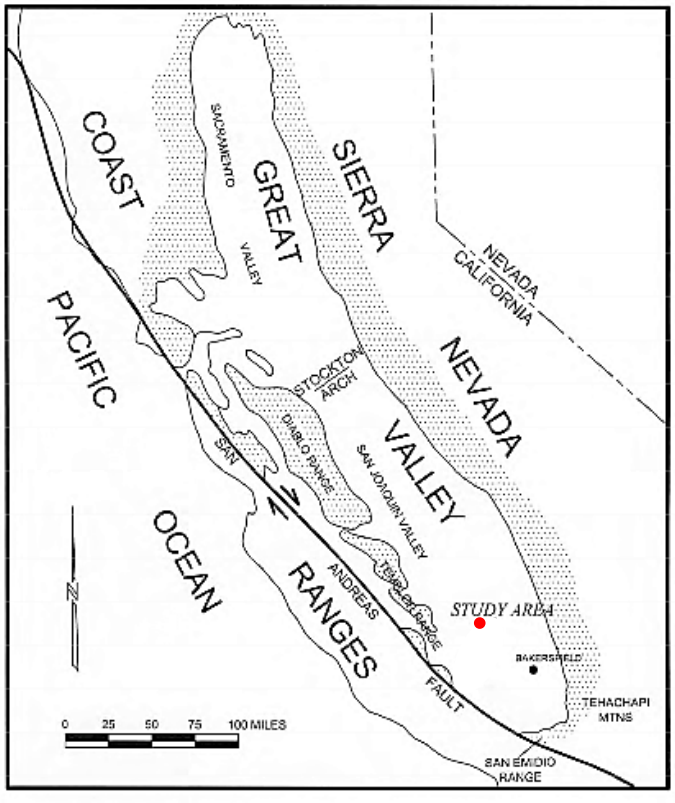


Figure 2: General location map showing the geologic and tectonic setting within the San Joaquin basin. Modified from MacPherson (1978).

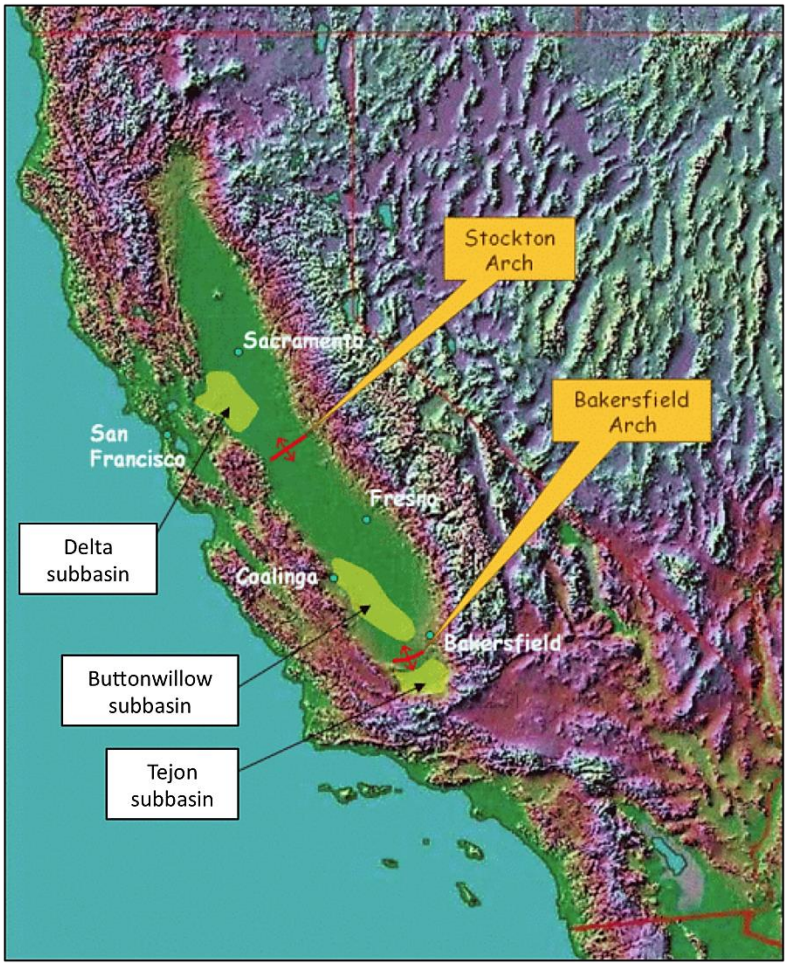


Figure 3: General map of the San Joaquin basin showing the locations of the arches and subbasins. Modified from sjvgeology.org.

The San Joaquin basin is characterized by a complex history of sedimentation and tectonics (Fischer & Surdam, 1988). During Late Jurassic and Cretaceous time, the San Joaquin basin formed the southern part of an extensive forearc basin (Bartow, 1991; Graham, 1987). During the Creatceous the Sierra Nevada arc developed as the Pacific plate subducted beneath the North American plate (Fischer & Surdam, 1988; Reid, 1988). The San Joaquin basin continued to evolve during the Tertiary as the East Pacific Rise collided with the subduction zone along the western margin of the North American plate (Atwater & Molnar, 1973). This consequently created right-lateral strike-slip movement along a fault system termed

the “proto-San Andreas fault” (Nilsen and Clarke, 1975; Bent, 1988). These events transformed the western margin of the San Joaquin basin from convergent-margin tectonics to wrench-style transform-margin tectonics (Bent, 1988). The changing stress regimes and resulting tectonic changes along the western margin of the basin are reflected in fold and thrust faults, which parallel the San Andreas Fault (Figure 2) (Bartow, 1991; Fischer & Surdam, 1988; Harding, 1976; Simonson, 1955; Wilcox et. al 1973). Most of the east-central San Joaquin basin lacks significant structural features other than normal faults concentrated in the area of the Bakersfield arch (Bartow, 1991).

Tertiary sedimentary sequences consist of deep-marine, shallow-marine, and continental deposits which thicken from east to west across the basin (Fischer & Surdam, 1988). The Vedder Sandstones are shallow marine and were deposited on a marine shelf during the Oligocene (Olson, 1988). The Vedder Sandstones contain several thin shale beds between the major sand bodies, and also contain a “grit” zone occurring around 11,315 ft (3,449 m) to 11,325 ft (3,452 m); this consists of a conglomerate of black pebbles with matrix of poorly-sorted and well-cemented sand (Kasline, 1941; Olson, 1988). The “grit” zone may represent small transgressive lags, followed by muddy silty embayment or lagoonal deposits, and capped by shallow-marine sands (Olson, 1988). Evidence from outcrops of the Vedder Sandstones provides support of a depositional environment ranging from inner shelf to the foreshore area (Olson, 1988).

Most known oil accumulations within the Vedder Sandstones are believed to have been sourced from shale of the Kreyenhagen Formation (Isaacson & Blueford, 1984; Lillis & Magoon, 2007), one of the major sources of oil and gas in the San Joaquin Valley. The Kreyenhagen Formation is a thermally mature, transgressive-unit in the Buttonwillow depocenter that covered most of the San Joaquin basin in the Late Eocene (Bartow, 1991; Gautier & Scheirer, 2007a; Gautier & Scheirer, 2007b; Isaacson and Blueford, 1984). The Kreyenhagen Formation is thickest on the west side of the San Joaquin basin and thins to the east (Isaacson & Blueford,

1984). The Eocene Tumey Formation may have also produced and expelled oil in the Vedder Sands (Gautier & Scheirer, 2007a; Gautier & Scheirer, 2007b; Reid, 1988). Both formations are composed of mostly deep-marine shale, with minor siltstone and sandstone interbeds (Isaacson & Blueford, 1984; Reid 1988).

STRUCTURE

The Rio Bravo-Vedder pool at the Rio Bravo oil field consists of an elongated asymmetrical dome trending generally northwest-southeast. It is located on the north flank, just off the crest, of the Bakersfield arch (Figure 1, 3) (Hiatt & Gallagher, 1975; Sullivan & Weddle, 1960). This anticlinal fold extends a distance of 20 miles (32 km), from the Greeley to Wasco oil field. Dips along the southwestern and southern flanks are slight ranging from four to eight degrees, while the northeastern and northern flanks are much steeper at twelve to fifteen degrees. Oil accumulation in the Vedder Sandstones is controlled by structural traps, with stratigraphic traps playing a very minor role (Richardson, 1966). The Rio Bravo oil field also includes several faults (Figure 4). The most important fault runs along the eastern edge of the field and through the center of Section 35. This fault is a continuation of the Greeley fault (south of the Rio Bravo field), which forms the updip closure in the Greeley oil field, and determines the southeastern limits of production for the Rio Bravo oil field. This fault has a vertical displacement of about 250 ft (76 m) (Sullivan & Weddle, 1960). A northern normal fault, downthrown to the east, with vertical displacements from 0 in the south to over 225 ft (69 m) in the north, passes through the northen end of the dome along the eastern border of Section 28. North-west of the former, a third fault trends almost due north-south with vertical displacement ranging from 0 in the south to 140 ft (43 m) in the north. A fourth parallel fault is downthrown to the east and displaces the Rio Bravo Sandstones by approximately 20 ft (6 m). The minor faults are documented as not affecting production, which leads to the hypothesis that the faults formed after the oil was in place (Sullivan & Weddle, 1960).

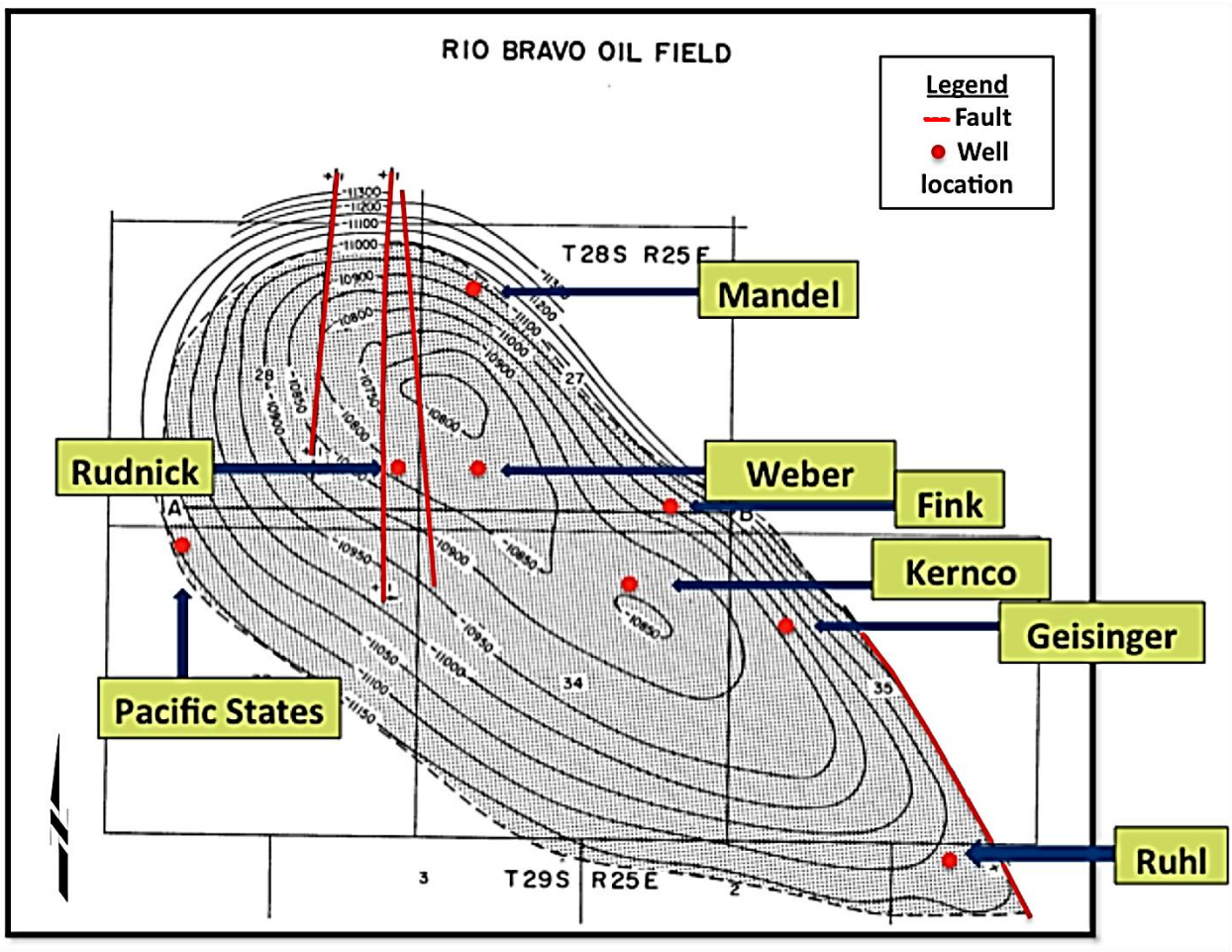


Figure 4: Contour map on top of Rio Bravo Sandstone with the location of wells Fink-1, Geisinger-2, Kernco 61-34, Mandell-3, Rudnick-1, Ruhl-1, Pacific States, and Weber shown. Modified California Division of Oil and Gas (1941).

STRATIGRAPHY

The Vedder Sandstones are widespread in the southeastern San Joaquin basin and range up to 1,246 ft (380 m) in thickness. The Vedder Sandstones crop out as a narrow sand lense ranging up to approximately 260 ft (79 m) thick north of Poso Creek where they are composed of light gray, well-sorted fine- to medium-grain sandstone and dark brown shales (Bartow & McDougall,1984). In general, the Vedder Sandstones increase in thickness from the outcrop belt on the east toward the west as they dip into the San Joaquin basin (Olson, 1988). In the subsurface the marine Vedder Sandstones disconformably overlie and interfinger with the non-marine sandstones of the Walker Formation, which most likely resulted from eustatic oscillation (Olson, 1988). Included within the upper portion of the Vedder Sandstones are three important oil producing zones: Main Vedder, Osborn, and Helbling. The marine Rio Bravo Sandstone unconformably overlies the three upper Vedder Sandstones and is bound above by deep-marine shales of the Freeman-Jewett Formation (Figure 5) (Sullivan & Weddle, 1960).

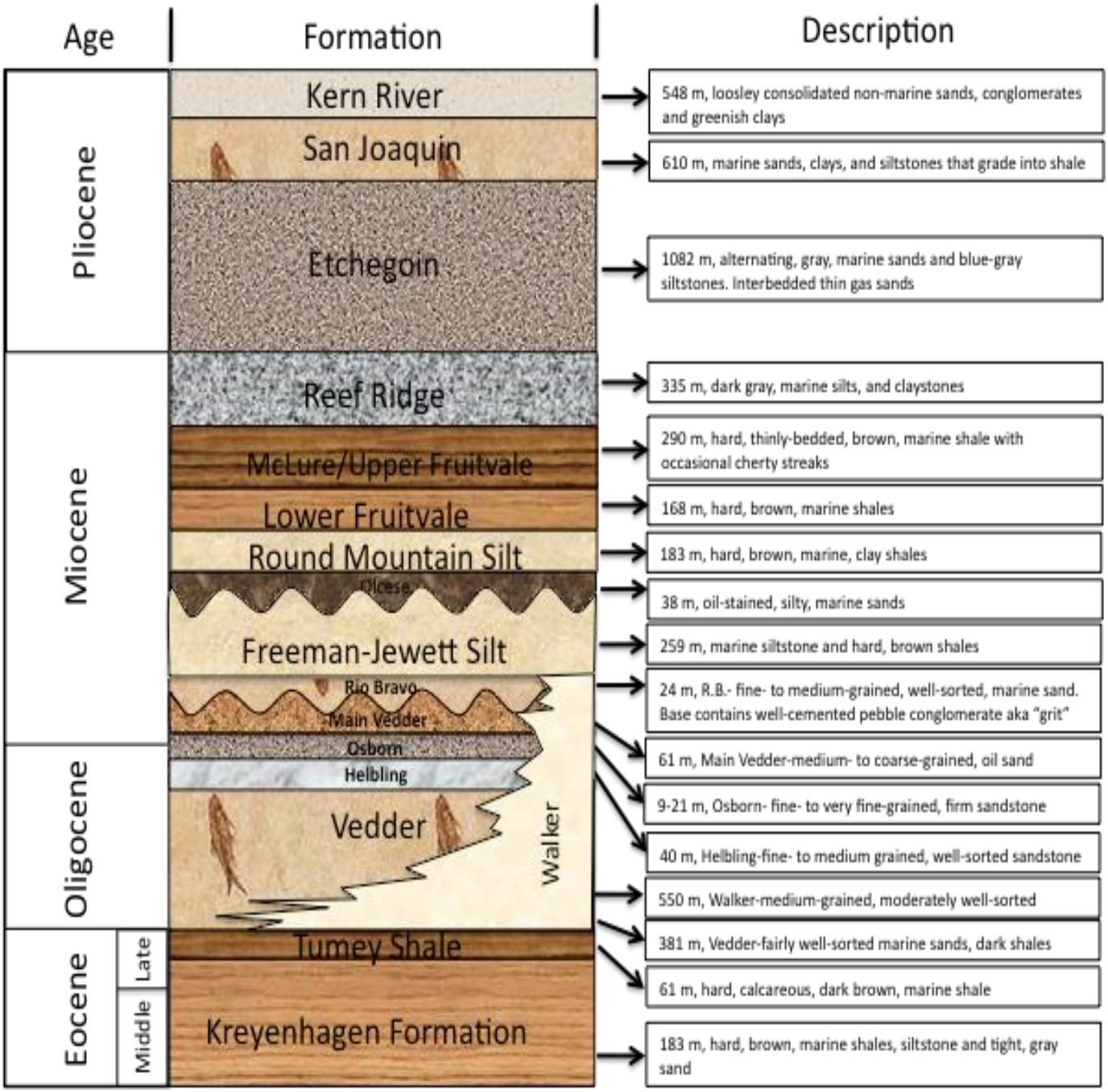


Figure 5: Generalized stratigraphic column of the Rio Bravo oil field. Based on data in Sullivan and Weddle (1960).

METHODS

Research was conducted using samples of the Vedder Sandstones from eight Rio Bravo oil field wells: Fink-1, Geisinger-2, Kernco 61-34, Mandell-3, Rudnick-1, Ruhl-1, Pacific States, Weber (Figure 4). These samples were obtained from the California Well Sample Repository. Samples were taken from depths between 11,380 (3,469 m) to 11,580 ft (3,530 m). Sixty-five (65) thin sections were point-counted (300 points per thin section) using a petrographic microscope. All thin sections were impregnated with a blue epoxy in order to show porosity. Some of the thin sections were stained yellow for potassium. For each thin section the mineralogy, grain size, roundness, and sorting were recorded. Diagenetic features such as cementation, alteration, dissolution, and compaction were also recorded. The methodologies of Schmidt and McDonald (1979) and Shanmugam (1985) were used to distinguish secondary porosity from primary porosity. The petrographic criteria used for recognition of secondary sandstone porosity included: (1) partial dissolution; (2) molds; (3) inhomogeneity of packing and floating grains; (4) oversized pores; (5) elongate pores; (6) corroded grains; (7) honeycombed grains; and (8) fractured grains. Selected thin sections were analyzed using a Hitachi S-3400 scanning electron microscope (SEM) equipped with a back-scattered electron (BSE) imaging and Gatan cathode luminescence (CL) systems, as well as an Oxford INCA energy-dispersive x-ray spectrometer (EDS). The SEM-EDS analytical system supplied the chemical components of the minerals while the SEM-BSE and SEM-CL systems supplied the textural relationships between the cements, detrital grains, and fractures. Each chemical analysis was normally acquired using the SEM in single spot mode with an electron-interaction area of approximately 10µm in diameter.

Quantitative analysis of compaction of the Vedder Sandstones were documented using the contact index (CI) and tight-packing index (TPI) following the methodologies of Wilson and McBride (1998). Sandstone data gathered from petrographic analysis were plotted on three

ternary diagrams following schemes of Dickinson (1970), Dott (1964) as modified by Pettijohn et al. (1987), and Harris (1989).

Mass transfer of aluminum was calculated from point-counted volumes of leached feldspars and authigenic kaolinite. Hayes and Boles (1992) initial average composition of $Na_{0.7}Ca_{0.3}Al_{1.3}Si_{2.7}0_8$ (An_{30}) for plagioclase from the Sierra Nevada was assumed. Assuming all Al^{3+} liberated during feldspar dissolution and precipitated as kaolinite, for each mole of An_{30} plagioclase dissolved, 0.65 mole of kaolinite could have precipitated:

$$Na_{0.7}Ca_{0.3}Al_{1.3}Si_{2.7}0_8 + H^+ + 3.75H_2O \rightarrow$$

(Plagioclase)

$$0.65Al_2Si_2O_5(OH)_4 + 1.4H_4SiO_4 + 0.7Na^+ + 0.3Ca_2 + 0.3OH^-$$

(Kaolinite)

For each mole of K-feldspar dissolved, 0.5 mole of kaolinite could have precipitated:

$$KAlSi_3O_8 + H^+ + 4.5H_2O \rightarrow 0.5Al_2Si_2O_5(OH)_4 + 2H_4SiO_4 + K^+$$

(K-feldspar) (Kaolinite)

Clays other than kaolinite as well as zeolites in the Vedder Sandstones represent potential aluminum sinks, however, they are volumetrically minor and have minimal impact on the aluminum mass balance (Hayes and Boles, 1992). A potential source of error when calculating mass-balance is secondary porosity for which the dissolved mineral could not be identified. Therefore, the mass-balance calculations of the Vedder Sandstones are conservative.

RESULTS

Detrital Composition

The Vedder Sandstones at the Rio Bravo oil field are arkosic to lithic arenites (Figure 6) and plot mostly in the basement uplift and dissected arc region of the QFL diagram (Figure 7). Samples that contained significant amounts of pseudomatrix were further classified as arkosic wackes (Pettijohn et al., 1987). The sandstones are composed of quartz, K-feldspar (orthoclase, microcline, perthite), plagioclase, and rock fragments. The mean value for the Vedder Sandstones is $Q_{44}F_{41}Rf_{15}$.

Framework-grain size of the Vedder Sandstones ranges from fine to medium sand (Figures 8, 9), with wacke grain size typically smaller (Figure 9). The Vedder Sandstones are generally moderately to well sorted with framework grains that vary from angular to subround. Some of the samples are tightly packed as indicated by long (Figure 10), concavo-convex, and sutured grain contacts (Figure 10), as well as brittle-grain fracturing. Ductile minerals such as biotite and volcanic rock fragments are commonly deformed and squeezed into surrounding pore spaces due to compaction.

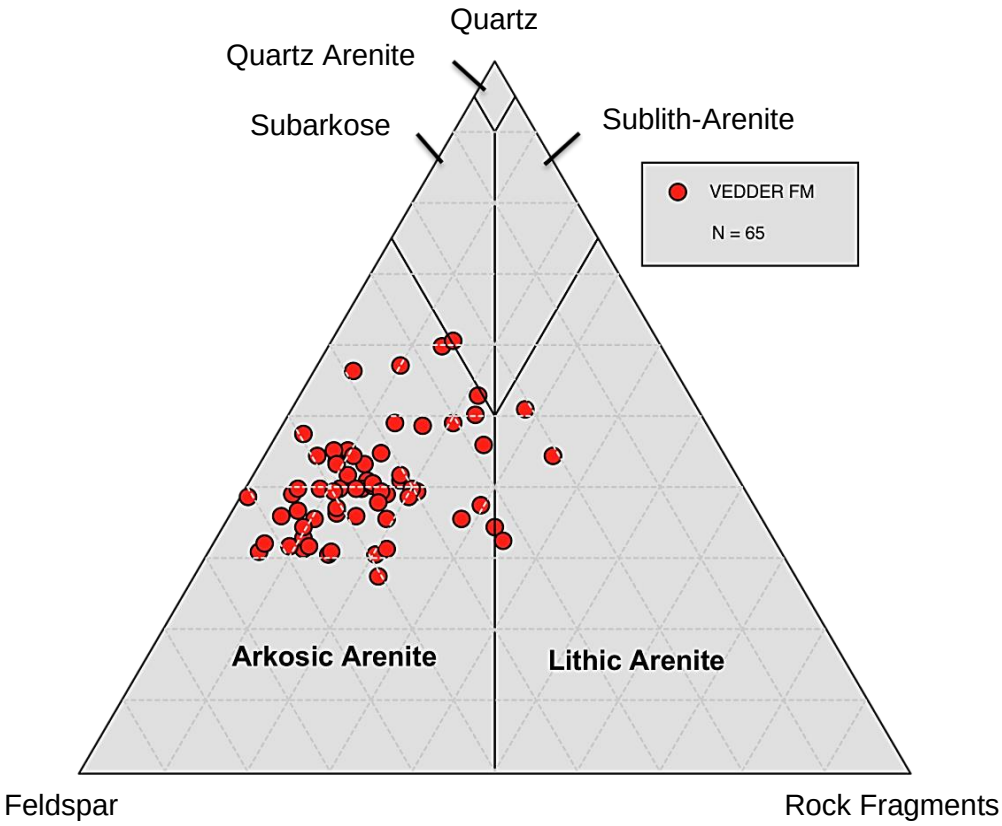


Figure 6: QFRf ternary diagram (Pettijohn et al., 1987) for Vedder Sandstones.

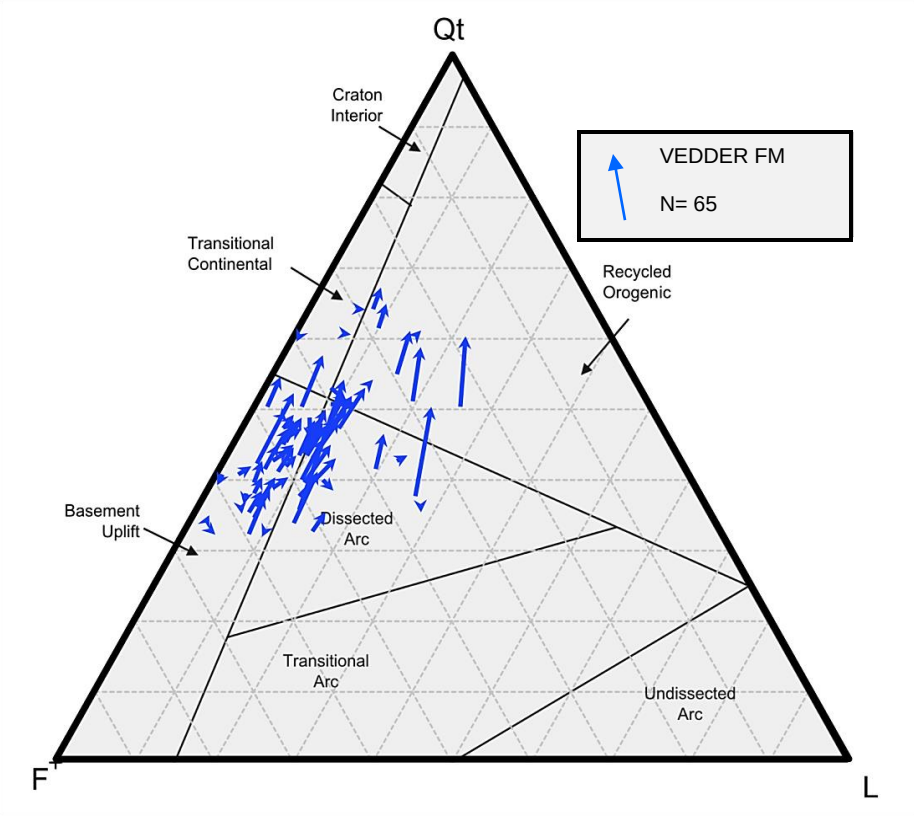


Figure 7: QFL ternary diagram (Dickinson, 1985) for Vedder Sandstones. The arrow heads represent the present composition, the arrow tails represent compositions reconstructed following Harris (1989).

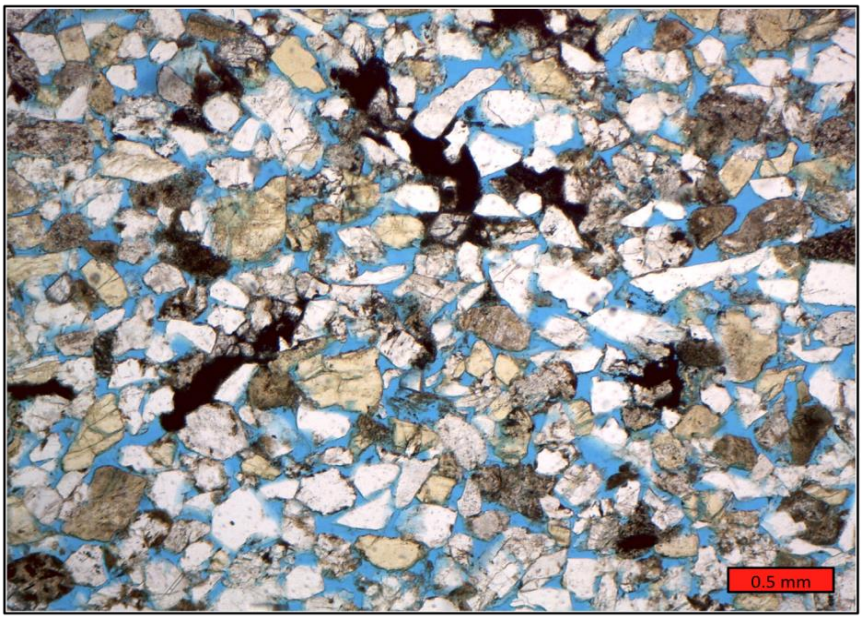


Figure 8: Typical texture of the Vedder Sandstones. The sample shows porosity stained blue. Well: Ruhl, depth: 11,437 ft (3,486 m).

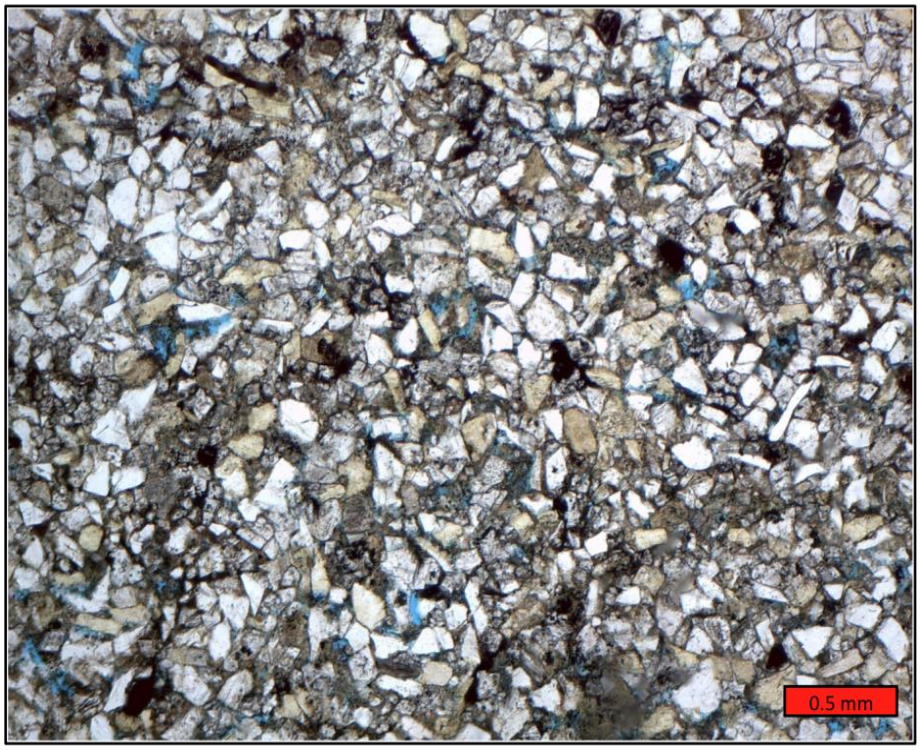


Figure 9: Atypical texture of the Vedder Sandstones with pseudomatix occluding pore space. Well: Ruhl, depth: 11,574 ft (3,528 m).

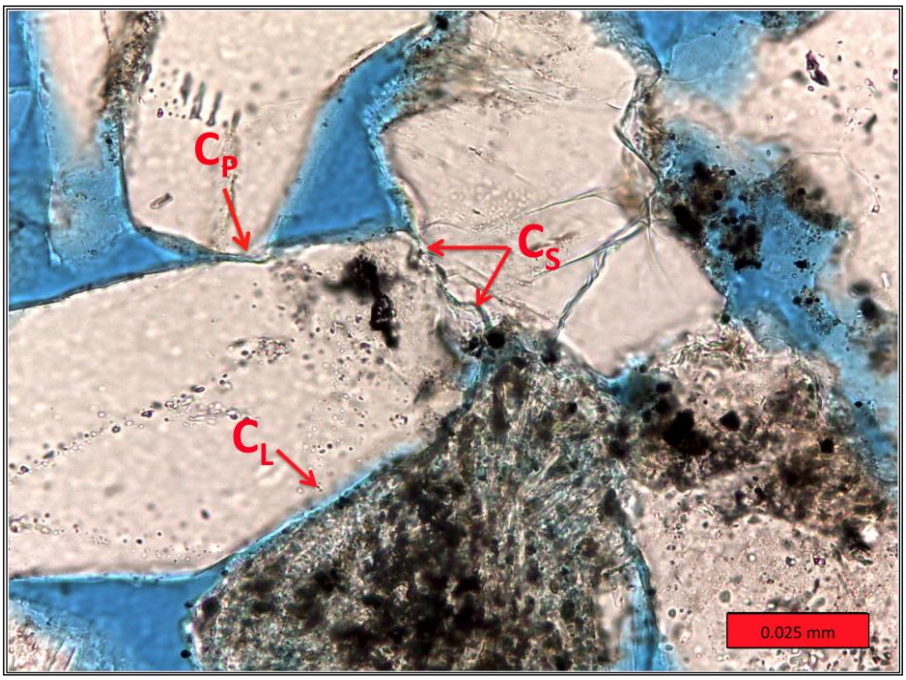


Figure 10: Detrital quartz grains showing evidence of compaction by long (C_L) and sutured contact (C_s) grains. Point contact (C_P) is also present. Well: Fink, depth: 11,387 ft (3,471 m).

DETRITAL MINEROLOGY

Quartz

Quartz is generally monocrystalline and is the most common type of detrital grain in the Vedder Sandstones. Quartz grains range anywhere from 12 to 43% of the rock volume, averaging 23%. Detrital quartz luminesces blue. Other characteristics quartz grains exhibit within the Vedder Sandstones are undulose extinction patterns, cloudy appearances, fracturing, grain-edge dissolution, pressure-induced dissolution, and some vacuoles; however, most quartz grains are free of inclusions.

Potassium Feldspar

Detrital potassium feldspars range from 2 to 16% of the total rock volume and luminesce pink and blue under SEM-CL analysis. Most potassium feldspar grains consist of orthoclase, however, small amounts of perthite and microcline are present in most samples. SEM-EDS analyses indicates potassium feldspar compositions in the Vedder Sandstones range from Or_{83} to Or_{98} (Figure 11). Some grains contain small amounts of barium. Figure 12a shows that total feldspars decrease with depth. Figure 12b is a plot of potassium feldspar vs. depth suggesting a slight decrease in potassium feldspar with increasing depth.

Plagioclase

Detrital plagioclase feldspars range from 5 to 26% of the total rock volume and luminesce pink under SEM-CL analysis. Plagioclase grains were affected by fracturing, alteration, replacement by calcite, and ablitization. SEM-EDS analyses indicates detrital plagioclase ranges from An_{53} to An_{5} (Figure 11). Figure 12c is a plot of plagioclase feldspar vs. depth indicating a general decrease in plagioclase grains with increasing depth. Plagioclase decreases at a higher rate compared to potassium feldspars (Figure 12a-c).

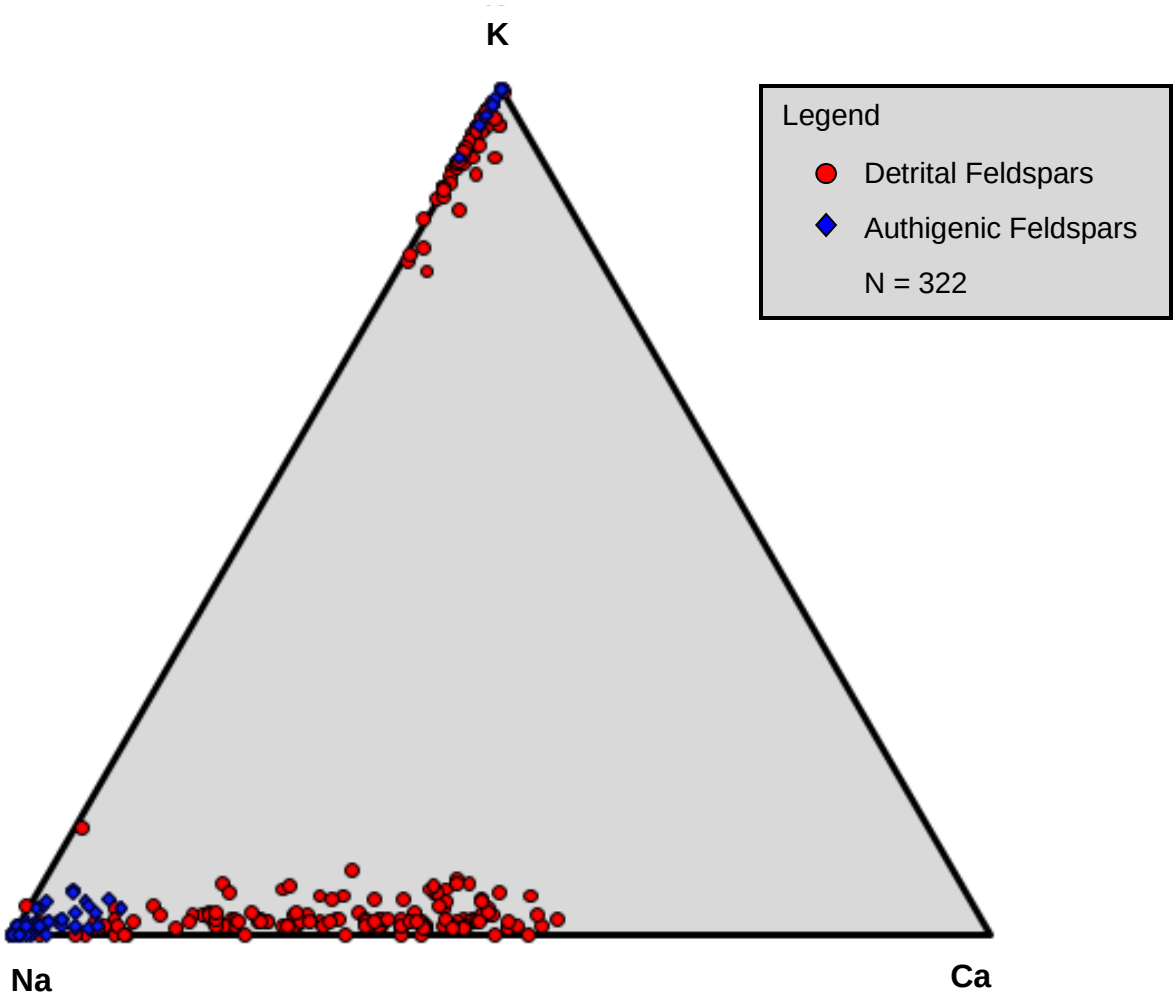
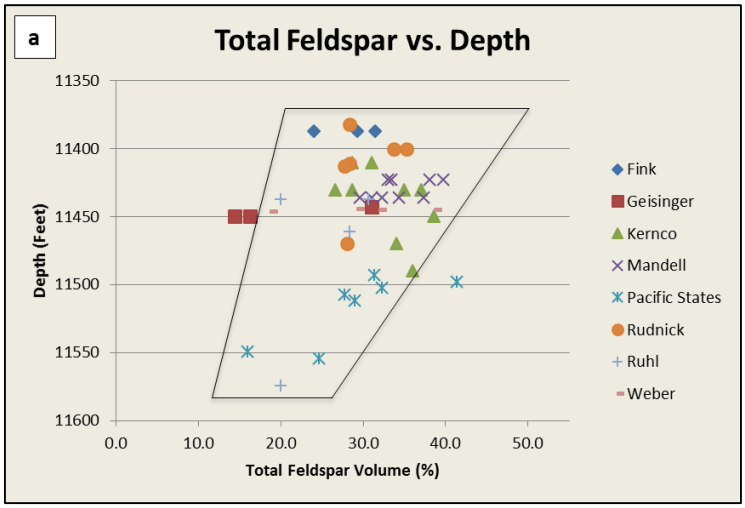
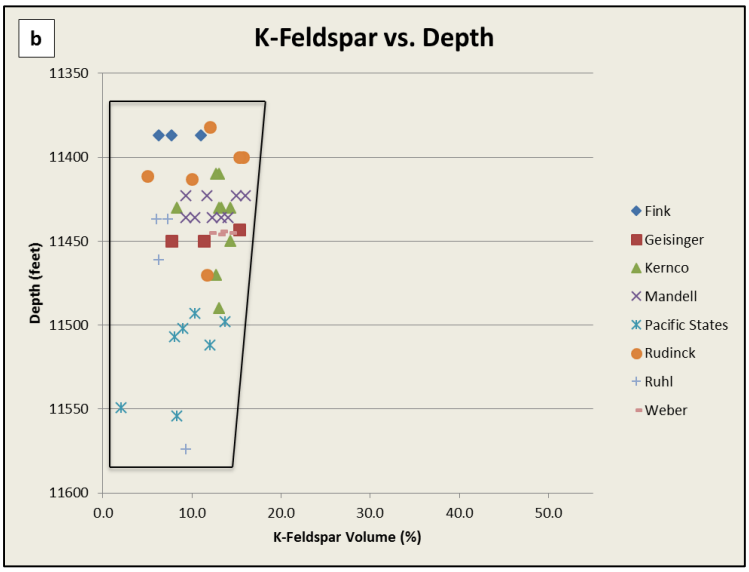


Figure 11: K,Na,Ca ternary diagram of detrital and authigenic feldspars.





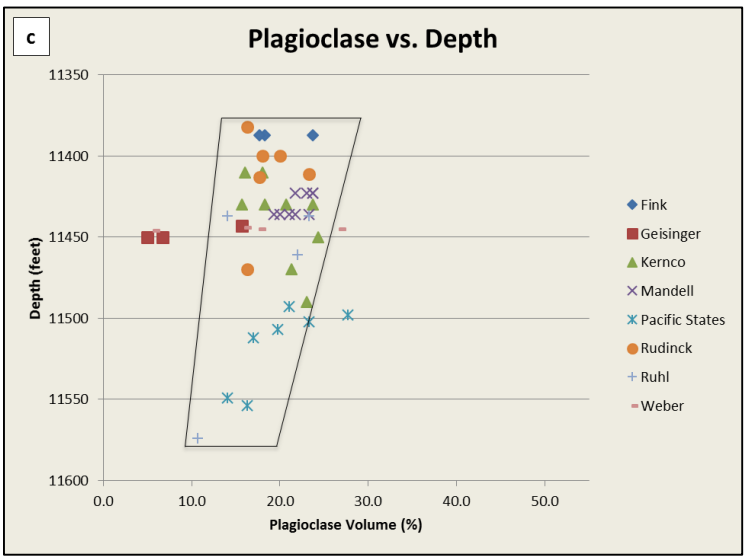


Figure 12: (a-c) Plots of felspars vs. depth, N = 65.

Rock Fragments

Rock fragments range from 2 to 20% of the rock volume in the Vedder sandstones and are generally volcanic in origin with minor amounts of sedimentary (shale clasts, chert, siltstone), metamorphic (quartzite, schist), and igneous (microphanaritic) rock fragments. Many of the volcanic grains have undergone alteration and deformation to form pseudomatrix and clays.

Accessory Minerals

Accessory minerals range from traces to 17% of the rock volume. Biotite is the most common accessory mineral and is present in almost all of the samples. Other detrital minerals include muscovite, zircon, hornblende, rutile, garnet, epidote, and magnetite/titanomagnetite.

Fossils

Fossils are present in some samples (Figure 13), however, no attempt was made to identify them.

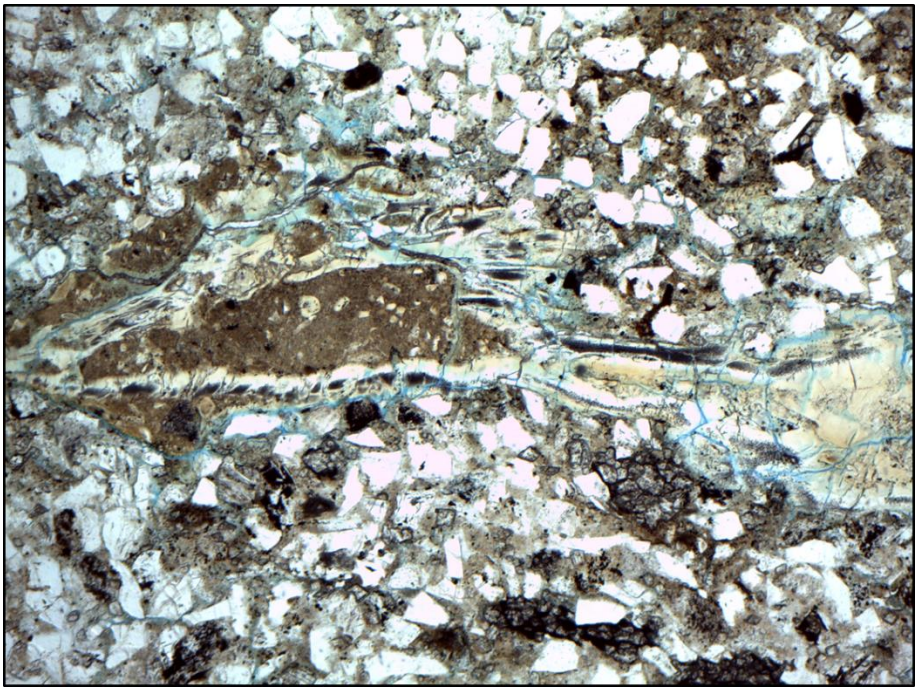


Figure 13: Unidentified fossil. Well: Ruhl, depth: 11,574 ft (3,528 m).

AUTHIGENIC MATERIAL

Glauconite

Glauconite grains occur as dark green round peloids and are present as trace amounts in most samples. However, some samples contain up to 6% glauconite. Glauconite grains commonly were deformed by compaction and squeezed into surrounding pore space. Additionally, glauconite partially to completely replaced gains along grain boundaries, especially in feldspars (Figure 14).

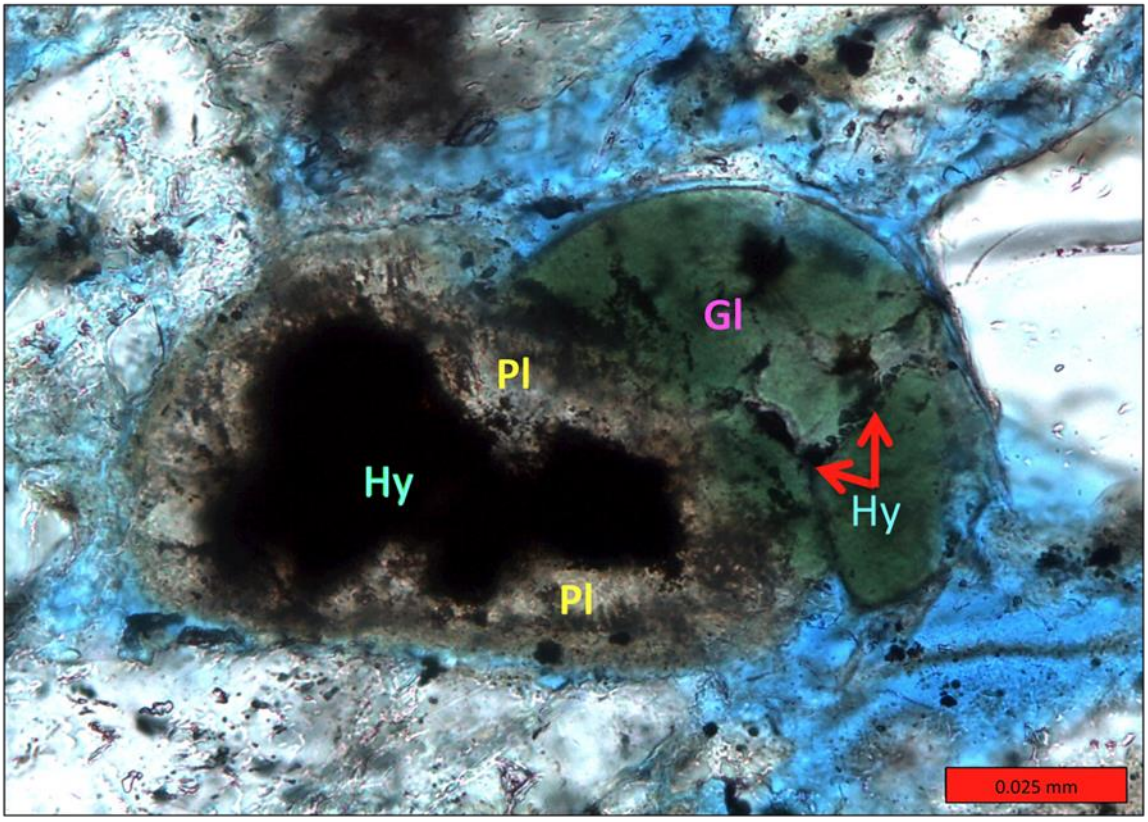


Figure 14: Partially dissolved glauconite (Gl) grain along a partially dissolved plagioclase (Pl) grain contact. Hydrocarbons (Hy) fill fractures in the glauconite (red arrows) grain as well as the intragranular pore in the plagioclase grain. Well: Kernco 61-34, depth 11,410 ft (3,478 m).

Phosphate

Phosphate is generally associated with glauconite and occurs as round dark brown peloids (Figure 15a), coatings on framework grains, and cement. It is present in trace amounts in most samples. Phosphate replaced glauconite, feldspars, and quartz both within the grains and along grain boundaries (Figure 15b).

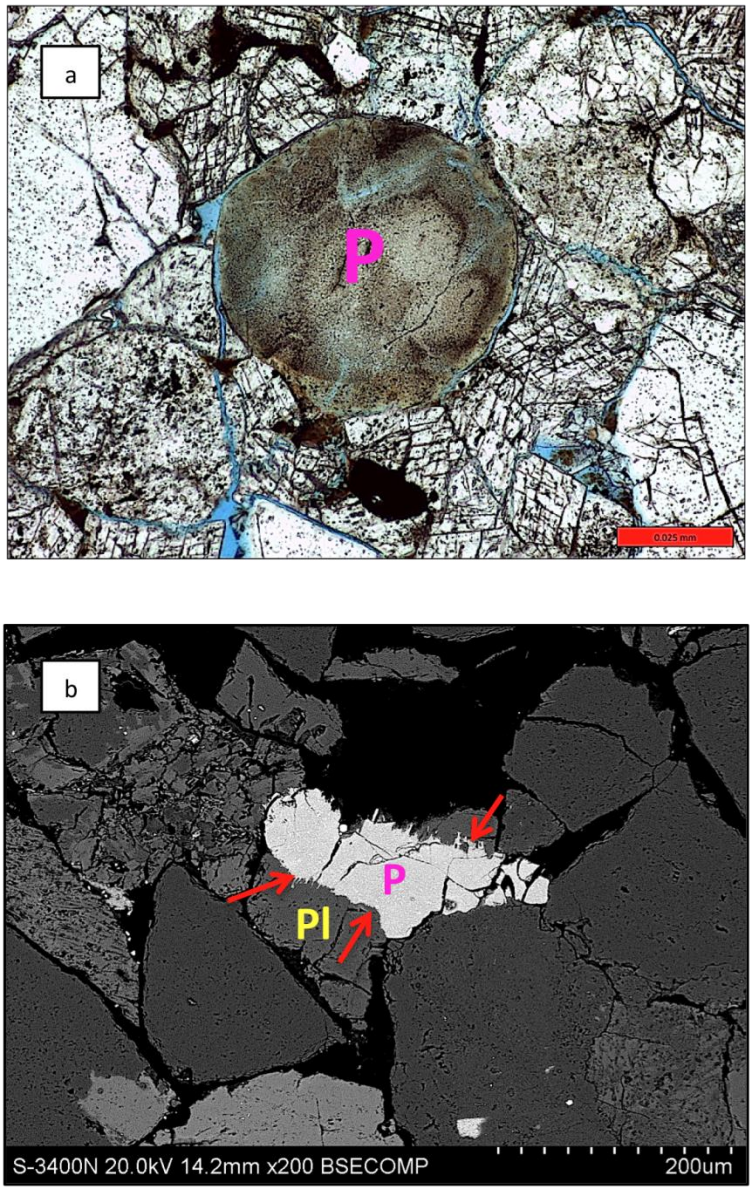


Figure 15: **(a)** Individual rounded phosphate (P) peloid in carbonate cement. Well: Ruhl 1, Depth: 11,502 ft (3,505 m). **(b)** SEM-BSE image of phosphate (P) replacing plagioclase (Pl) grain (red arrows). Well: Mandell 3, depth: 11,436 ft (3,486 m).

Pyrite

Authigenic pyrite occurs throughout the sandstones as scattered crystals, cement, or small framboidal masses (Figure 16a), and ranges up to 10% of the rock volume. Pyrite crystals range in size from < 1 to 4 μm. Pyrite formed along biotite cleavage planes (Figure 16b), within chloritized biotite, and within hydrocarbon-filled pores (Figure 16c, 16d), and it occurs in association with glauconite.

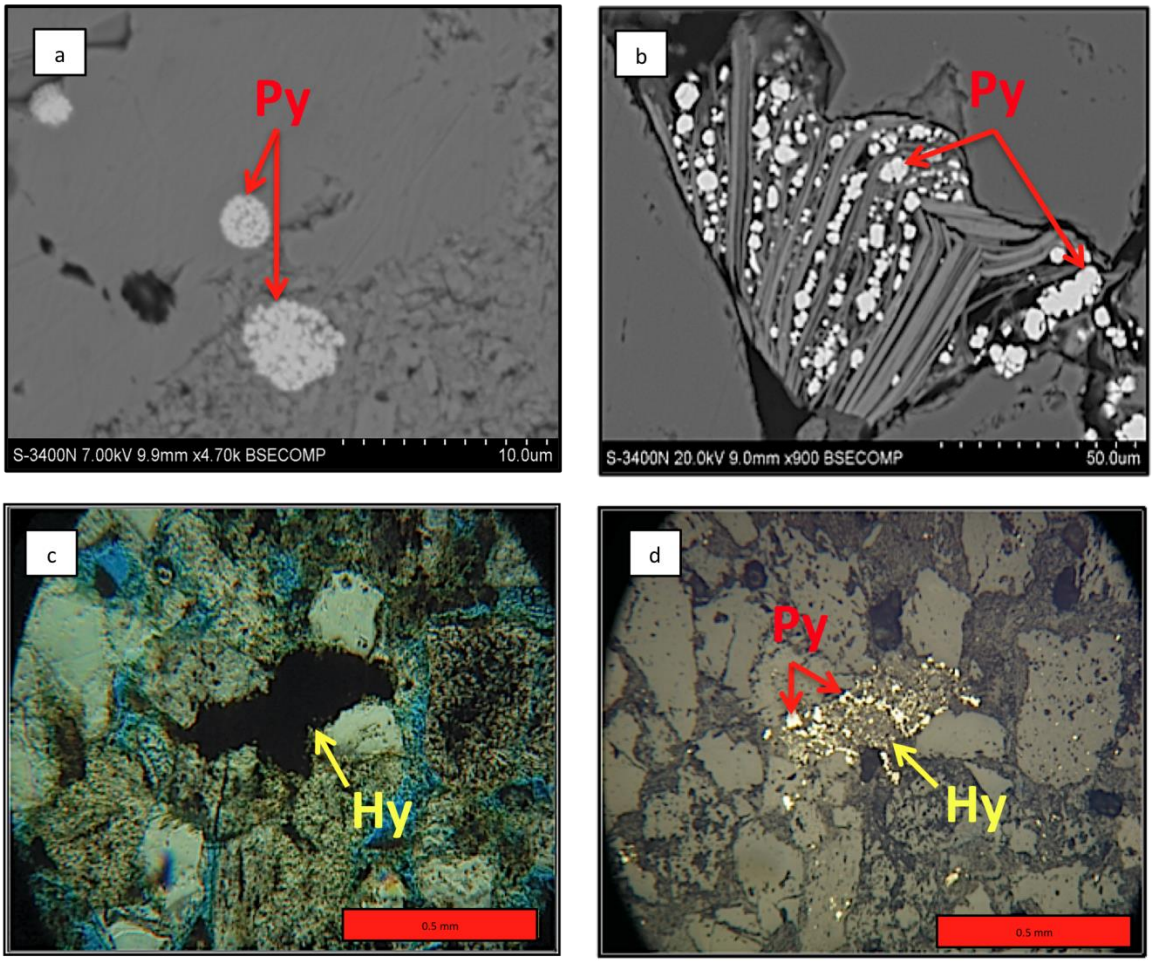


Figure 16: **(a)** SEM-BSE image of framboidal pyrite (Py). Well: Kernco 61-34, depth: 11,490 ft (3,502 m) **(b)** SEM-BSE image of pyrite (Py) that formed along biotite cleavage planes. Well: Ruhl 1, depth: 11,437 ft (3,486 m) **(c)** Transmitted light photomicrograph of hydrocarbon (Hy) (yellow arrows) Well: Kernco 61-34, depth: 11,410 ft (3,478 m) **(d)** Reflected light photomicrograph of the same area as figure 16c showing pyrite (Py) (red arrows) that formed within hydrocarbon (Hy) (yellow arrows) in oversized pore. Well: Kernco 61-34, depth: 11,410 ft (3,478 m).

Rutile

Diagenetic rutile crystals occur in minor amounts, typically in coarser samples. These crystals occur in association with pyrite and clay (Figure 17).

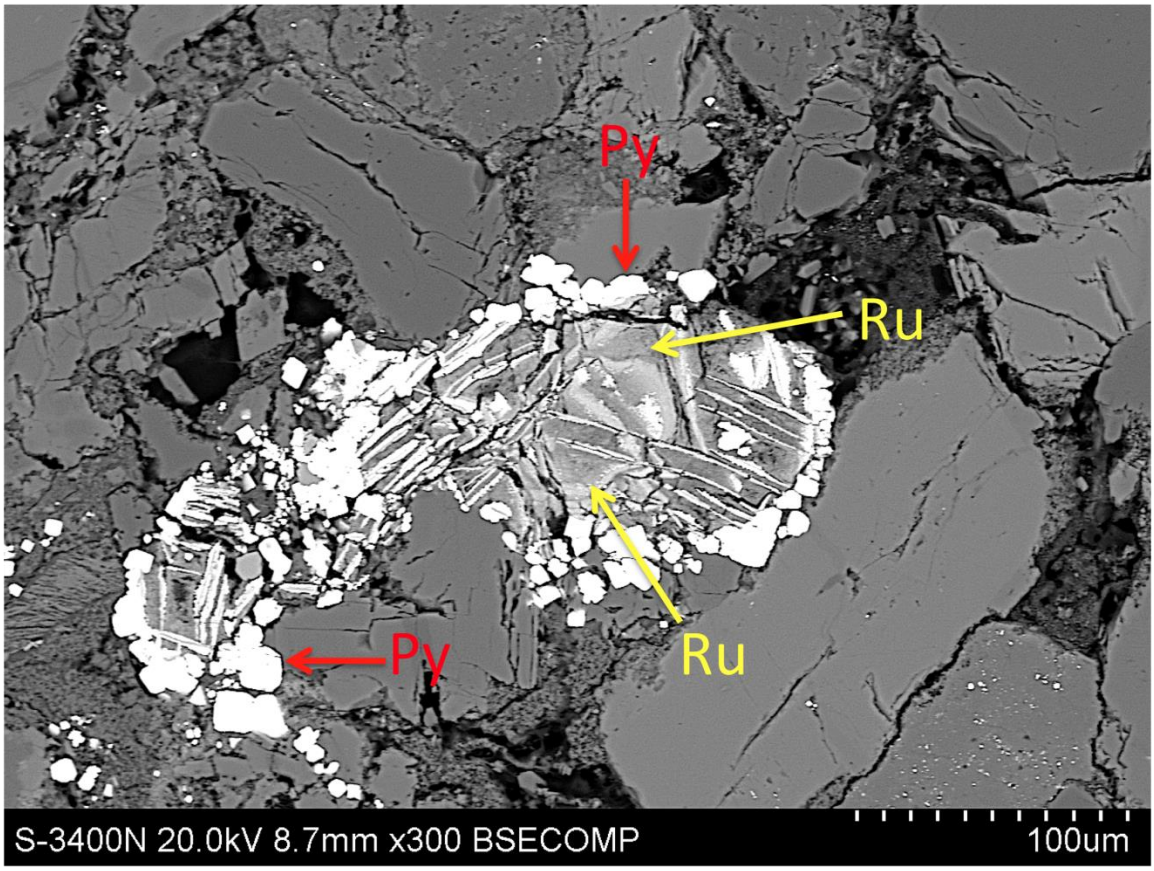


Figure 17: SEM-BSE image of rutile (Ru) (yellow arrows) that formed in a round oversize pore with pyrite (Py) (red arrows). Well: Kernco 61-34, depth: 11,410 ft (3,478 m).

Clays

Authigenic clays occur as alteration products (Figure 18), pore-linings, clay-coatings (Figure 19, Figure 20) and pore-filling cements. Chlorite, kaolinite, and mixed-layer illite/smectite or illite/chlorite is present throughout the Vedder Sandstones identified through petrographic and SEM-EDS analysis. Clay minerals range from trace amounts up to 18% of the rock volume (Table 1). Most clays in these sandstones occurred as a pseudomatrix from alteration of feldspars and rock fragments (Figure 18).

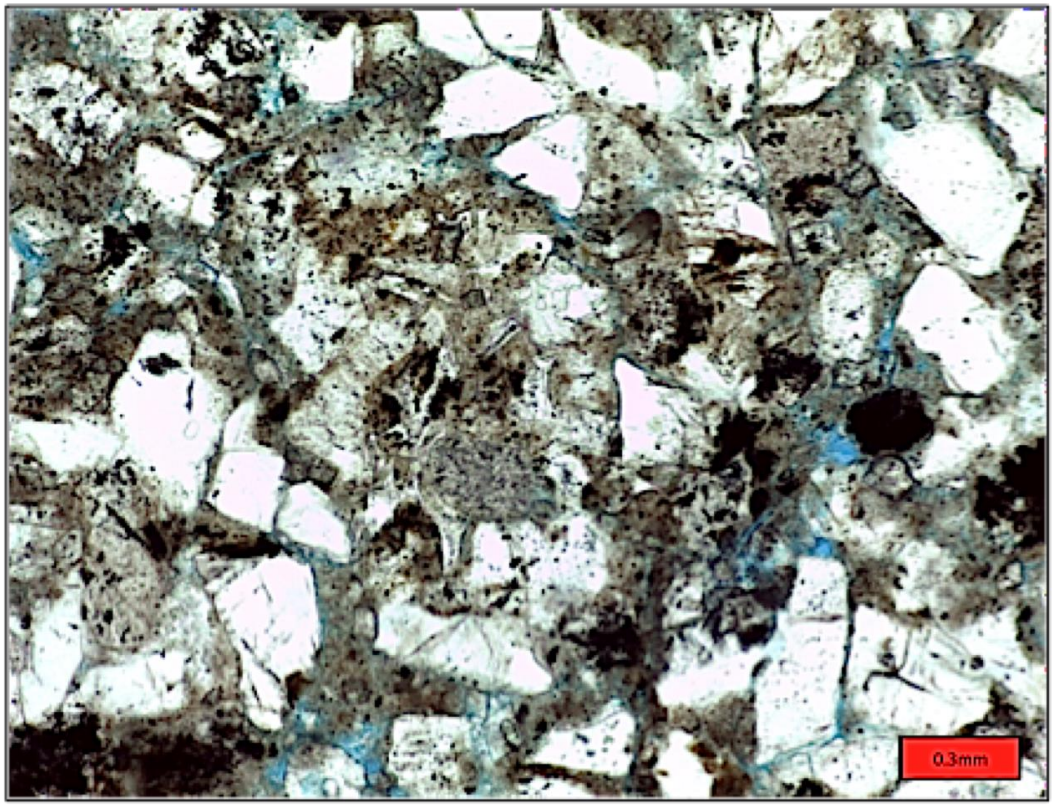


Figure 18: Mixture of grains that have been altered to clay and squeezed into surrounding pore spaces. Well: Rudnick 1, depth: 11,400 ft (3,475 m).

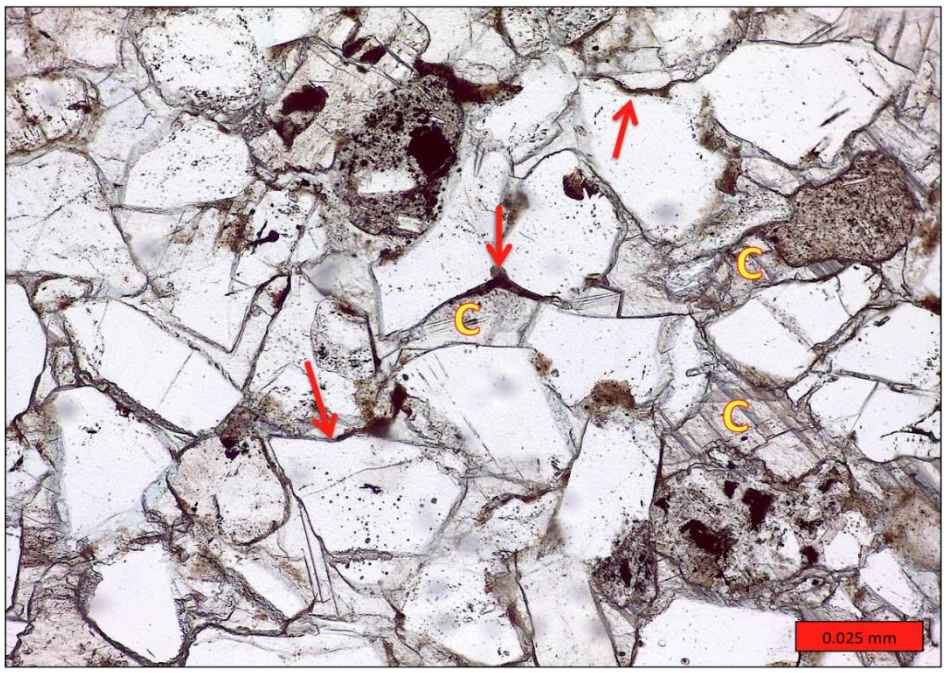


Figure 19: Clay coatings (red arrows) surround detrital grains in pokilotopic calcite (C) cement. Well: Pacific States 21, depth 11,543 ft (3,518 m).

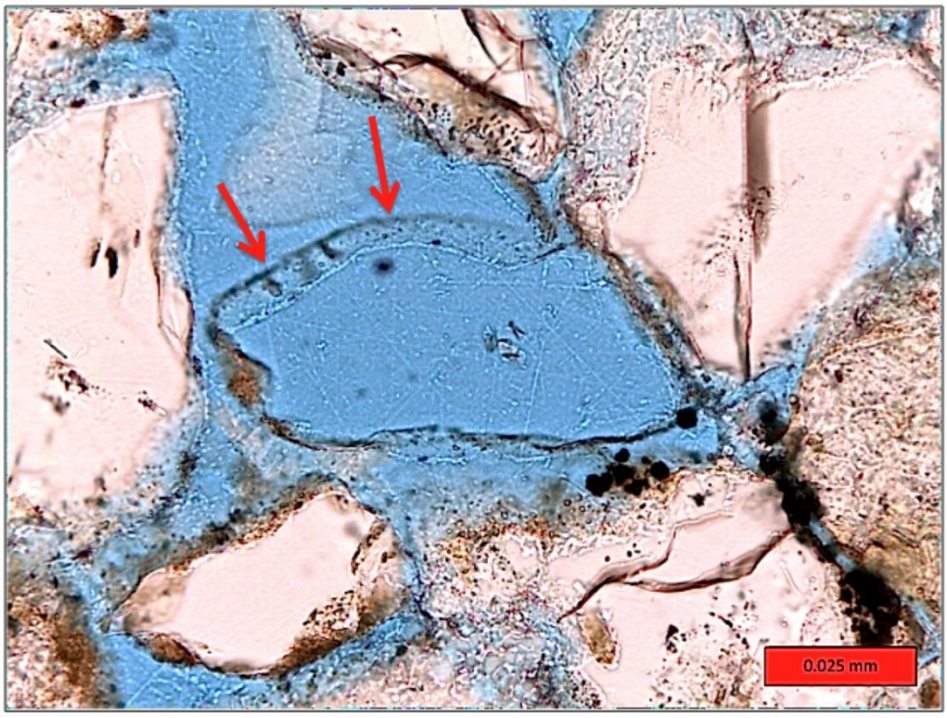


Figure 20: Remnant clay coating (red arrows) from detrital grain that was dissolved. Well: Ruhl 1, depth: 11,437 ft (3,486 m).

Chlorite

Chlorite is present in small amounts in most samples. It occurs along fractures within detrital grains (Figure 21a), as thin coatings on detrital grains (Figure 21b), as a product of alteration of biotite (Figure 22) and volcanic grains, and as cement filling nearby pores (Figure 23).

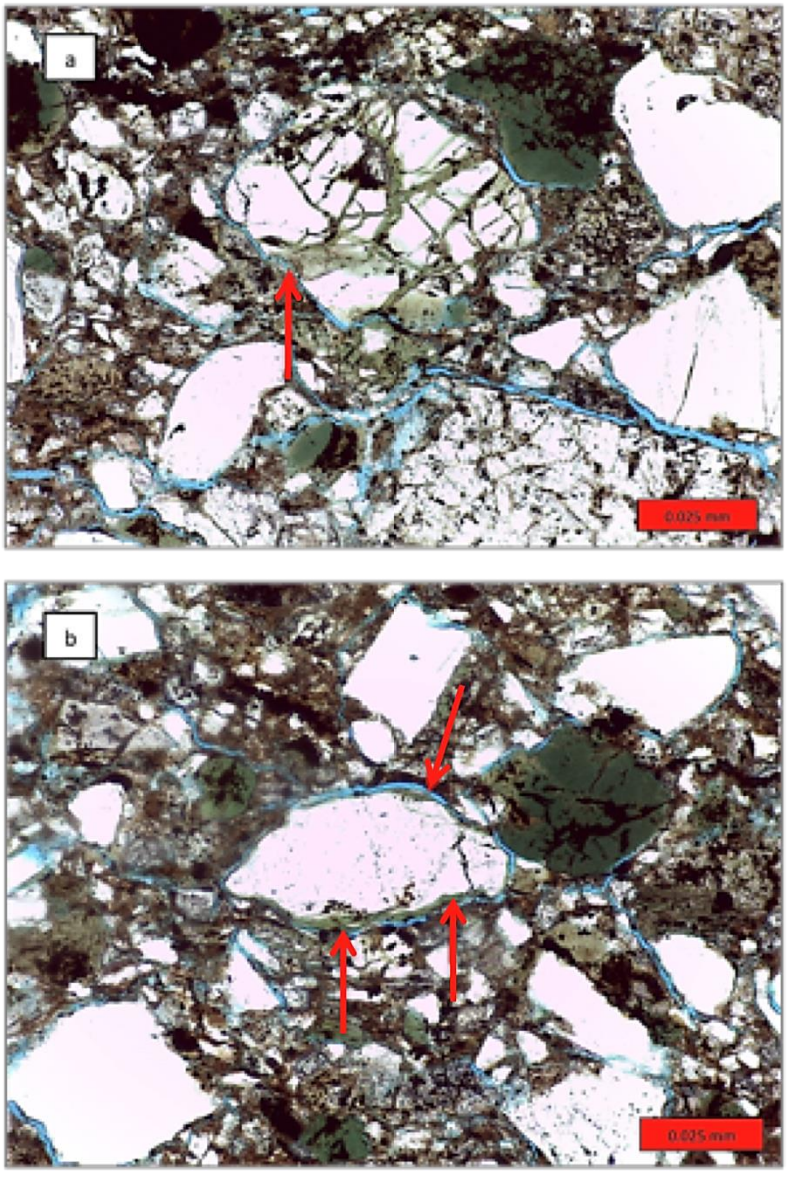


Figure 21: (**a**) Chlorite occurring along fractures within the grain (red arrows). Well: Pacific States 21, depth: 11,549 ft (3,520 m). (**b**) Chlorite occurring as a thin coating on a detrital grain (red arrows). Well: Pacific States 21, depth: 11,549 ft (3,520 m).

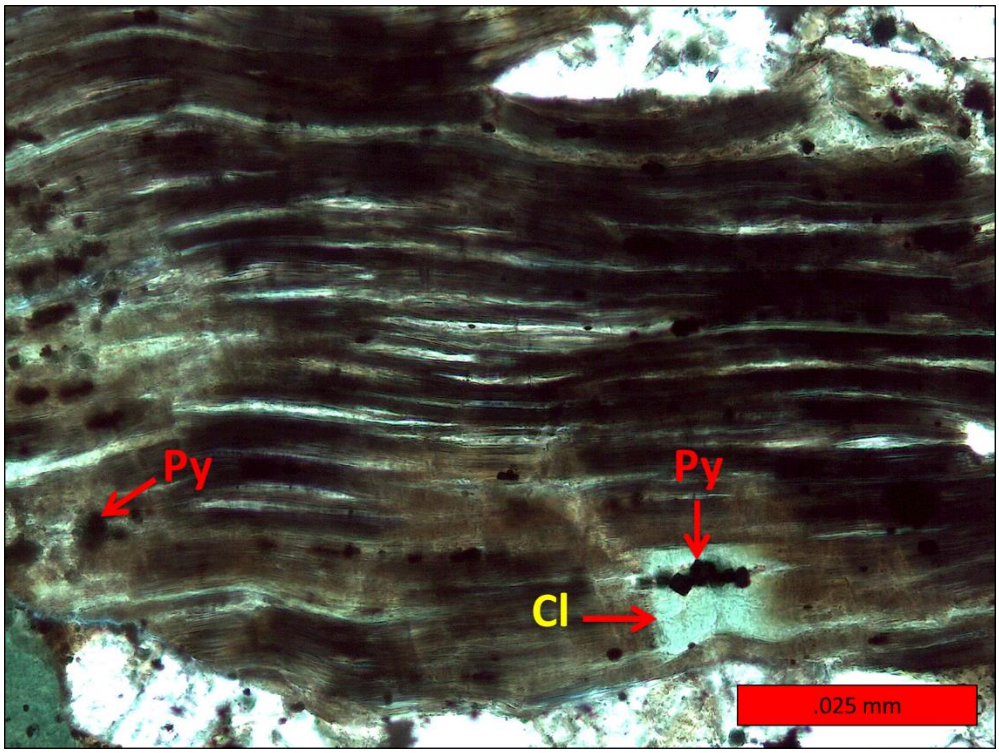


Figure 22: Biotite grain that is partially altered to chlorite (Cl) with pyrite (Py) crystals. Well: Pacific States 21, depth: 11,549 ft (3,520 m).

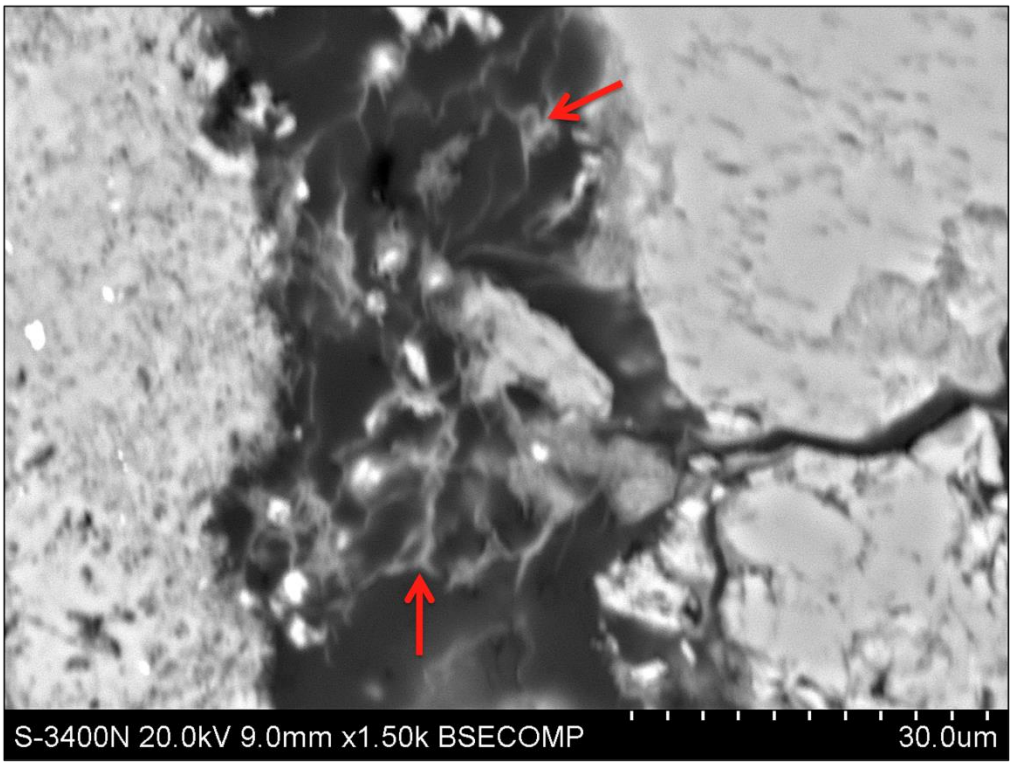


Figure 23: Chlorite cement (red arrows) filling pores. Well: Mandell 3, depth: 11,436 ft (3,489 m).

Illite

Mixed-layer illite/smectite or illite/chlorite occur within shards of feldspar grains (Figure 24) and as pore-linings or coatings (Figure 25). SEM-EDS analyses show that this material contains small amounts of calcium, iron, sodium, and magnesium. Mixed-layer illitic clays range from trace amounts to 28%.

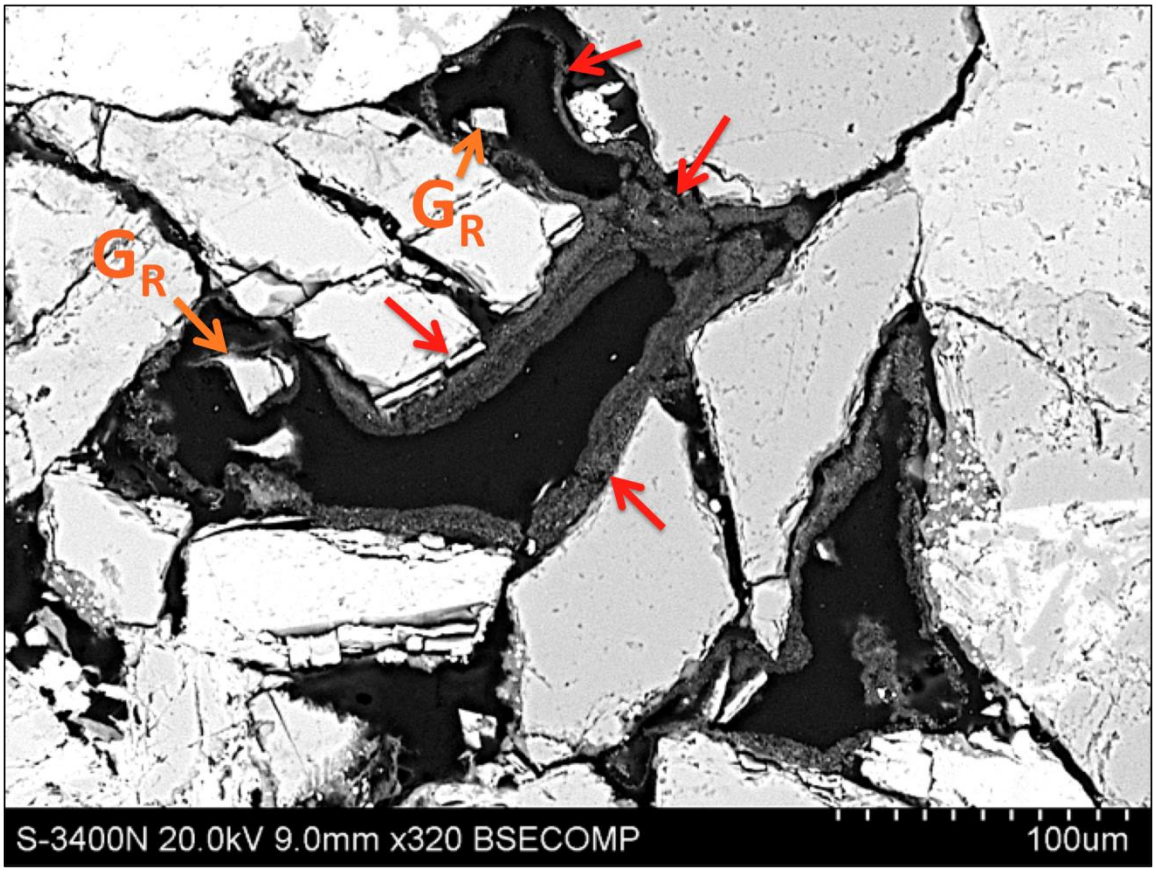


Figure 24: Pore-lining illite/smectite or illite/chlorite (red arrows) with relic detrial grains (G_R). Well: Mandell 3, depth: 11,436 ft (3,486 m).

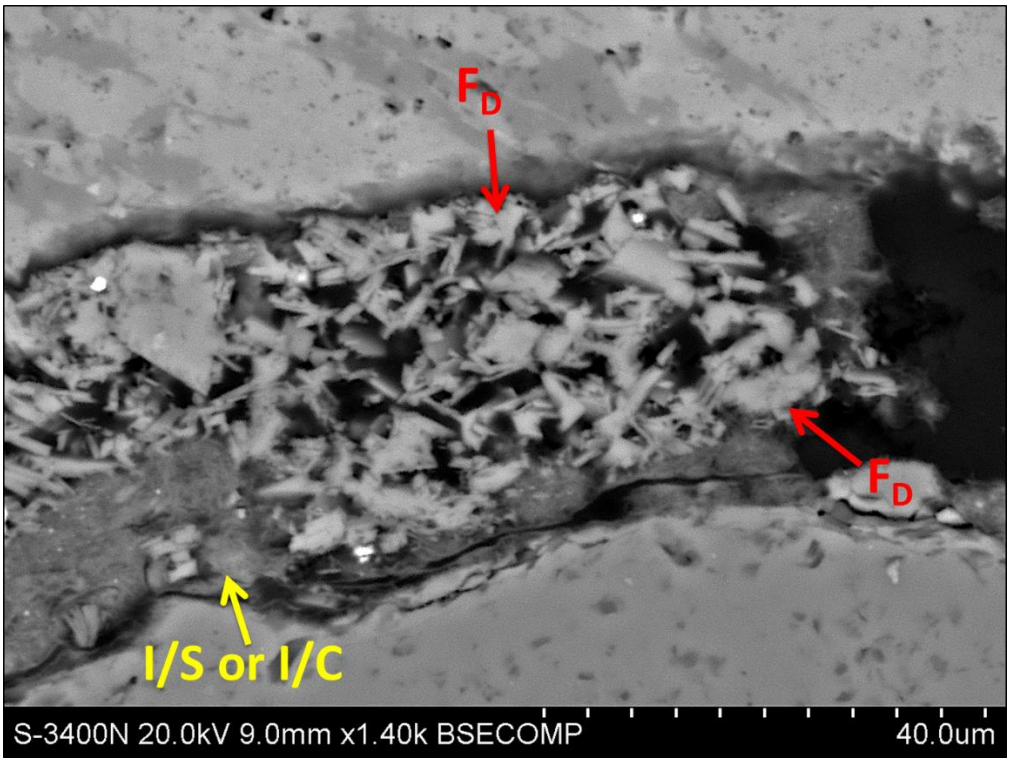


Figure 25: Illite/smectite or illite/chlorite is present between a dissolved feldspar (F_D) grain. Well: Mandell 3, depth: 11.436 ft (3,486 m).

Kaolinite

Kaolinite is present in the majority of samples and occurs as pore-lining and pore-filling cement with a rock volume ranging from trace to 6%. Kaolinite commonly occurs as well developed booklets of micron-size crystals that partially to completely fill intergranular pores (Figure 26). Kaolinite cement in the Rio Bravo Vedder Sandstones contains an estimated microporosity of 40%. Kaolinite often formed adjacent to dissolved feldspars (Figure 27). Occasionally kaolinite replaced volcanic rock fragments.

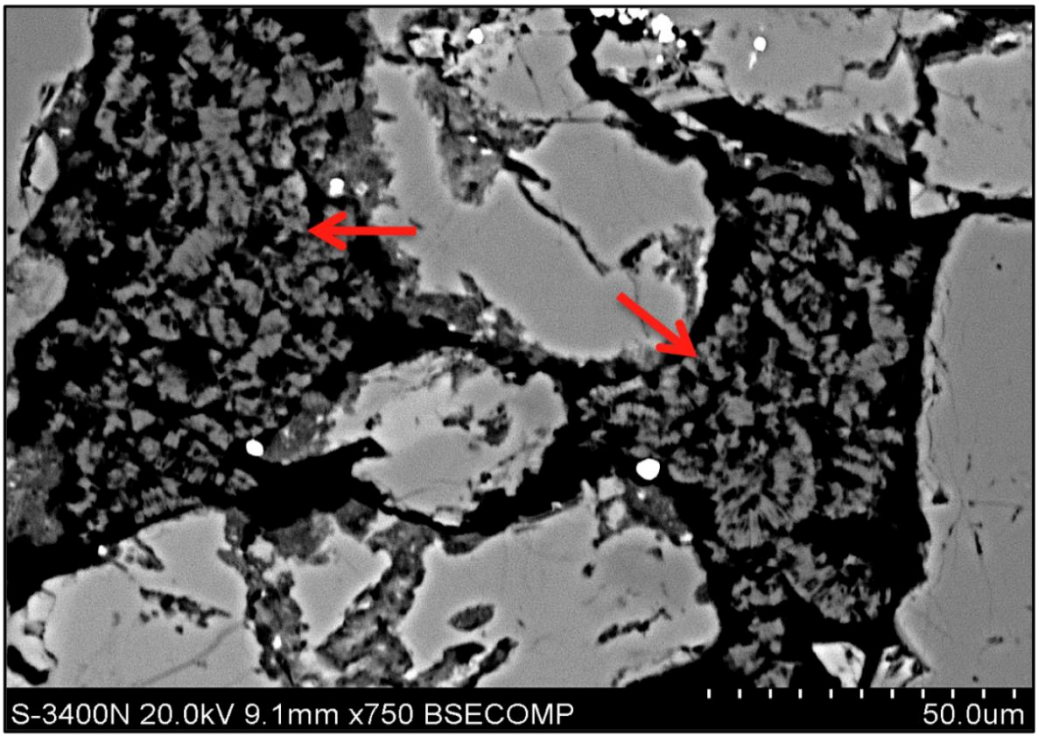


Figure 26: SEM-BSE image of kaolinite showing booklets and associated microporosity (red arrows). Well: Ruhl 1, depth: 11,437 ft (3,486 m).

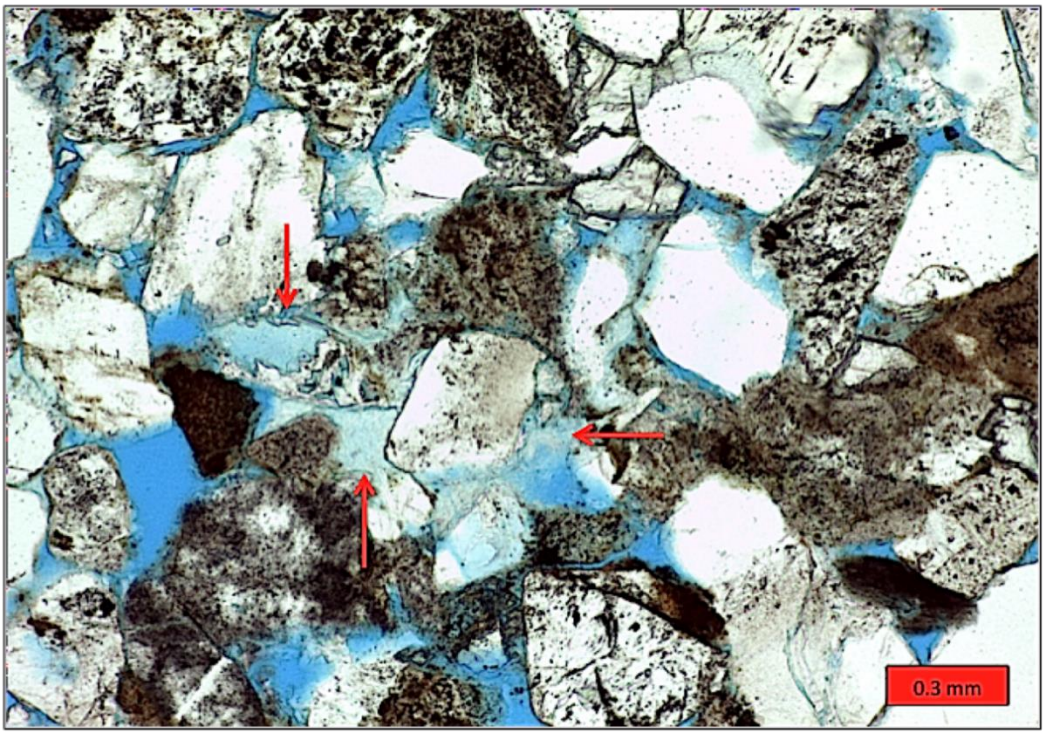


Figure 27: Kaolinite occluding pore spaces adjacent to partially dissolved grains (red arrows). Well: Pacific States 21, depth: 11,554 ft (3,522 m).

Dolomite

Dolomite cement ranges from trace amounts to 52%. It is present as pore-filling cement and as euhedral rhombic crystals (Figure 28). Compositional zoning is common in the crystals where some samples display thin iron-rich zones (Figure 28). Some dolomite crystals have dissolved cores (Figure 29). Dolomite occurs as a replacement of detrital feldspars (Figure 30) and between biotite cleavage planes (Figure 31).

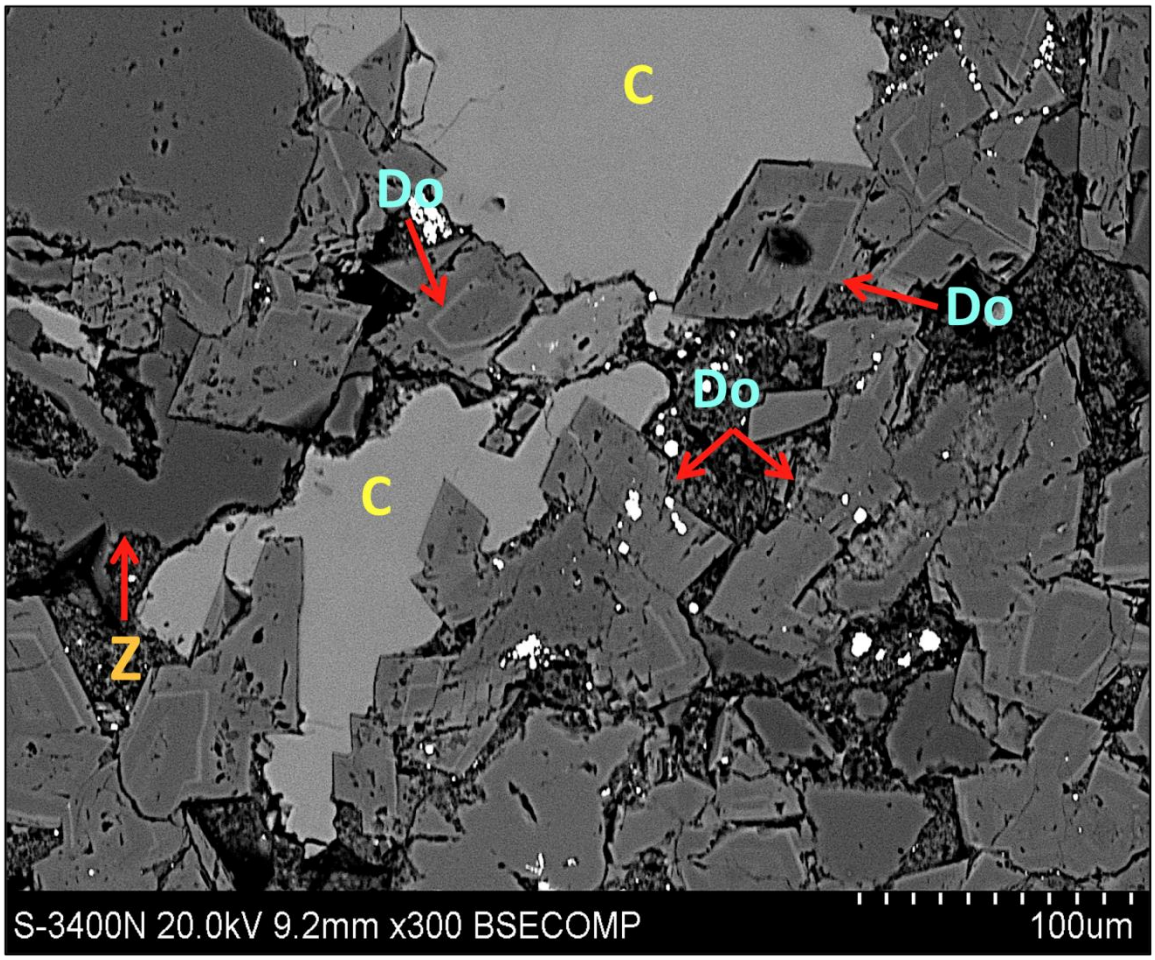


Figure 28: SEM-BSE image of zoned dolomite (Do), calcite (C), and zeolite (Z) cemented sandstone. Well: Kernco 61-34, depth: 11,450 ft (3,490 m).

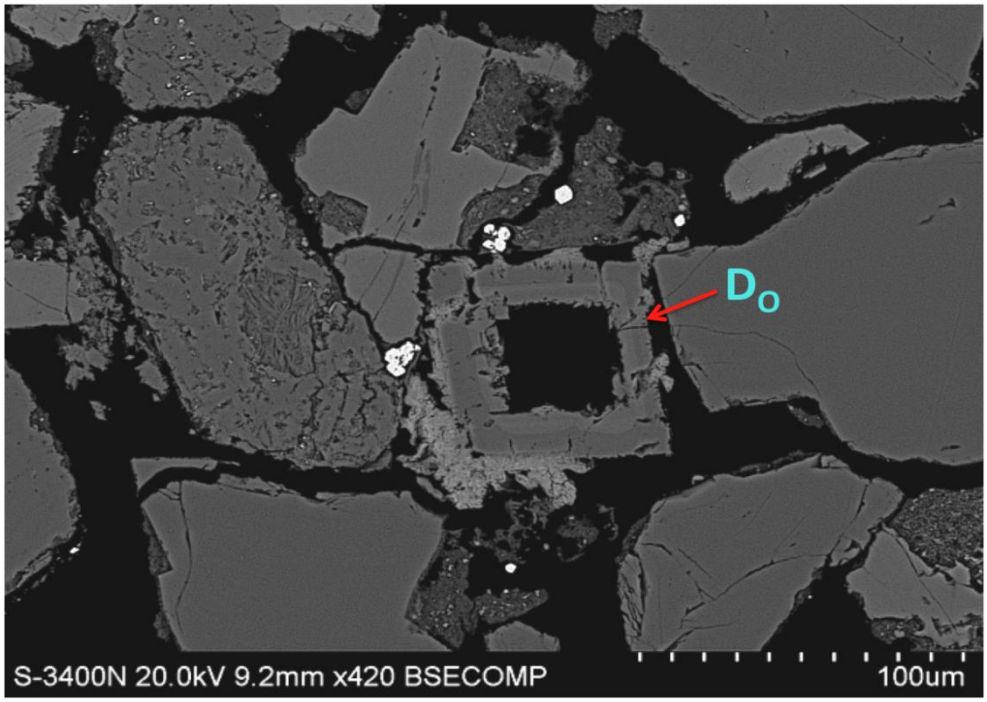


Figure 29: Diamond-shaped hollow core from dissolution of dolomite rhomb (D_O). Well: Ruhl 1, depth: 11,437 ft (3,486 m).

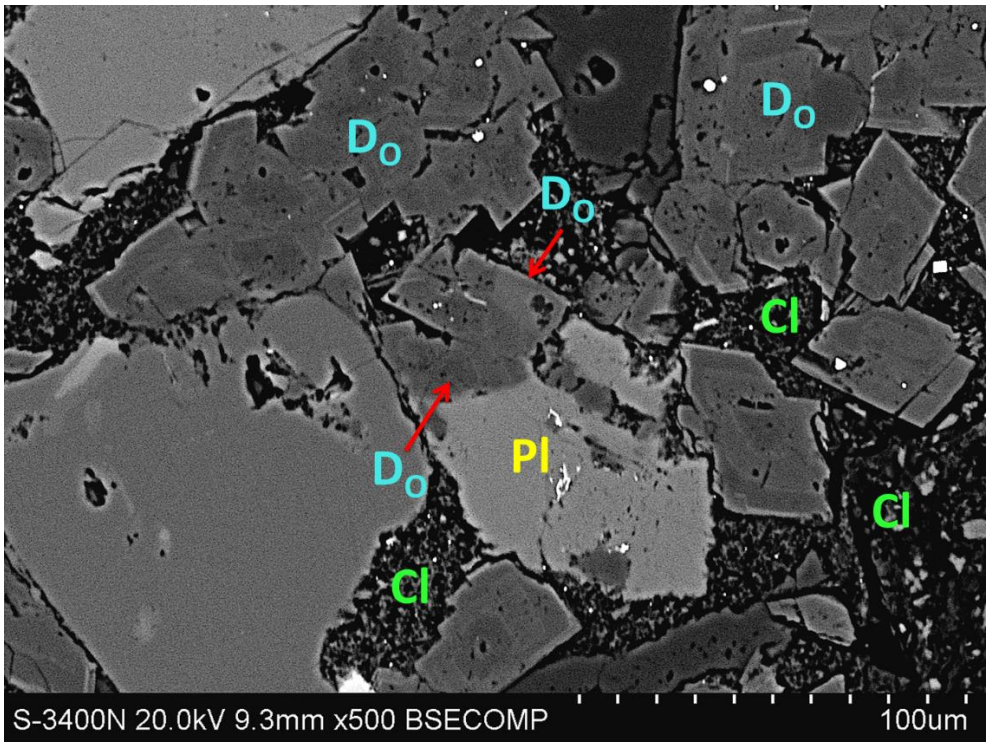


Figure 30: Dolomite (D_O) that has replaced a plagioclase (P) grain. Chlorite (C) is present as pore-filling cement. Well: Kernco 61-34, depth: 11,450 (3,490 m).

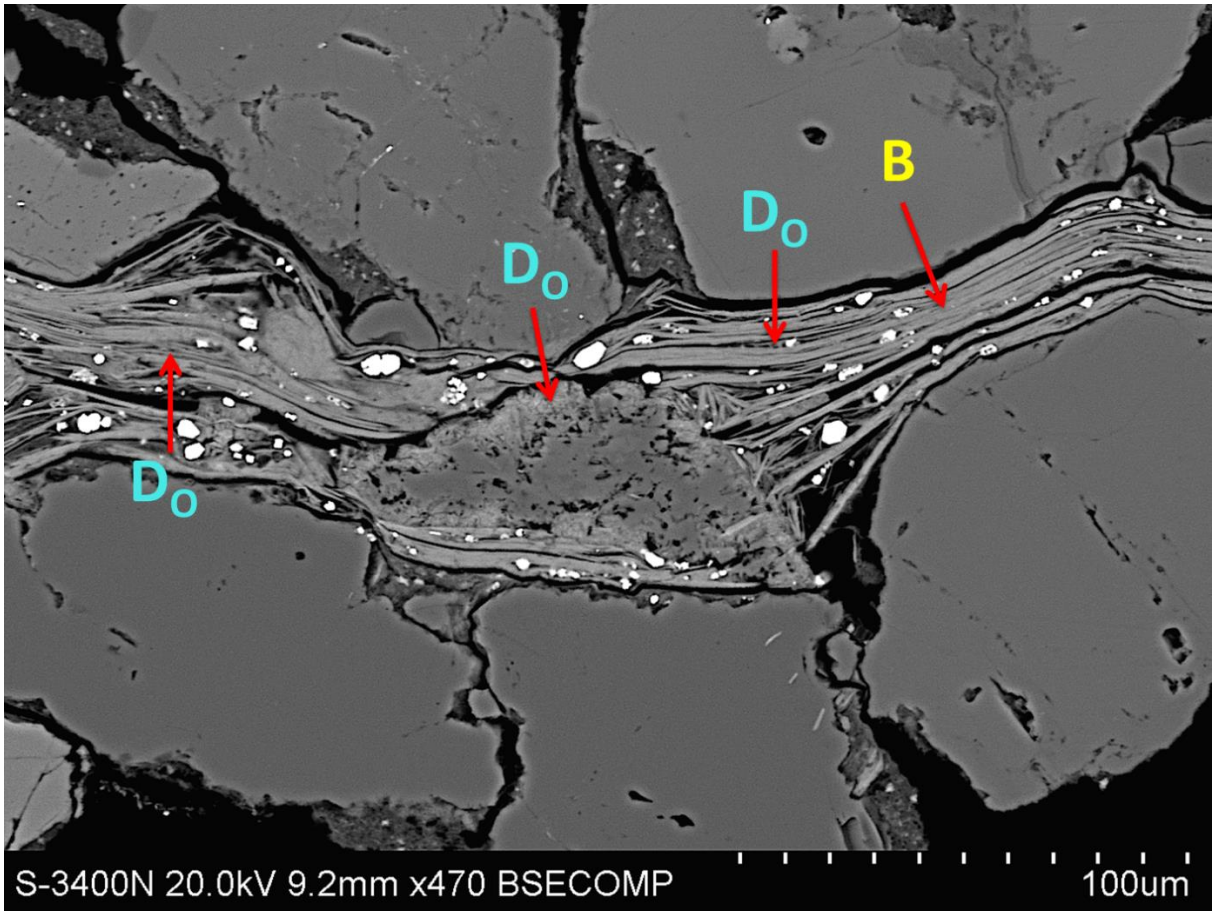


Figure 31: Dolomite (D_O) between biotite cleavage planes. Well: Ruhl 1, depth: 11,437 ft (3,486 m).

Calcite

Calcite cement occurs in the majority of samples from trace amounts to 55%. Early-stage calcite forms as poikilotopic pore-filling cement (Figure 19) in large intergranular spaces where little to no porosity exists. Some samples show evidence of early clay coatings surrounding the detrital grains in the calcite cement (Figure 19). Grains in cemented sands are less altered than in non-cemented sands. Authigenic overgrowths were not observed in sandstones cemented by early poikilotopic calcite. A later stage of calcite cementation occurred in which calcite also replaced grains, including quartz, plagioclase (Figure 32), K-feldspars, and volcanics. Late-stage calcite also occurs within through-going fractures (Figure 33).

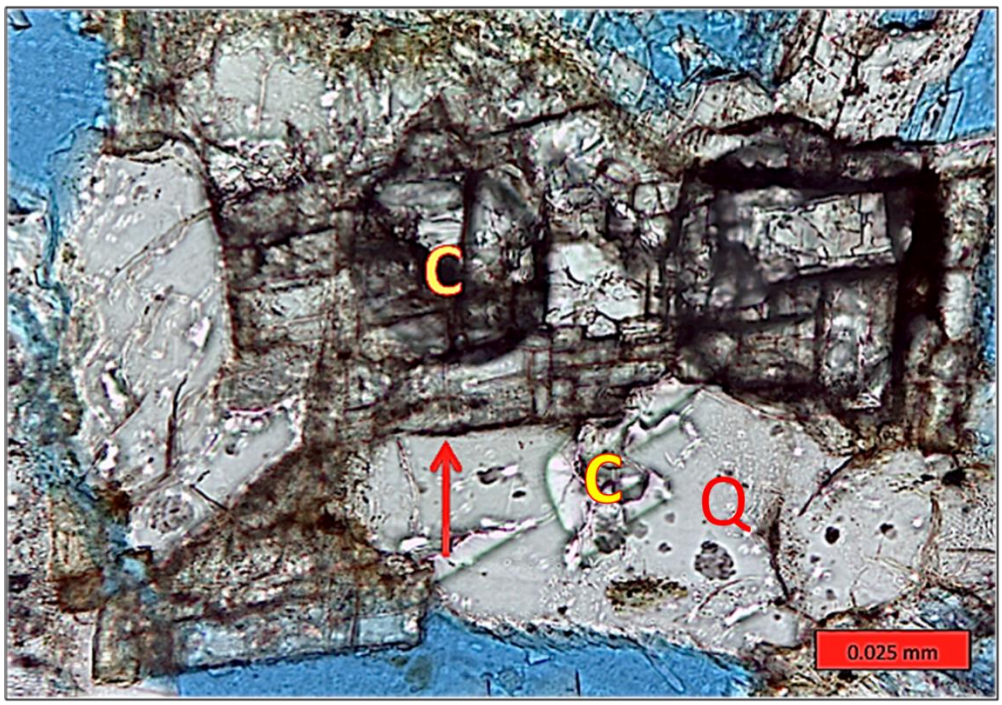


Figure 32: Calcite that partially replaced a plagioclase grain (red arrow) and quartz grain (Q). Hydrocarbon is present within the fractures of the calcite. Geisinger 2, depth: 11,443 ft (3,488).

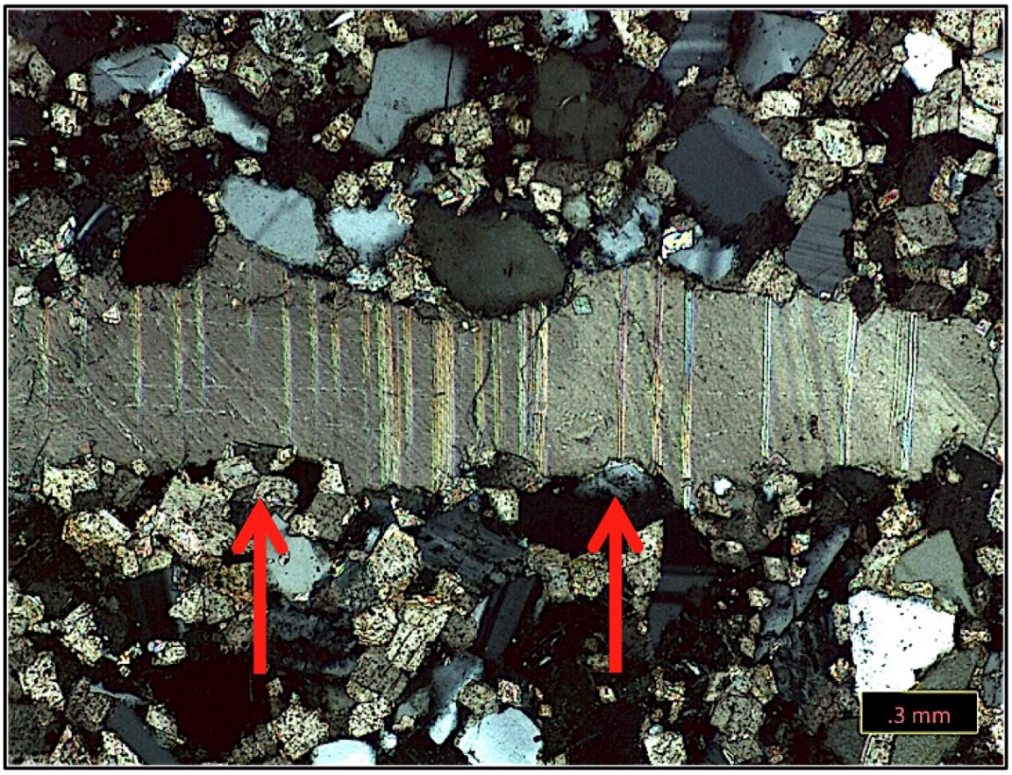


Figure 33: Through-going fracture filled with poikilotopic calcite (red arrows). Well: Rudnick 1, depth: 11,400 ft (3,475).

Zeolite

Zeoloite cement occurs as poikilotopic pore-filling cement (Figure 34). Zeolite cement is common among many of the samples containing significant volcanic grains. The most abundant amounts of zeolite cement are found in samples from well Kernco 61-34. SEM-EDS analyses indicate that zeolite cement is sodium rich.

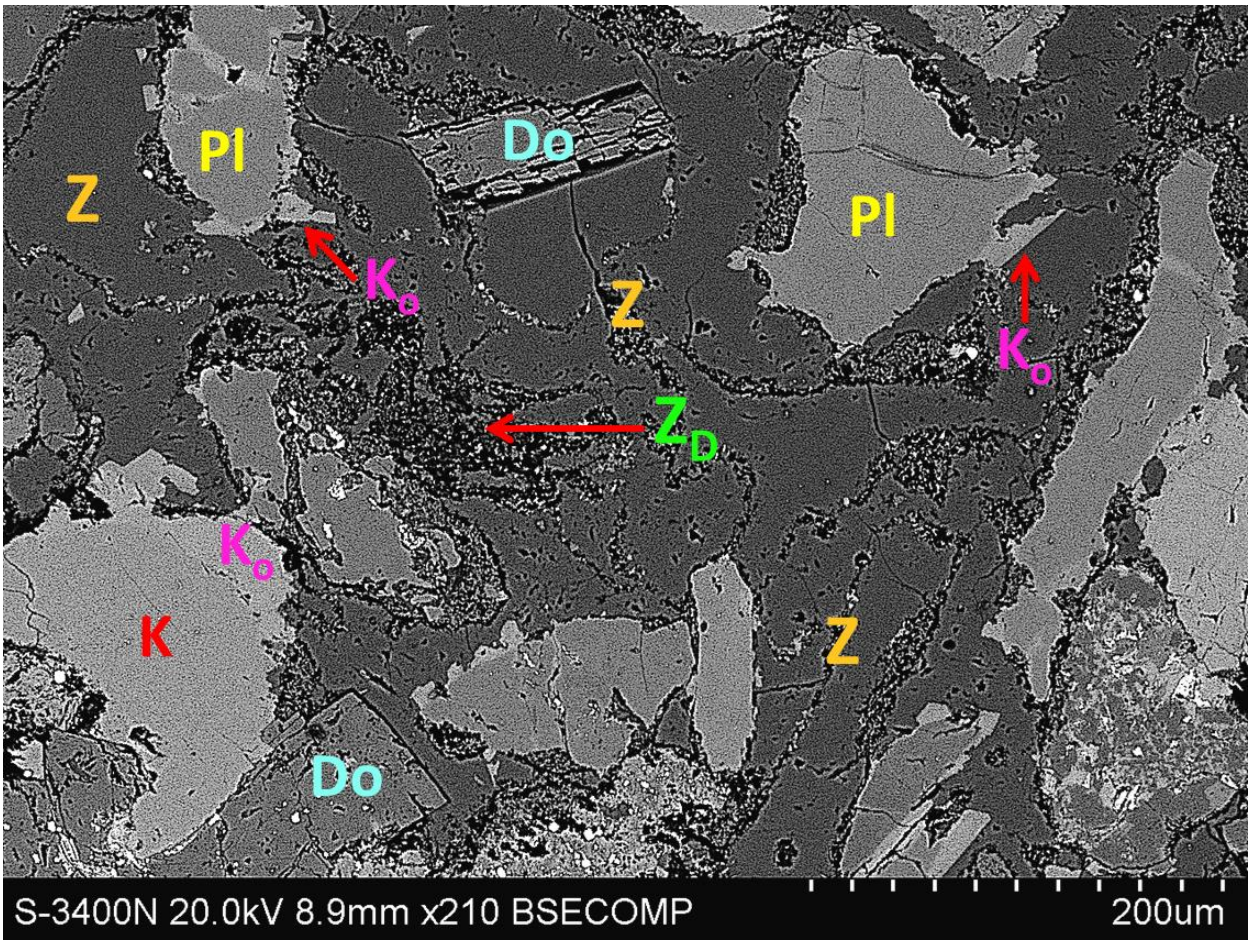


Figure 34: SEM-BSE image of poikilotopic zeolite (Z) cement. Plagioclase (Pl) grains exhibit K-feldspar overgrowths (K_O) (red arrows) surrounded by zeolite cement. Dolomite (Do) rhomb is surrounded by zeolite (Z) cement. Zeolite cement shows partial dissolution (Z_D). Well: Kernco 61-34, depth: 11,410 ft (3,478 m).

Albite

Authigenic albite is present in the majority of samples and partially to completely replaced plagioclase and K-feldpar grains. The average composition for albite in samples is $Ab_{98.9}An_{0.7}Or_{0.4}$. Albitization of detrital feldspars occured along cleavage planes and fractures (Figure 35). Authigenic albite is non-luminescent (Figure 36).

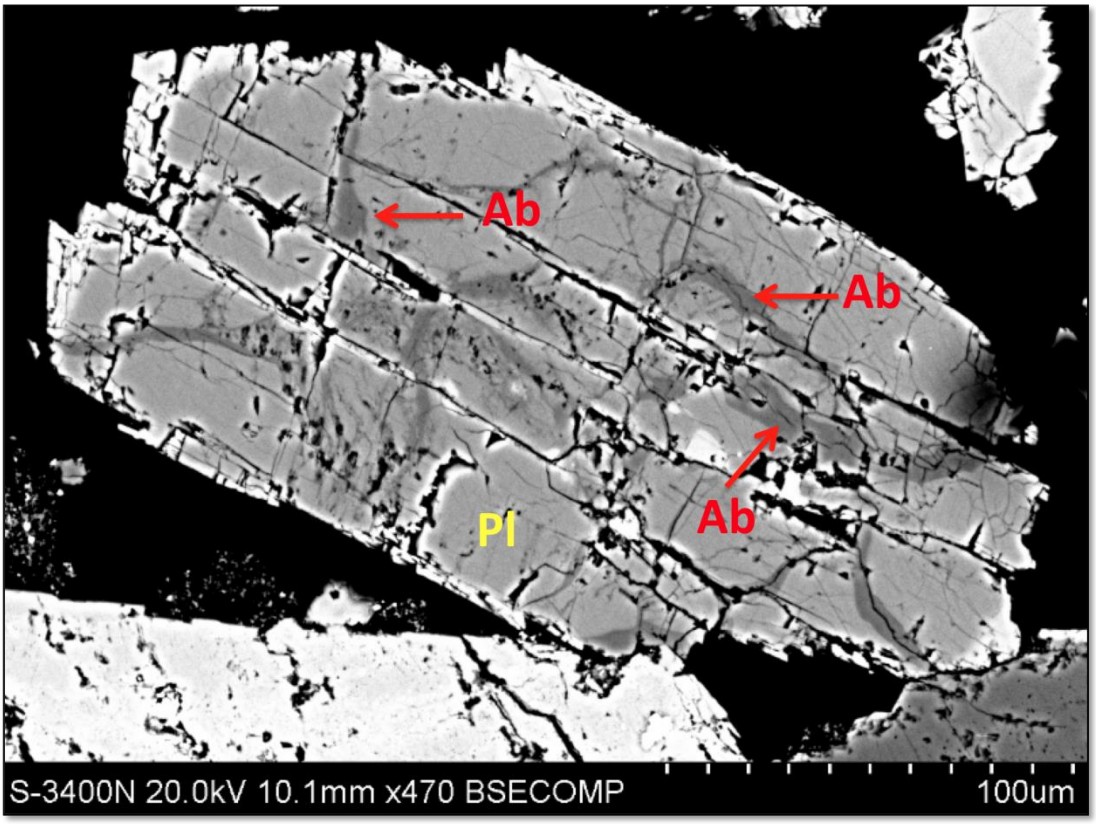


Figure 35: SEM-BSE image of authigenic albitization (Ab) (red arrows), along fractures within a detrital plagioclase (Pl) grain. Well: Weber, depth: 11,445 ft (3,488 m).

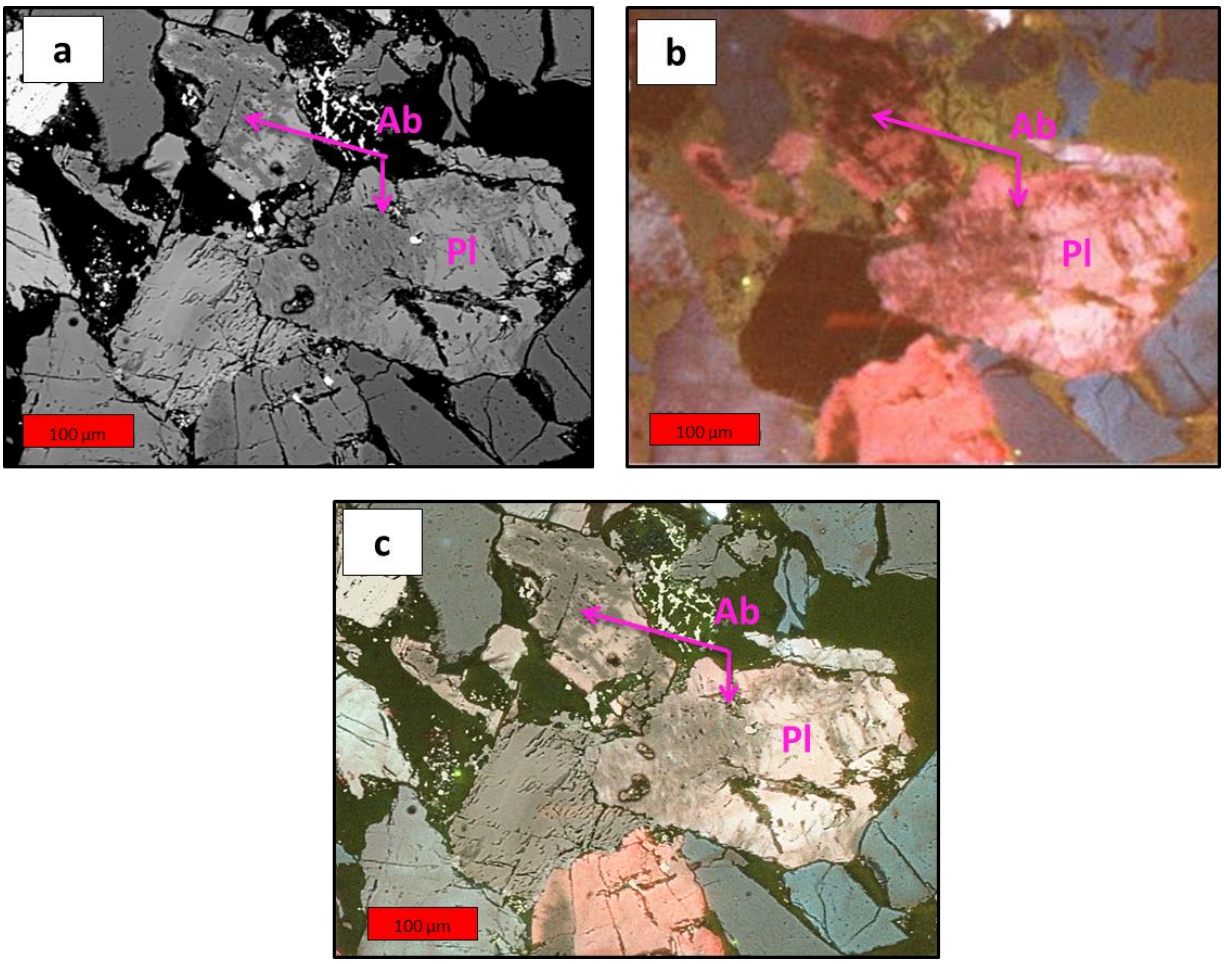


Figure 36: **(a)** SEM-BSE image of plagioclase (Pl) grains that are albitized (Ab). **(b)** CL image reveals authigenic albite is non-luminecent **(c)** Composite image of SEM-BSE and CL images reveals authigenic albite is non-luminescent. Well: Mandell 3, depth: 11,436 ft.

Potassium Feldspar

Authigenic K-feldspar (Average: $Or_{97.5}Ab_{2.5}An_{0.0}$) occurs as overgrowths and within fractures in plagioclase and K-feldspar grains. In some cases potassium feldspar overgrowths have formed along fractures in authigenic albite (Figure 37). Some potassium feldspar overgrowths exhibit partial dissolution (Figure 37). Overgrowths were not observed in sandstones cemented by poikilotopic calcite. Authigenic potassium feldspar is non-luminescent.

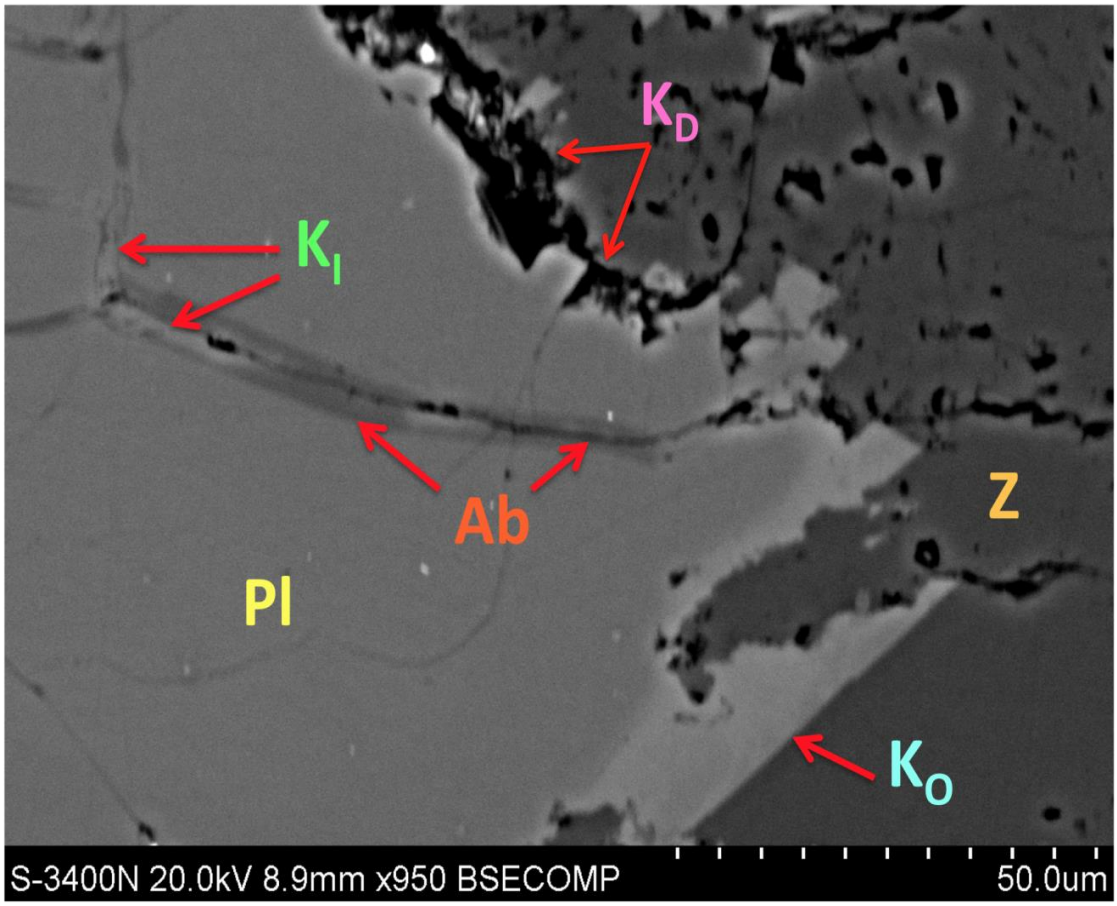


Figure 37: SEM-BSE image of albitized (Ab) plagioclase (Pl) exhibiting K-feldspar infilled (K_I) fractures along with K-feldspar overgrowth (K_O) in zeolite (Z) cement. K-feldspar overgrowth shows partial dissolution (K_D). Well: Kernco 61-34, depth: 11,410 ft (3,478 m).

Quartz

Authigenic quartz developed mostly as overgrowths on detrital quartz grains (Figure 38, 39) and makes up less than 1% of the rock volume. Authigenic quartz also fills fractures within detrital quartz grains (Figure 39). Authigenic quartz often cannot be identified under the petrographic microscope because it is optically continuous with the detrital grain. In some instances the authigenic overgrowths are separated from the detrital grains by clay coatings that delineate the grain boundaries (Figure 38). In other instances where clay coatings are absent authigenic overgrowths can be recognized by the presence of euhedral crystal shapes where they are fully developed. SEM-CL images reveal that authigenic quartz overgrowths and healed fractures are non-luminescent (Figure 39)

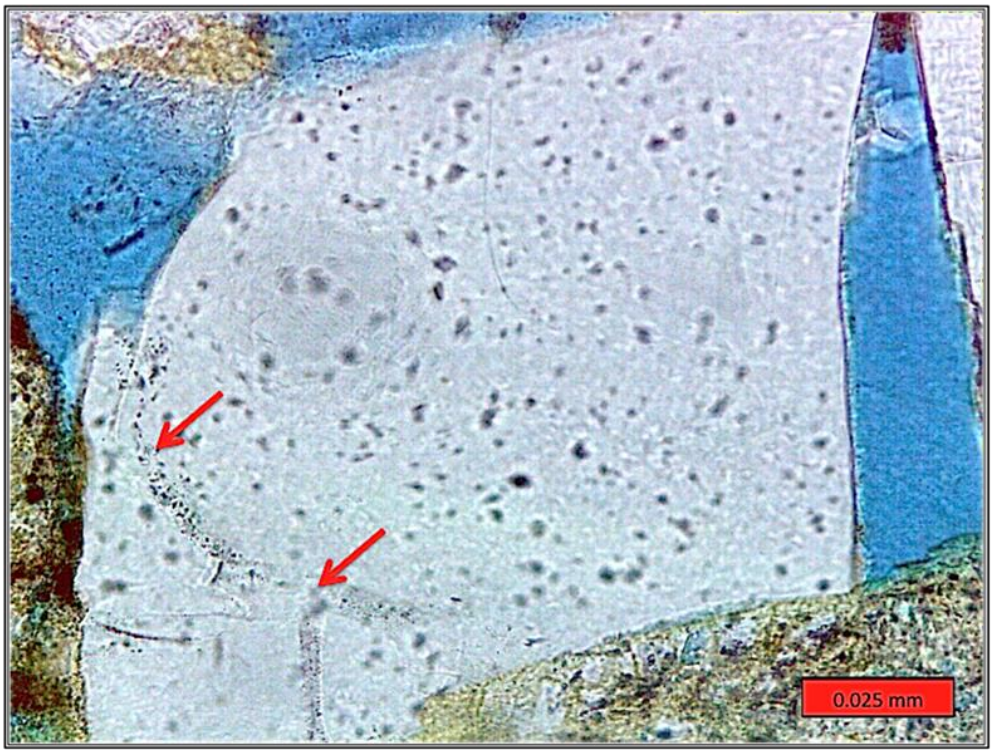


Figure 38: Overgrowth with euhedral termination on detrital quartz grain. The red arrows point to the detrital grain edge. Well: Rudnick 1, depth: 11,413 ft (3,479 m).

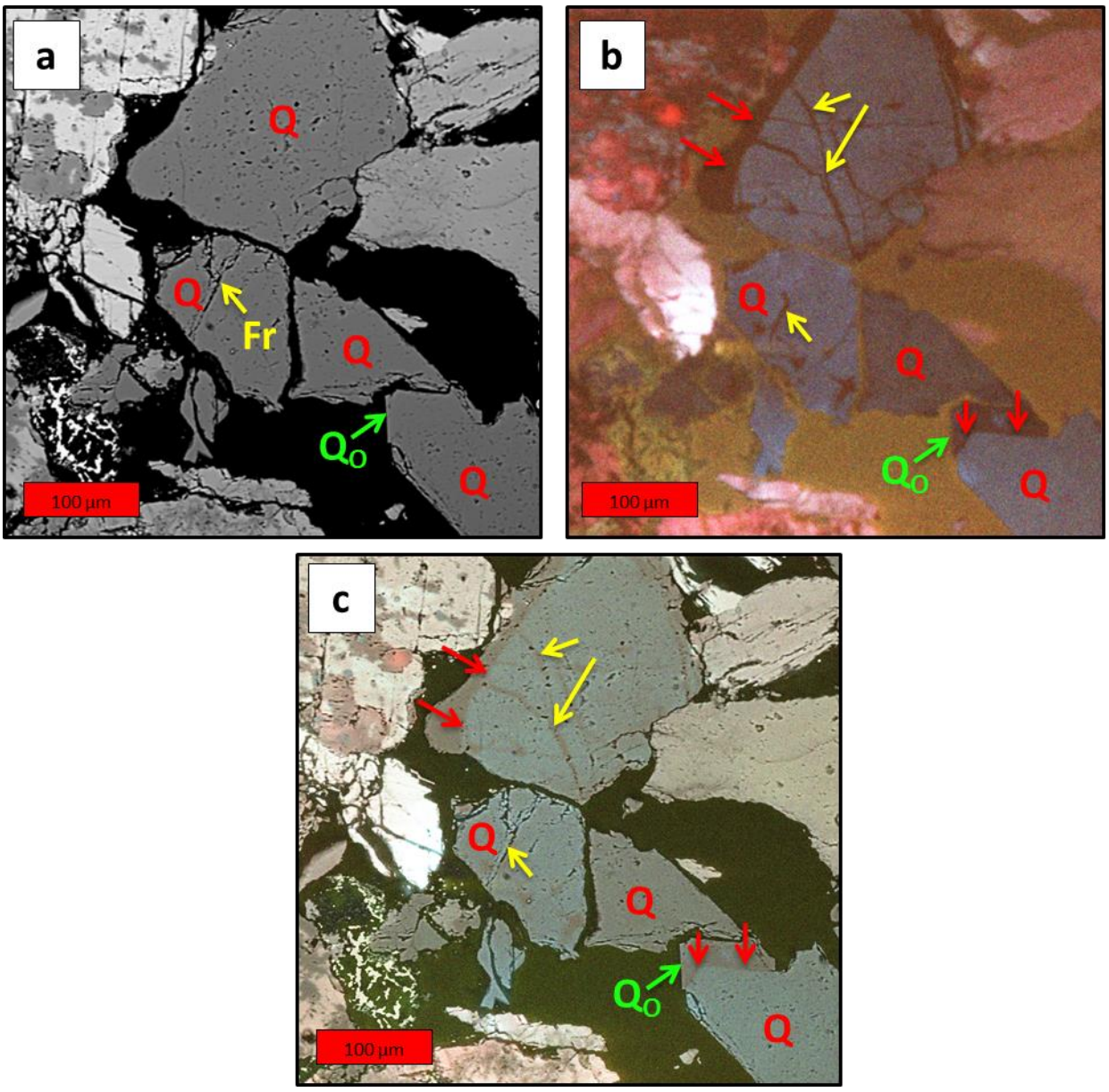


Figure 39: **(a)** SEM-BSE image of fractured (Fr) quartz (Q) and quartz overgrowth (Q_O) on quartz grain. **(b)** CL image reveals quartz overgrowth (Q_O) on a quartz grain (red arrows) and healed fractures (yellow arrows) are non-luminescent. **(c)** Composite image of SEM-BSE and CL images reveals quartz overgrowth (Q_O) on a quartz grain (red arrows) and healed fractures (yellow arrows). Well: Mandell 3, depth: 11,436 ft.

Pseudomatrix

Pseduomatrix is abundant in over half of the samples ranging from 0 to 27% of the rock volume. Pseudomatrix formed by mechanical compaction and squeezing of ductile grains such as micas and rock fragments into intergranular pores. Pseudomatix is most common in sandstones containing significant amounts of volcanic rock fragments (Figure 18, 40).

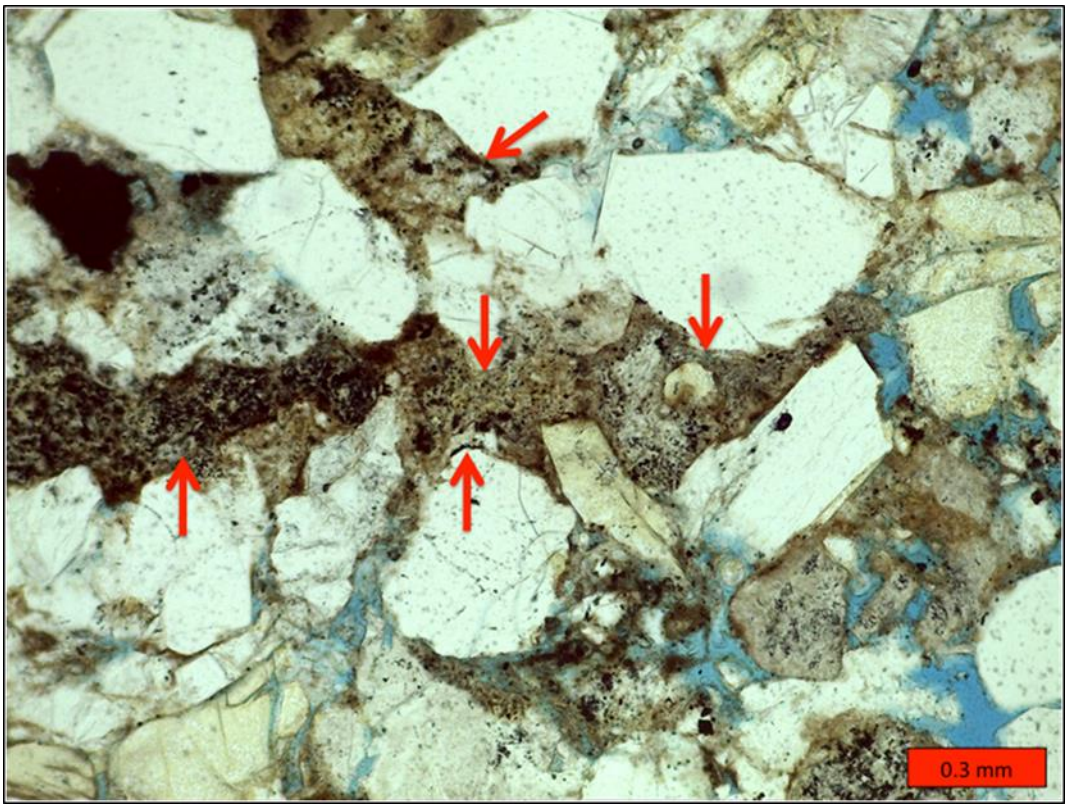


Figure 40: Pseudomatrix (red arrows) formed by deformation of labile volcanic fragments. Well: Rudnick 1, depth: 11,413 ft (3,478 m).

Barite

Barite is present in small amounts throughout the Vedder Sandstones. It occurs as pokilotopic cement, occupies secondary pore spaces, and possibly replaces feldspar grains (Figure 41).

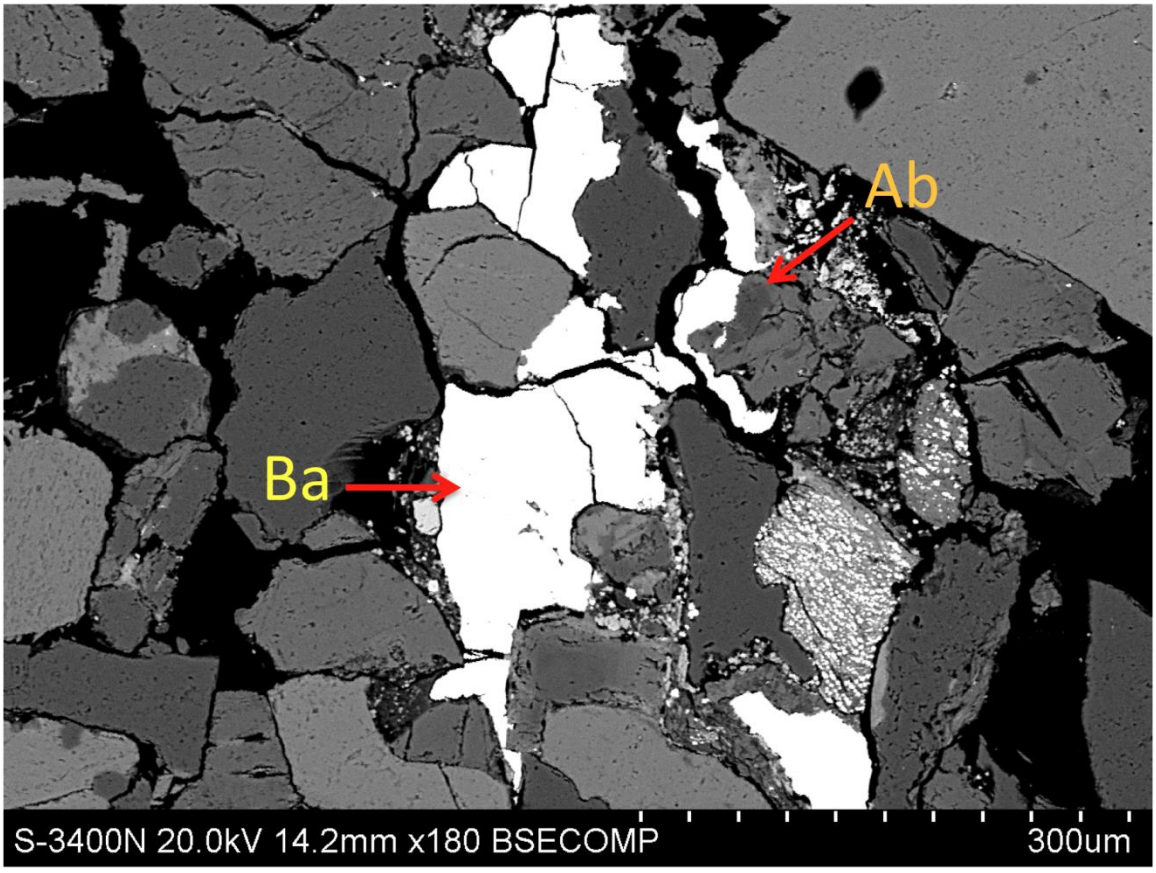


Figure 41: SEM-BSE image of barite (Ba) cement present within secondary porosity. Barite (Ba) is also present as either replacing an albitized (Ab) plagioclase grain or as cement filling secondary pore space in plagioclase. Well: Mandell 3, depth: 11,436 ft (3,486 m).

Anhydrite

Anhydrite cement was identified using SEM-EDS analysis. It is present in minor amounts in samples that contain dolomite cement and occurs as thin coatings surrounding the dolomite rhombohedra (Figure 42). However, the petrographic thin sections were prepared using water, which could have dissolved some anhydrite. Therefore, the actual amount of anhydrite is unknown.

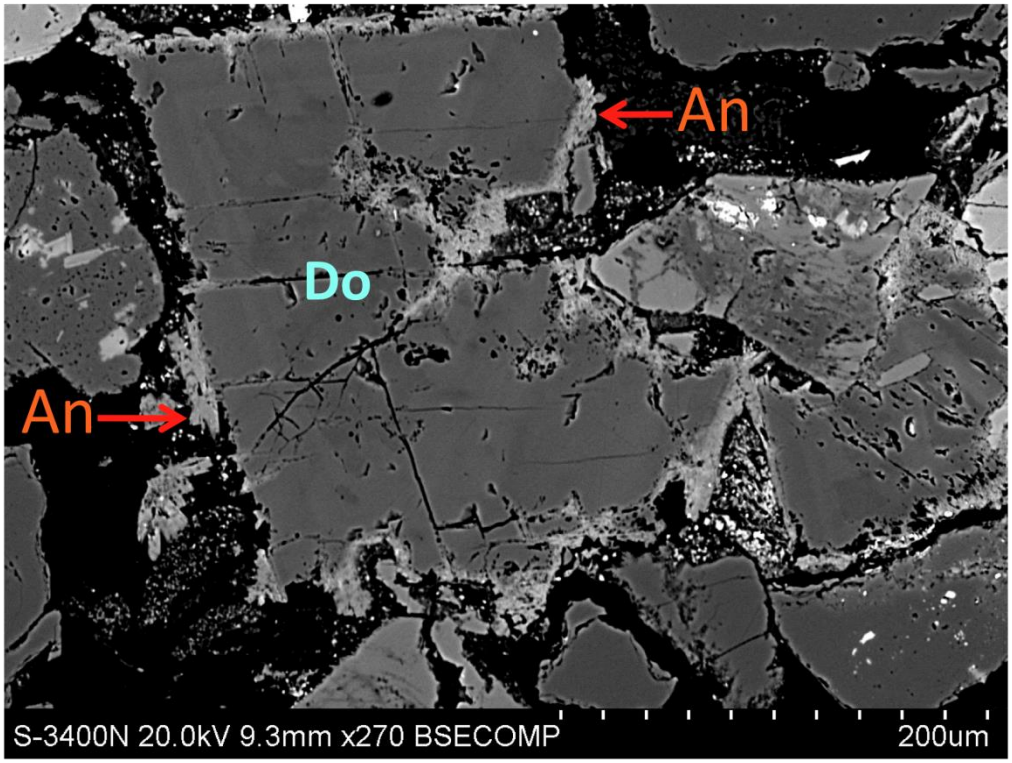


Figure 42: Anhydrite (An) coating on dolomite (D_O) cement. Well: Ruhl 1, depth: 11,512 ft (3,509 m).

Hydrocarbons

During the manufacturing of the thin sections most hydrocarbons were removed, however, small amounts of hydrocarbons still remain. The residual hydrocarbons reside in pores containing clays that could have interfered with the removal process (Figure 43). No attempt was made to further characterize the hydrocarbons due to the instability of the old cores.

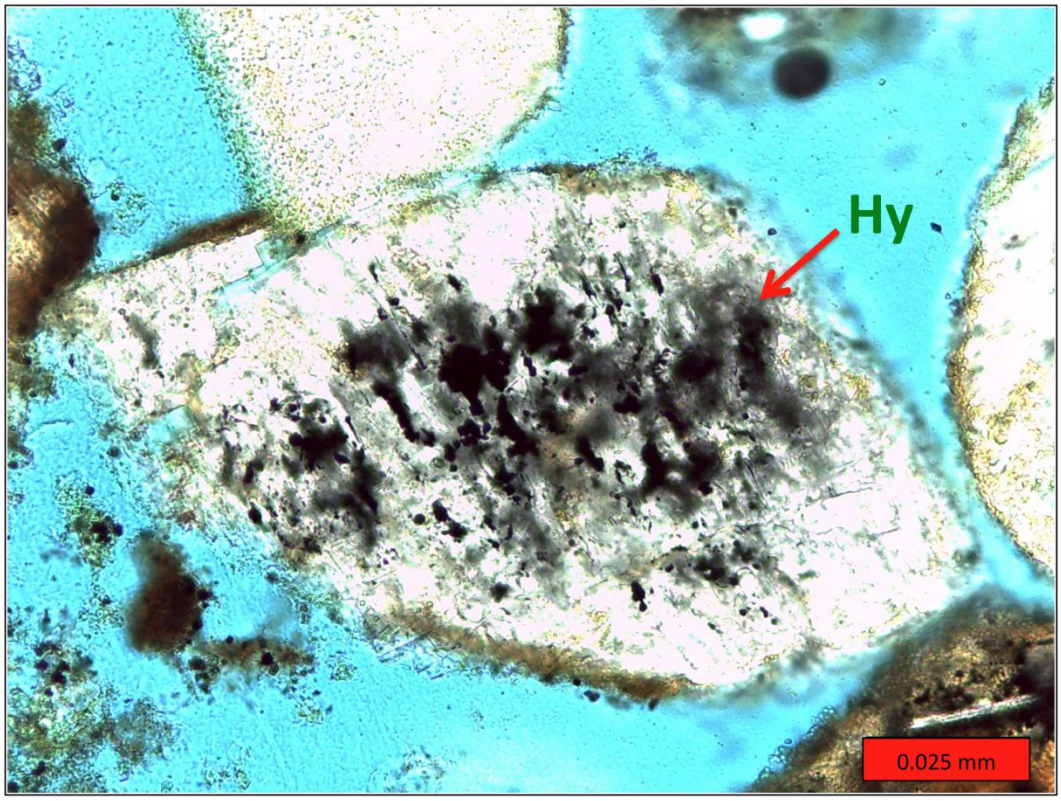


Figure 43: Partially dissolved plagioclase grain showing varying degrees of alteration to clay or sericite with hydrocarbons (Hy) present in secondary pore space. Well: Rudnick 1, depth: 11,413 ft (3,479 m).

Compaction and Fractures

Following the methodologies of Wilson and McBride (1988) contact index (CI = average number of contacts per grain) and tight-packing index (TPI = average number of long, interpenetrating, and sutured contacts per grain) data were gathered from the Vedder Sandstones. CI and TPI are highly dependent on sorting and grain size, therefore, only medium-size arenites with less than 15% cement and ductile grains were used. The CI for the Vedder Sandstones ranges from 1.9 to 3.7 and TPI range from 1.3 to 2.2 (Figure 44a, b) (Table 9).

The CI and TPI values suggest that the Vedder Sandstones are moderate to tightly compacted with exception of calcite-cemented samples, and fall within the ranges reported by Horton et al. (2009) for similar depths. Tangential and point contacts are more common in shallower samples (Figure 44a) as well as samples containing abundant carbonate cement. Long, concavo-convex, and sutured contacts were more common in deeper samples (Figure 10). Compaction commonly deformed the grains that were more ductile in nature such as micas (biotite, muscovite), glauconite, and volcanics. The grains most affected by compaction were biotite and volcanics, which often were squashed to formed pseudomatrix.

Fracturing of brittle grains is another common result of compaction and all grains were susceptible. Individual fractures (Figure 45) within grains as well as through-going fractures (Figure 46) are common in the Vedder Sandstones. Some through-going fractures contain calcite cement, suggesting that the fracture served as a pathway for migrating pore fluids. SEM-CL analysis indicates that some fractured grains were healed with other authigenic minerals (Figure 39).

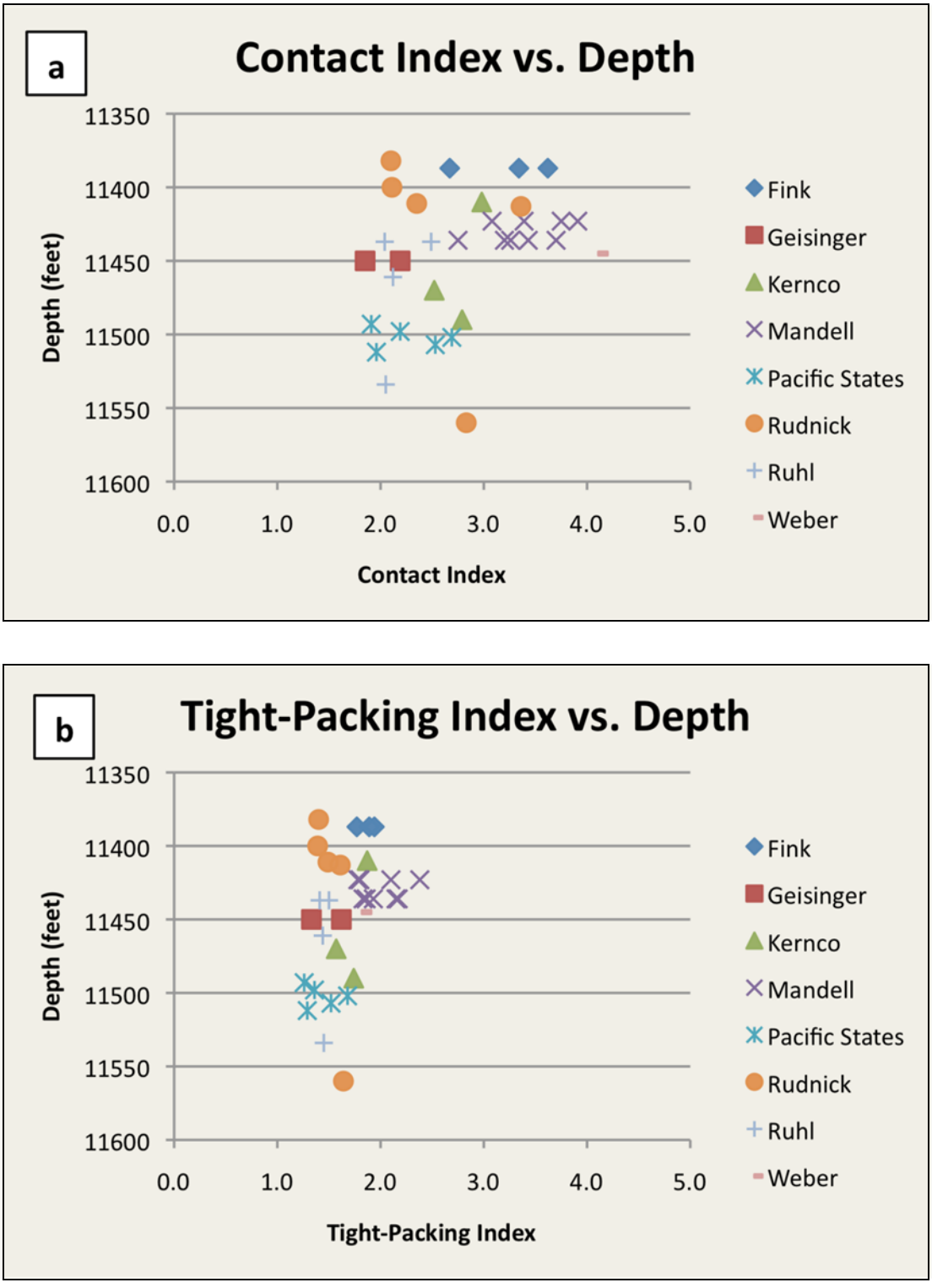


Figure 44: **(a)** Contact index **(b)** and tight-packing index of the Vedder Sandstones.

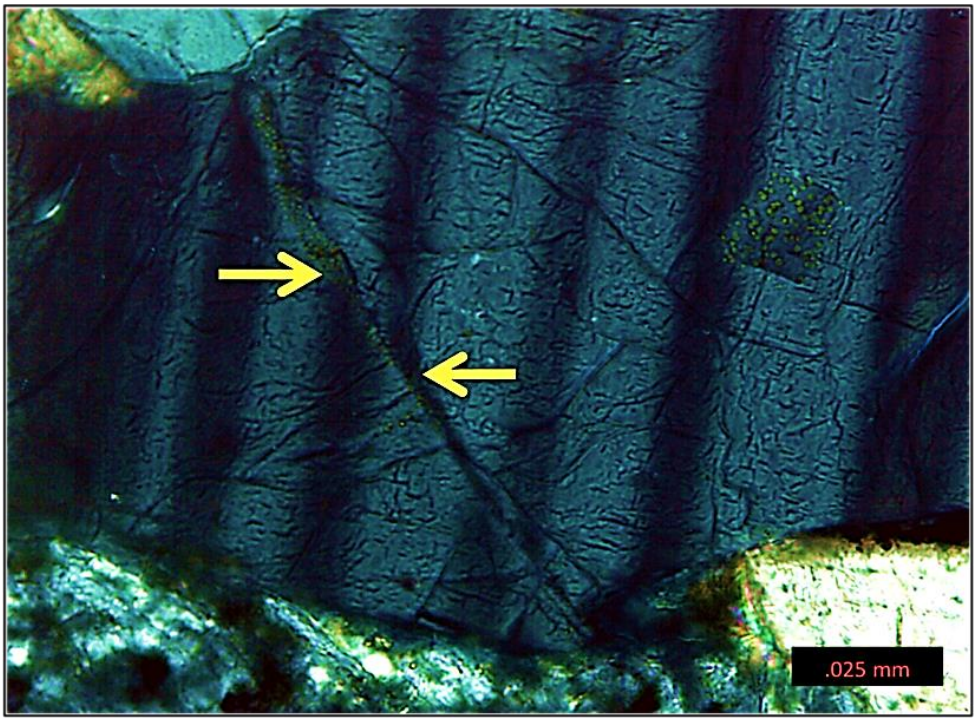


Figure 45: Twin lamellae in plagioclase grain offset along fracture (yellow arrow). Well: Pacific States 21, depth: 11,502 ft (3,505 m).

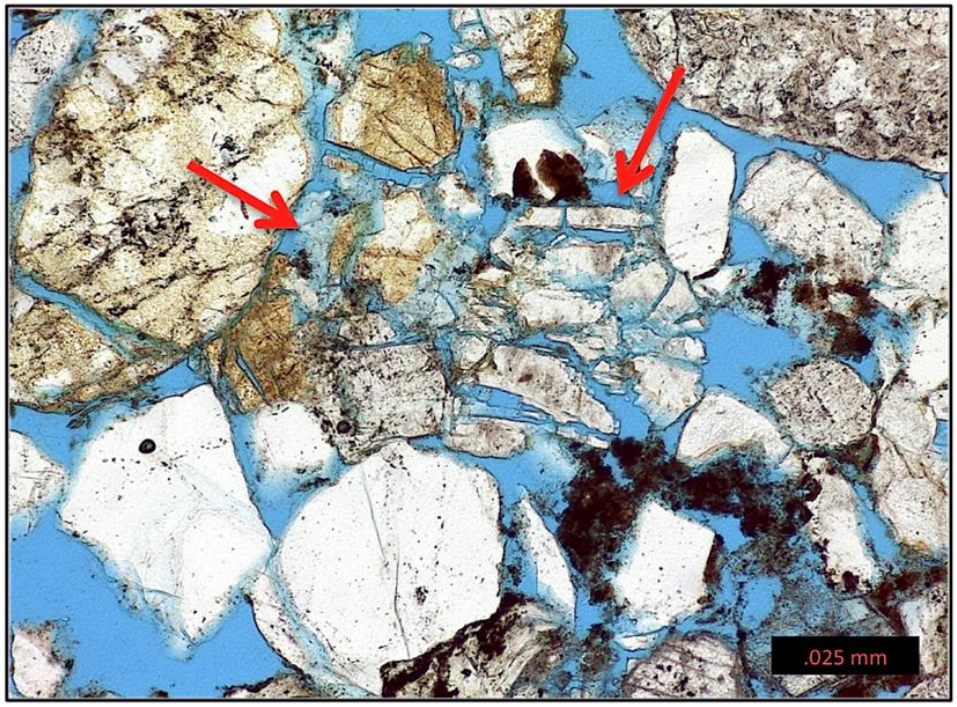


Figure 46: Intensely fractured feldspar grains (red arrows). Well: Kernco 61-34, depth: 11,410 ft (3,478 m).

Porosity

Thin-section porosity ranges from trace to 31% of the rock volume (Tables 1-8) and shows considerable variation even through very narrow depth intervals (Figure 47). However, there is a general trend of decreasing thin-section porosity with increasing depth (Figure 47). Intragranular porosity averages 1% of the rock volume (Tables 1-8), and intergranular porosity averages close to 12% of the rock volume (Tables 1-8). Porosity is significantly less in carbonate cemented sandstones, matrix rich sandstones such as wackes, and sandstones rich in pseudomatix (Figure 48).

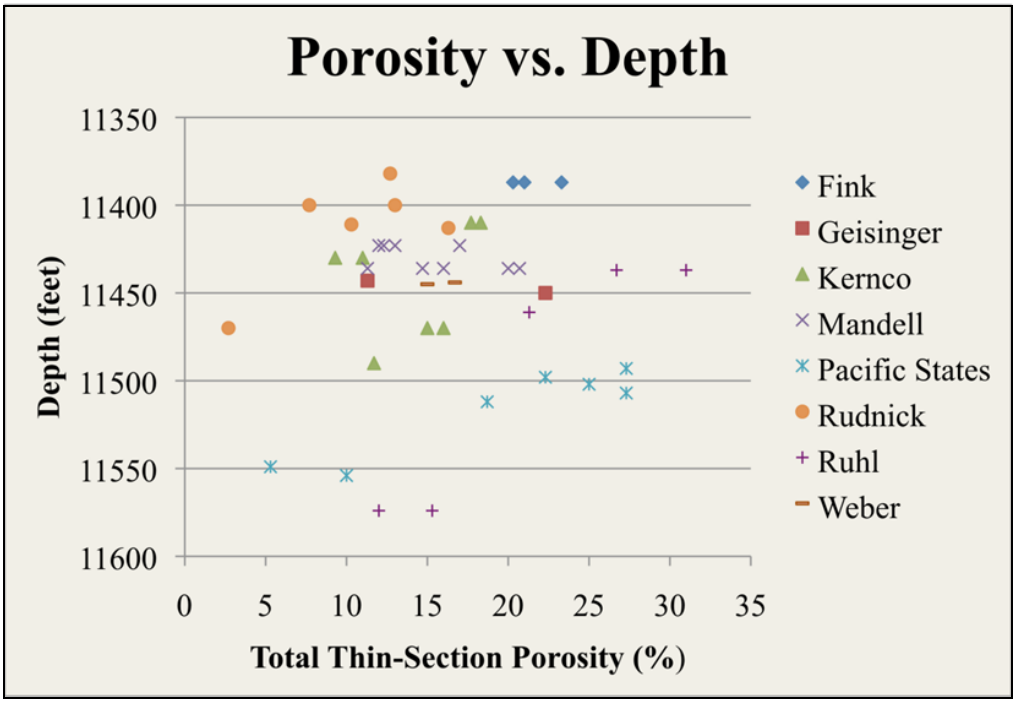


Figure 47: Plot of total porosity vs. depth (feet) for samples with less than a 15% combination of calcite, dolomite, clay, and ductile grains.

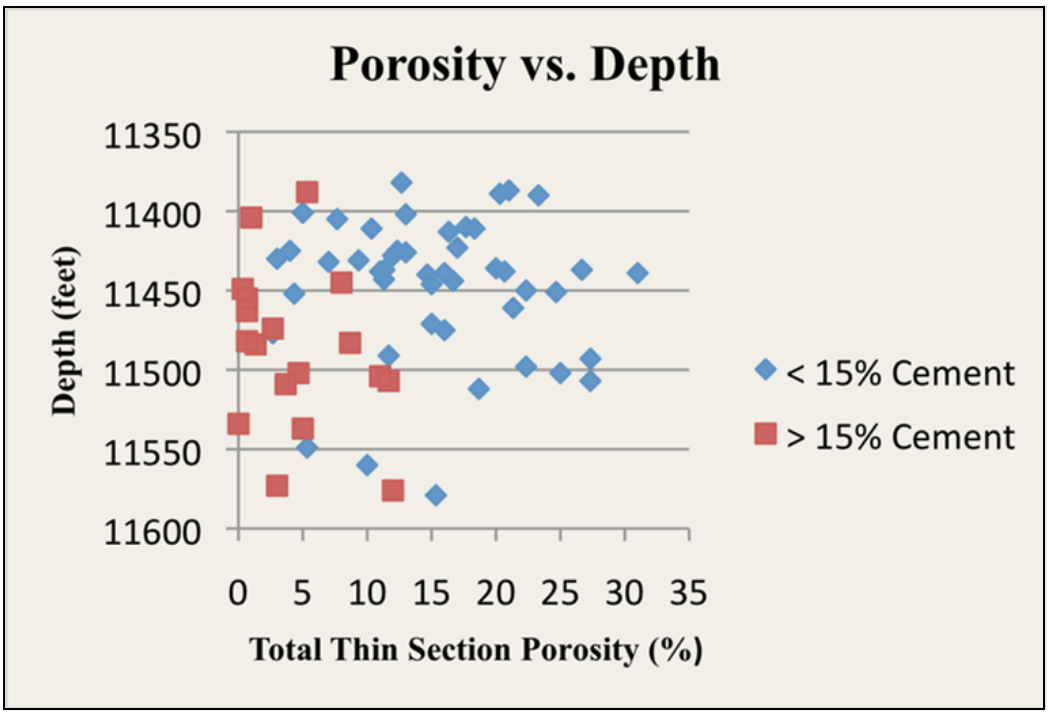


Figure 48: Plot of total porosity vs. depth (feet) comparing cemented and uncemented sandstone porosity.

Mass Balance

Export and import of aluminum was investigated by comparing the volumes of kaolinite cement present to the volume of kaolinite cement predicted if all aluminum released during feldspar dissolution was incorporated into kaolinite. Figures 49 and 50 show the results assuming that there is 0% microporosity in the kaolinite. These data suggest a net export of aluminum from these samples.

However, based on SEM-BSE imaging of kaolinte at magnifications of 750 to 2,100X, the average kaolinite microporosity is estimated at 40% in these rocks. Figures 51 and 52 show expected kaolinite versus actual kaolinite assuming 40% microporosity. The distribution of the points suggests that aluminum released through feldspar dissolution was exported out of the system (at least on the scale of a thin section) for approximately 65% of the samples. Aluminum import is indicated for 7%, and neither export nor import of aluminum is indicated for 28% of the

thin sections. These calculations are conservative in that unidentified dissolved grains were ignored, no adjustments were made for secondary porosity that may have been destroyed due to subsequent compaction; and no adjustments were made for mobilization of aluminum from albitization of feldspars.

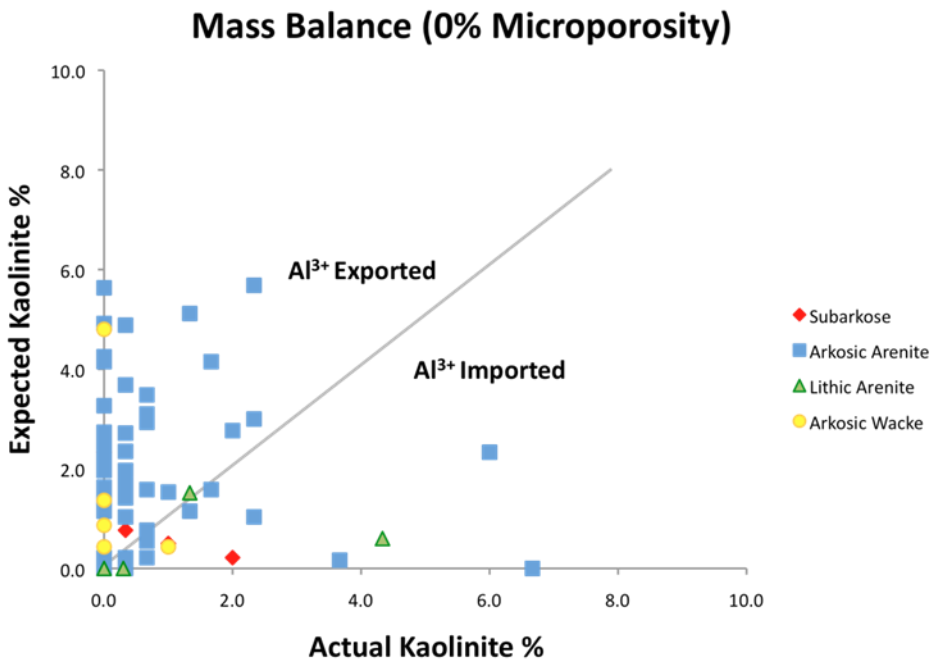


Figure 49: Plot of actual percent kaolinite vs. expected percent kaolinite assuming a microporosity of 0% according to the classification of examined Vedder Sandstones.

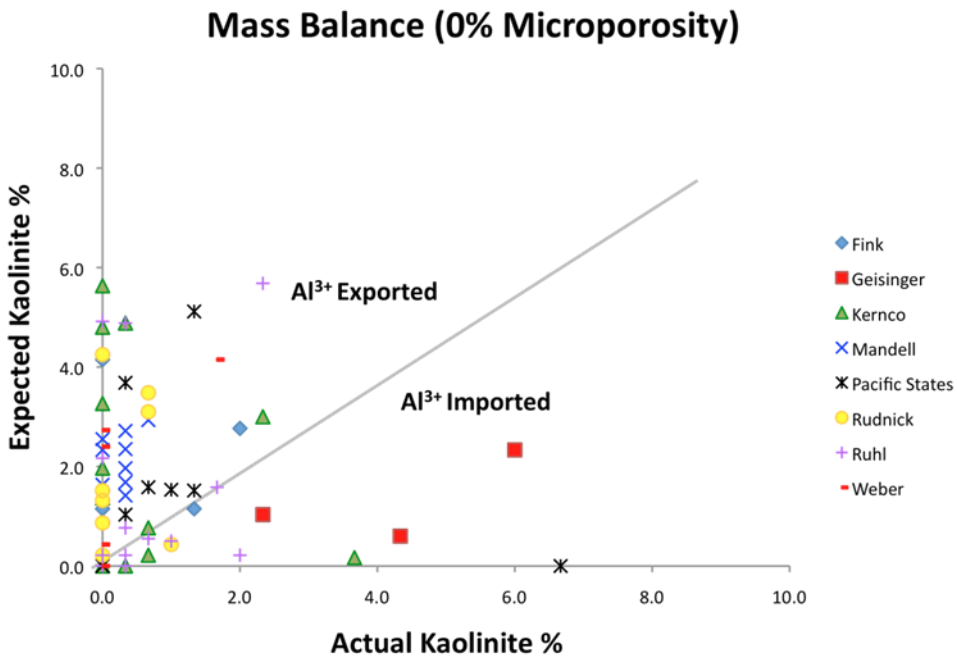


Figure 50: Plot of actual percent kaolinite vs. expected percent kaolinite assuming a microporosity of 0% according to each Rio Bravo well examined.

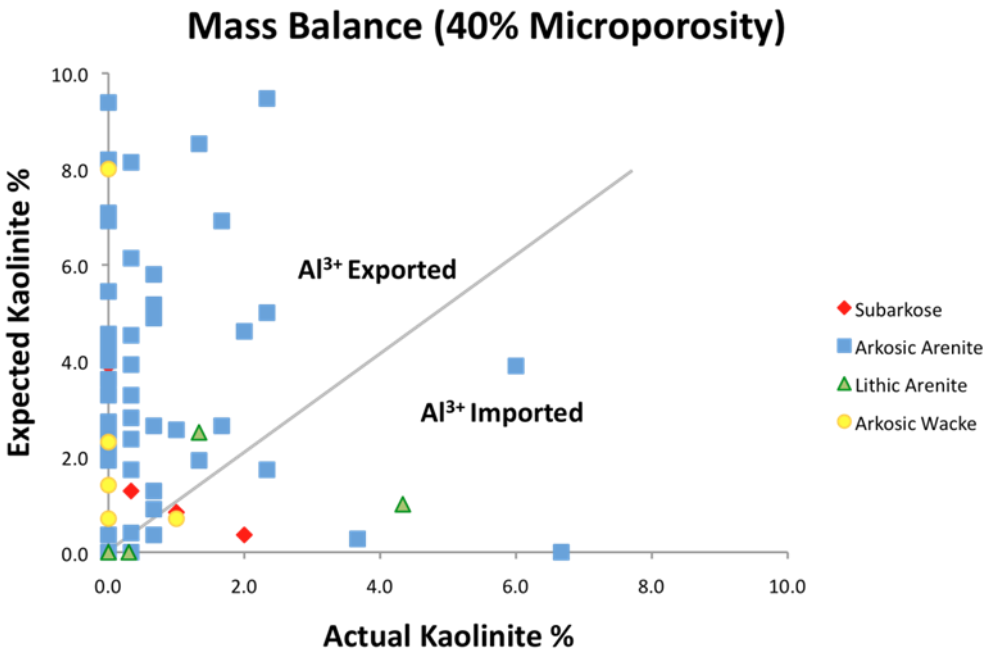


Figure 51: Plot of actual percent kaolinite vs. expected percent kaolinite assuming a microporosity of 40% according to the classification of examined Vedder Sandstones.

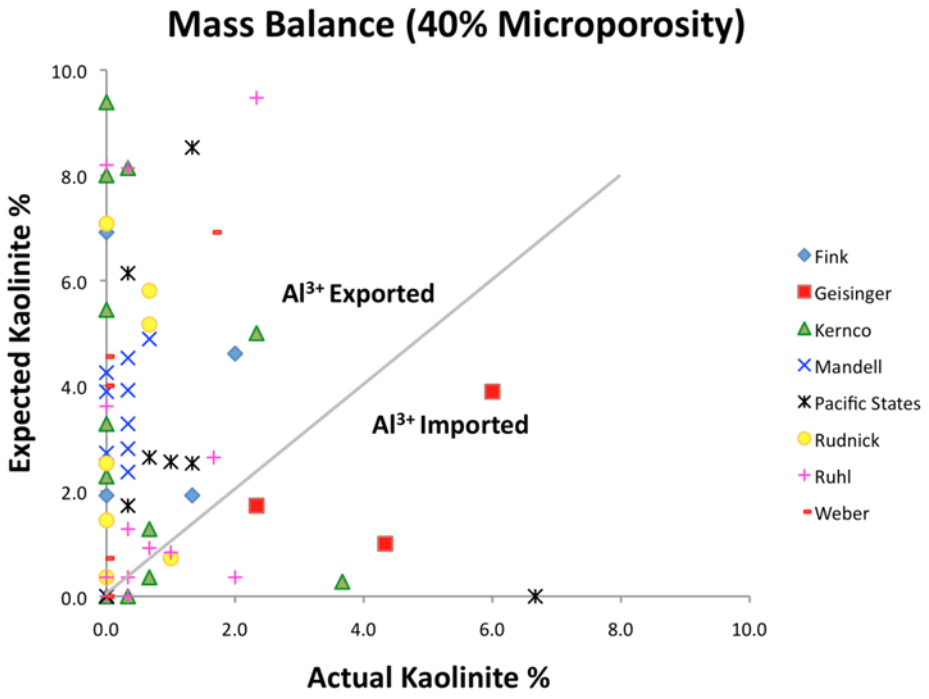


Figure 52: Plot of actual percent kaolinite vs. expected percent kaolinite assuming a microporosity of 40% according to each Rio Bravo well examined.

DISCUSSION

The Vedder Sandstones at the Rio Bravo oil field were affected by numerous diagenetic processes which include compaction (ductile and brittle grains), cementation (grain coatings, overgrowths, pore-filling cements, clays), alteration (recrystalization of minerals, albitization), and dissolution of grains. These processes are of great importance from the standpoint of the oil reservoir. Each contributes to the destruction or development of porosity, which ultimately determines the reservoir quality and its potential to effectively produce hydrocarbons.

A paragenetic sequence of overlapping diagenetic events was established based on the textural relationships of the minerals (Figure 53). The earliest diagenetic events are shown occurring shortly after deposition and the latest occurring up until present time.

Early diagenesis of the Vedder Sandstones began penecontemporaneously with deposition. For glauconization to occur an abundant supply of potassium and iron must be present (Hower, 1961). This is essentially facilitated by the presence of decaying organic matter in reducing conditions accompanied by a slow rate of detrital influx (Cloud, 1955; Odin 1980; Stonecipher, 1999). These conditions are met in a submarine environment with depths ranging from 328 ft (100 m) to 984 ft (300 m) (Jimenez-Millan et al., 1998). During early diagenesis glauconite may also form from the alteration of micas, volcanic glass, biogenic pellets, and feldspars (Wilson and Pittman, 1977). Although Cloud (1955) suggests glauconite may be transported from its place of origin, reworked, or chemically mobilized and moved after burial, the Vedder Sandstones contained high concentrations of glauconite (Figure 14) suggesting it formed in place and supports the interpretation that the Vedder Sandstones were deposited in a marine shelf environment.

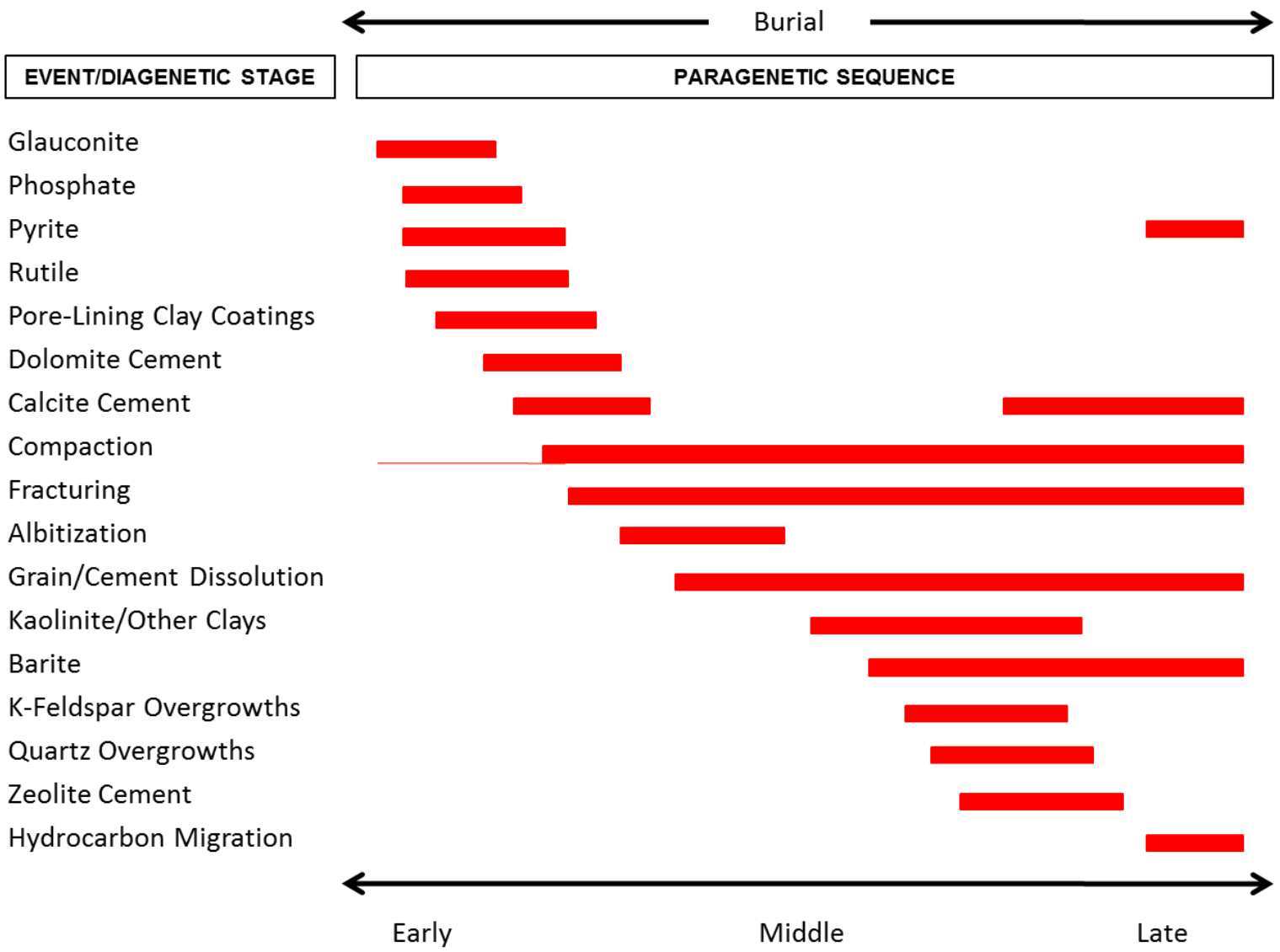


Figure 53: Paragenetic sequence for the Vedder Sandstones.

Phosphate (Figure 15) and glauconite (Figure 14) are often found together in marine sediments. While phosphate is known to be deposited in a wide range of depositional environments (Baturin, 1982), it normally occurs in a low energy marine environment. Phosphorites are linked to microbial decomposition of organic matter within sediments in which the decomposed organic matter releases phosphorous into the pore waters, or phosphate is released from hydrous ferric-oxide minerals (Glenn et al., 1994; Carson & Crowley, 1993). The occurrence of rounded glauconite and phosphate peloids occurring together and replacing silicate minerals is consistent with their formation penecontemporaneous with deposition and continuing through early diagenesis. Nguyen (2014, in press) analyzed the Vedder Sandstones at the Greeley oil field located southeast of the Rio Bravo oil field and observed phosphate nucleated on glauconite grains, further supporting the interpretation that phosphate formed shortly after glauconite.

Authigenic pyrite commonly occurs in association with glauconite grains that have been replaced by phosphate. Like glauconite and phosphate, pyrite formation is also dependent on decomposable organic matter and anoxic environments (Berner, 1970). The early formation of pyrite occurs during shallow burial in organic rich sediments, and is formed by the reaction of sulfide ions with fine-grained iron minerals (Berner, 1970; Morad, 1986a).

Authigenic pyrite also formed between cleavage planes within biotite (Figure 16b). This caused expansion of the biotite fabric thus creating pore space along the cleavage planes. These pores persist in tightly compacted sandstones where expansion of the fabric would have been unlikely; therefore this is an indication that formation of pyrite within biotite occurred during early stages of diagenesis. Textural relationships between pyrite crystals embedded within biotite suggests that alteration may have provided the iron source necessary for pyrite to precipitate as well as potentially providing the iron and potassium necessary for the formation of glauconite (Berner, 1970; Morad, 1986a).

Authigenic pyrite is present as well within chlorite that formed from alteration of biotite (Figure 22). The likely sources of iron for the formation of authigenic chlorite are attributed mostly to detrital biotite and Fe-Ti oxides such as ilmenite (Morad, 1986a). The pyrite observed within chlorite has expanded the fabric of the mineral, thus suggesting the formation of chlorite and pyrite under reducing conditions during early diagenesis.

Chlorite also occurs along fractures within silicate grains (Figure 21a), as thin coatings on detrital grains (Figure 21b), and as cement filling nearby pores (Figure 23). The occurrence along fractures suggests that while the chlorite formed early in the diagenetic history, it continued forming after the initiation of fracturing.

Authigenic rutile is minor and occurs predominantly as clusters of crystals within interstitial cements and on detrital grains. It is associated with pyrite and clays and possibly formed from dissolution of titanium-rich minerals such as ilmenite (Figure 17) (Morad, 1986b).

Carbonate cements observed within the Rio Bravo/Vedder Sandstones consist of dolomite and calcite (Figure 54). Dolomite precipitated as isolated euhedral rhombic (Figure 28) crystals, between biotite cleavage planes (Figure 31), and as pore-filling cement composed of euhedral to subhedral crystals (Figure 28). The expanded fabric shown in Figure 31 indicates a pre-compaction origin for the dolomite. Compositional zoning is common in dolomite crystals where the majority of samples display thin iron-rich zones (Figure 29). The zoning indicates precipitation under evolving geochemical conditions, thus suggesting the possibility of multiple periods of dolomite precipitation. In some rhombs the cores have been dissolved (Figure 29). This suggests that the dolomite contains varying trace element compositions within the crystals (Lee and Boles, 1996). Clay coatings and thin layers of anhydrite (Figure 42) cement are present on the dolomite rhombs. The presence of clay coatings suggest formation during early stages of diagenesis, while the timing of anhydrite precipitation is uncertain. However, dolomite commonly replaced quartz and feldspar grains (Figure 30) within compacted sandstones suggesting a later episode of dolomitic cement as well.

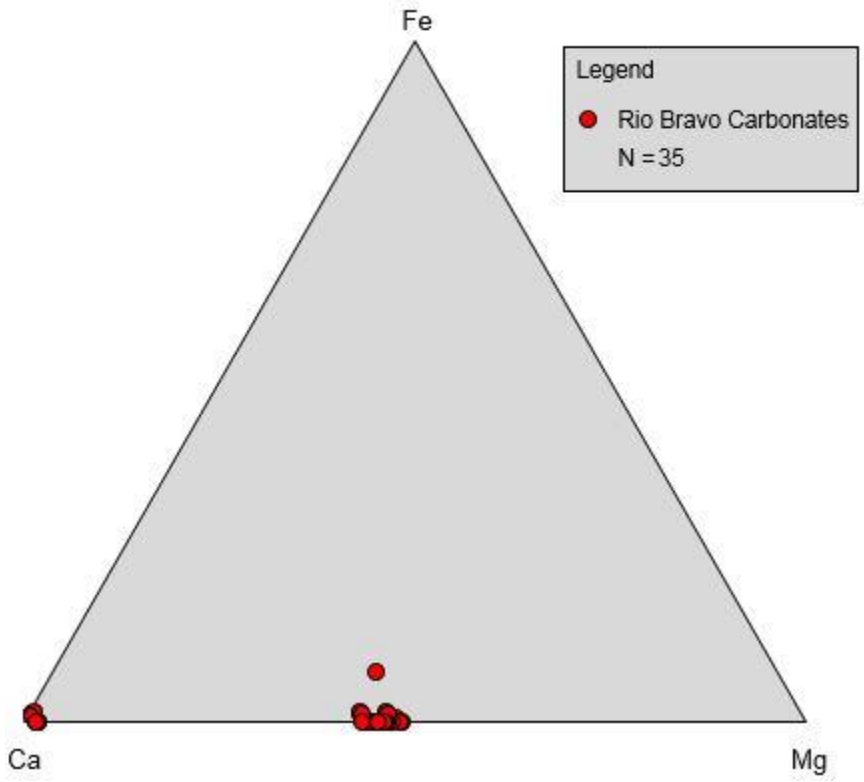


Figure 54: Ternary diagram showing Ca-Mg-Fe composition of carbonate cements (electron microprobe analysis).

The formation of early dolomite is followed by the precipitation of calcite. Early-stage calcite occurs as poikilotopic pore-filling cement in large pore spaces around detrital grains and early dolomite cement crystals. Clay coatings are present on detrital grains prior to the precipitation of early stage calcite (Figure 19). Calcite cementation can inhibit subsequent diagenesis by reducing the permeability to the point that migrating pore-fluids moved only minimally through the sandstone (Eslinger and Pever, 1988).

A second generation of calcite precipitation occurred as a late-stage cement within deeper compacted samples. Late-stage calcite precipitation is common in the San Joaquin basin as the albitization of plagioclase releases calcium ions into the pore fluids (Boles, 1984; Hayes and Boles, 1992; Perez and Boles, 2005). Late-stage calcite replaced quartz and

feldspar grains (Figure 32). In some instances calcite replaced albitized feldspars, indicating a later stage formation. Several through-going fractures are filled with calcite cement (Figure 33) suggesting that the fractures served as a pathway for migrating pore fluids.

Mechanical compaction in the Vedder Sandstones was one of the most important diagenetic processes that affected reservoir quality. Compaction began shortly after deposition causing deformation of labile grains (micas and volcanics) and squeezing them into adjacent pore spaces forming pseudomatrix (Figure 18, Figure 46). Significant volumes of pseudomatrix can clog pores resulting in a loss of usable porosity and connectivity, therefore, decreasing permeability. During early-stage diagenesis grains were also rearranged creating point and tangential contacts. As the sandstones were buried further, compaction increased and caused the grain contacts to evolve from point and tangential to long and concavo-convex as intergranular pressure-induced dissolution caused grains to dissolve into one another (Figure 10).

The frequency of occurrence of long, concavo-convex, and sutured contacts has been used as a measure of intensity of compaction of the sandstones. The detrital Vedder Sandstones contain an average of at least three contacts with adjacent grains (Table 9). No correlation and overall trend could be made in either CI or TPI in the Vedder Sandstones. Using samples from larger depth ranges, Horton et al. (2009) and Taylor (2007) found an increase of CI and TPI with increasing depth in the western San Joaquin Basin. The Rio Bravo/Vedder Sandstones fall within the ranges reported by Horton et al. (2009) for similar depths. The lack of any trend at the Rio Bravo oil field may reflect that the samples taken were from a narrow depth interval and showed considerable variations throughout.

Mixed-layer illite/smectite (I/S) or illite/chlorite (I/C) was formed during two diagenetic episodes, first as pore-lining clay and later as pore-filling cement. The initial clay rims are present as continuous linings of otherwise unfilled pores (Figure 24) and on detrital framework grains within poikilotopic calcite cement (Figure 19). This indicates that the clay rims formed

prior to precipitation of carbonates during early diagenesis. This type of early mixed-layer I/S or I/C is more abundant in shallower samples and may have formed during chloritization of biotite in which potassium was liberated (Morad, 1986a). Authigenic clays occurring as grain coatings, even in small amounts can severely restrict pore throats and thus significantly reduce permeability. In addition, clay coatings have been reported to inhibit quartz cementation by forming a protective coating over the quartz grain, thereby preventing the nucleation of quartz cement (Heald and Larese, 1973; Tillman and Almon, 1979).

Later-stage pore-filling illite/smectite or illite/chlorite is present in deeper samples but is generally absent in carbonate-cemented sands. Figure 24 shows I/S or I/C present as pore-lining cement. The pore linings span gaps created by fractures in feldspar grains suggesting that the clays formed after the initiation of grain fracturing.

Authigenic kaolinite formed during a later-stage of diagenesis after the onset of significant compaction, fracturing, dissolution, and albitization of feldspars. It occurs as well developed booklets that partially to completely fill intergranular pores (Figure 26). Kaolinite is frequently present adjacent to partially dissolved feldspars (Figure 27) suggesting that the silica and aluminum needed for kaolinite precipitation was probably derived from the dissolution and albitization of plagioclase grains (Helmold and Kamp, 1984; Morad et al., 1990; Perez and Boles, 2005).

With an increase in burial depth, and continuation of compaction and fracturing, albitization of plagioclase and potassium feldspars occurred within the Vedder Sandstones (Figure 35, 36, 41). Recognizing the occurrence of diagenetic albitization is important because this process can modify the pore size and influence the porosity and permeability of fluid reservoirs, especially when CO_2 supply is constant (Perez and Boles, 2005).

Albitization has been documented occurring within variable ranges of temperatures during middle-stage diagenesis (Gold, 1987; Boles and Ramseyer, 1988; Boles 1982; Morad et al., 1990). In the San Joaquin basin albite precipitation in open pore spaces has been

documented occurring at temperatures as low as 109º F (43º C), however albitization as a replacement doesn't start until temperatures are higher than 181º F (83º C) (Boles and Ramseyer, 1988). Perez and Boles (2005) proposed that fluid chemistry is important to the formation of authigentic albite, however, temperature is key. Albitization within the Rio Bravo Vedder Sandstones is more extensive in deeper sandstones that are poorly-cemented which suggests that albitization occurred after cementation.

Textural evidence reveals that sometimes albitization is guided by weaknesses in detrital grains like fractures and points of stress. Along the fractured grains pore fluids rich in sodium infiltrated the detrital feldspars and albitized along the fresh surface (Figure 35) (Taylor 2007, Horton et al., 2009;). Pseudomorphic replacement of detrital feldspars is also very common. This type of albitization consists of a gradual replacement of calcium and aluminum by sodium and silicon throughout the detrital grain and appears as a blocky to tabular pattern (Figure 36) (Boles, 1982; Gold, 1987).

Potassium feldspar is a common authigenic component in the Vedder Sandstones of the Rio Bravo oil field. Nearly pure authigenic potassium feldspar occurs within fractures in detrital feldspars and as overgrowths on both plagioclase and potassium feldspars (Figure 37). Cross-cutting relationships of fractures healed by authigenic albite and potassium feldspar indicate that albitization occurred prior to the precipitation of authigenic potassium feldspar (Figure 37). Authigenic feldspars precipitate under moderately high temperatures when sufficient concentrations of dissolved silica, sodium, and potassium are supplied in the pore waters (Kastner and Siever, 1979). It is estimated that precipitation temperatures for late diagenetic potassium feldspar ranges from 158º F (70º C) to 266º F (130ºC) (R. Horton, personal communication).

Zeolite cement is present in one well: Kernco 61-34, at the crest of the structure in the Rio Bravo oil field (Figure 4) where chemical mobility may have been greatest. The formation of zeolite cement typically involves dissolution of volcanic grains generating mobilized K^+, Na^+,

Ca^{+}, and Mg^{2+} (Broxton et al., 1987). Aoyagi and Kazama, (1980) suggest that the transformation from volcanic glass to clinoptilolite occurs at a reservoir temperature of 140º F (60º C), and while the mineralogy of zeolite at Rio Bravo oil field was not determined, clinoptilolite is a common zeolite cement elsewhere in the San Joaquin basin (R. Horton, personal communication). Zeolite cement commonly coexists with carbonate cement, and although it has reduced porosity and permeability it appears to have protected the pore structure against compaction (Figure 34). Textural relationships confirm that zeolite cement post-dates carbonates, authigenic albite, and authigenic potassium feldspars (Figure 34). Authigenic quartz was not observed in samples containing abundant zeolite cement suggesting authigenic quartz formed later.

Authigenic quartz cement is not as widespread as authigenic albite and potassium feldspars. It is present as overgrowths and as a fracture filling cement in detrital quartz grains (Figure 39). The fractures produced from early stages of compaction are healed by secondary quartz. Although extensive studies reveal quartz precipitation occurs within a wide range of temperatures, most studies indicate the genesis of quartz cementation at temperatures ranging from 167º F (75º C) to 212º F (100º C) (R. Horton, personal communication).

Barite is present in one sandstone sample (Figure 41). It occurs as cement and replacing detrital grains. Figure 41 illustrates barite replacing an albitized plagioclase grain indicating barite formed after albitization.

The development of secondary porosity through dissolution of framework-grains plays an important role in the diagenesis of sandstones. Dissolution is a special type of alteration that acts to negate the effects of compaction on porosity. It is of great importance to the oil industry because primary migration of hydrocarbons commonly follows closely after the secondary porosity has been formed (Schmidt and McDonald, 1979). The Vedder Sandstones display several episodes of dissolution. An early stage of dissolution occurred prior to the onset of significant compaction as indicated by earlier clay fillings and linings. A later stage of dissolution

occurred after the initiation of compaction and fracturing, dissolving framework-grains and cement. An even later stage of dissolution occurred as evidenced by the dissolution of zeolite cement (Figure 34).

Dissolution affected mostly framework grains, however, dissolution of authigenic-cement (carbonate and zeolite) also occurred. Feldspars (particularly plagioclase) and volcanic grains were the most susceptible to dissolution, however, quartz grains are also significantly dissolved, primarily along grain edges (Figure 55). Dissolution of feldspar grains typically occurred along cleavage traces and broken grains (Figure 56). Figure 57 shows a ternary diagram that has been adjusted for grain dissolution. The arrowheads point to the present compositions and the tail ends represent the reconstructed compositions. The arrowheads with no tails indicate no change in composition. The length of the arrows indicate the magnitude of compositional shift. Preferential dissolution of feldspars, in particular plagioclase, resulted in a shifted composition of sandstones towards the quartz apex on the ternary diagram. Figure 58 shows the amount of secondary porosity that formed by dissolution of plagioclase feldspar plotted against depth and indicates a general trend of plagioclase decreasing with depth. Figure 59 shows the amount of secondary porosity that formed by dissolution of potassium feldspar plotted against depth and indicates that there was no significant change. Figure 7 shows a provenance ternary diagram that has been adjusted for grain dissolution. In determining the provenance of the Vedder Sandstones, pseudomatrix was added to lithic fragments while quartz and feldspars were adjusted for secondary porosity. The arrow heads represent the present composition and the tail ends represent the compositions reconstructed following Harris (1989). Most of the sandstones fall in the field of continental block (basement uplift), suggesting that the Vedder Sandstones are derived from the eastern Sierra Nevada. However, the reconstructed data may not truly represent the original composition of the Vedder Sandstones because there is evidence that secondary porosity may have been destroyed by continued compaction during increasing burial (Horton et al., 2009).

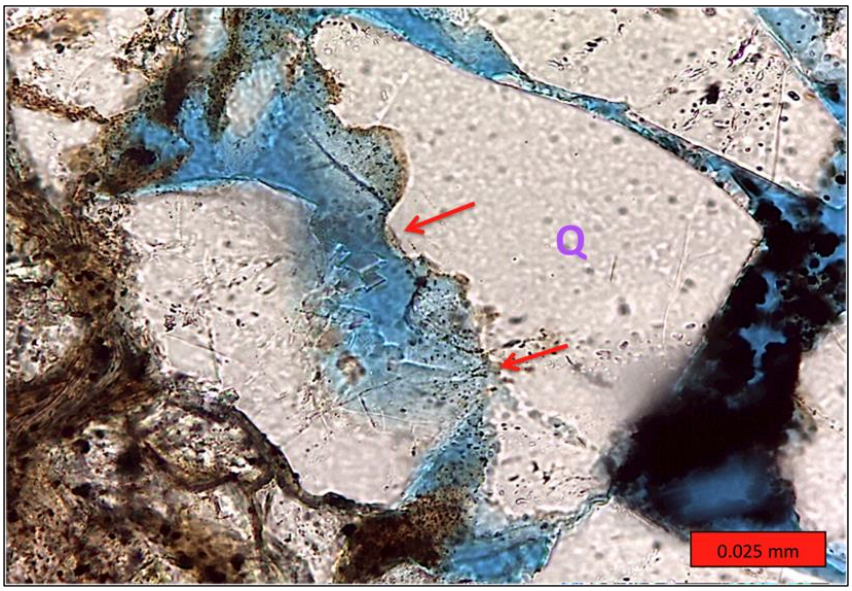


Figure 55: Quartz grain showing effects of dissolution along the grain's edge. Well: Fink 1, depth: 11,387 ft (3,471 m).

Figure 56: Partially dissolved K-feldspar (K) grain. Dissolution occurs parallel to cleavage plains. Well: Pacific States 21, depth: 11,382 ft (3,469 m).

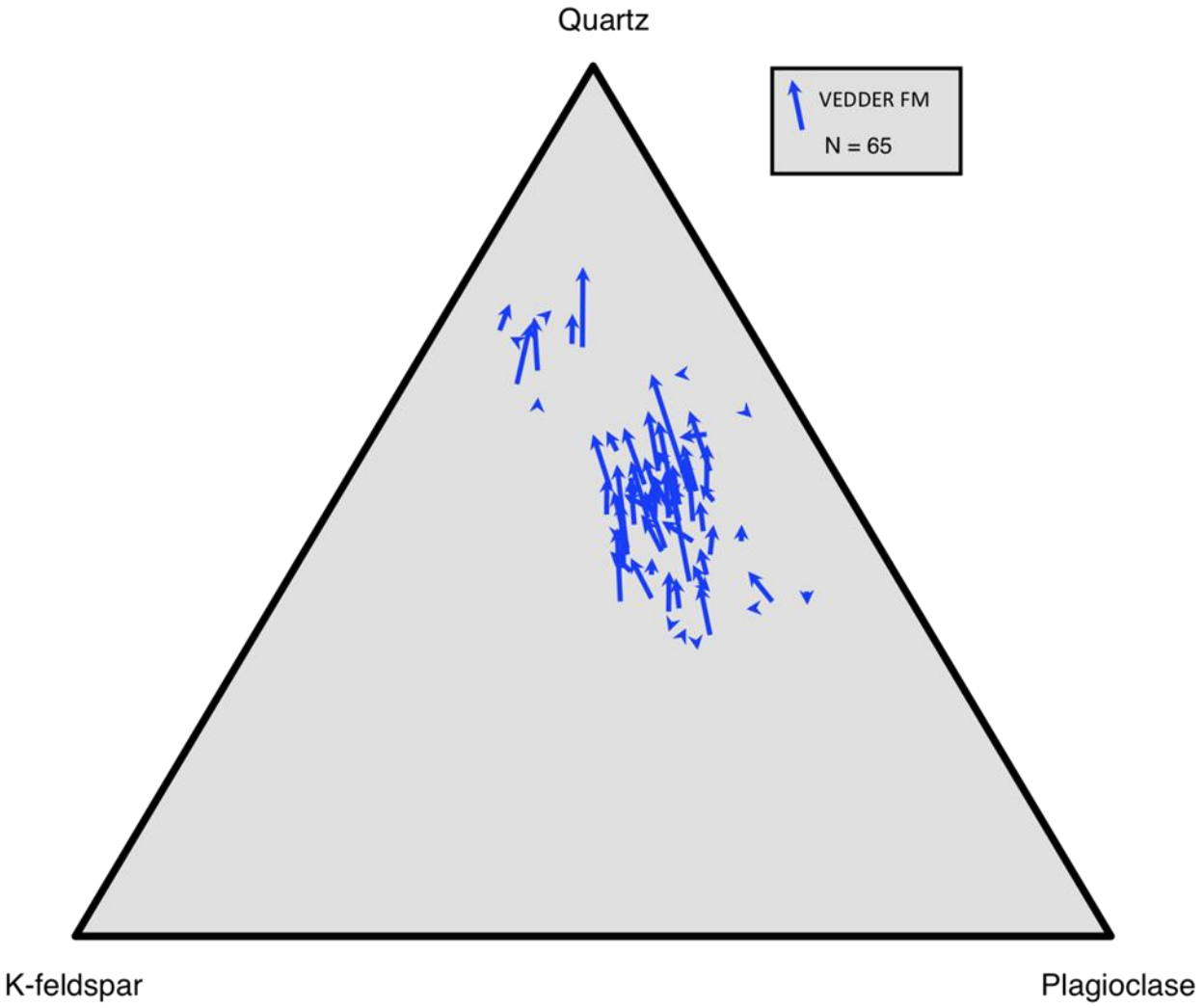


Figure 57: QKP ternary diagram plotted for the Vedder sandstones following the methodology of Harris (1989). The arrow heads indicate the present composition, the arrow tails show the reconstructed compositions.

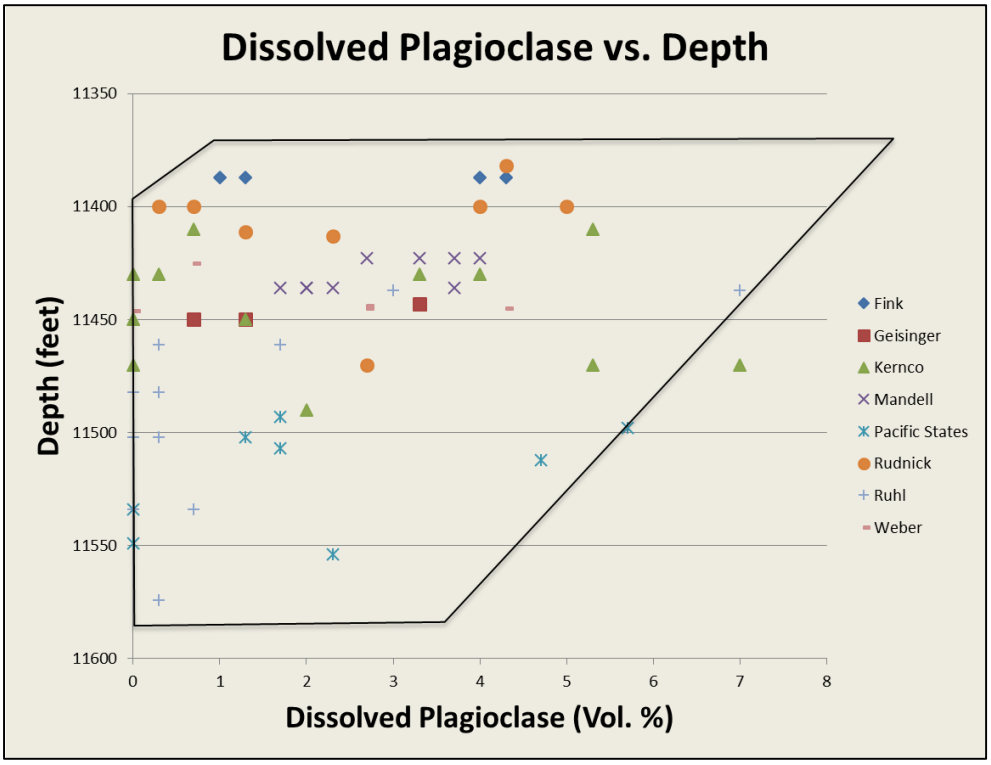


Figure 58: Plot of percent dissolved plagioclase volume vs. depth in feet.

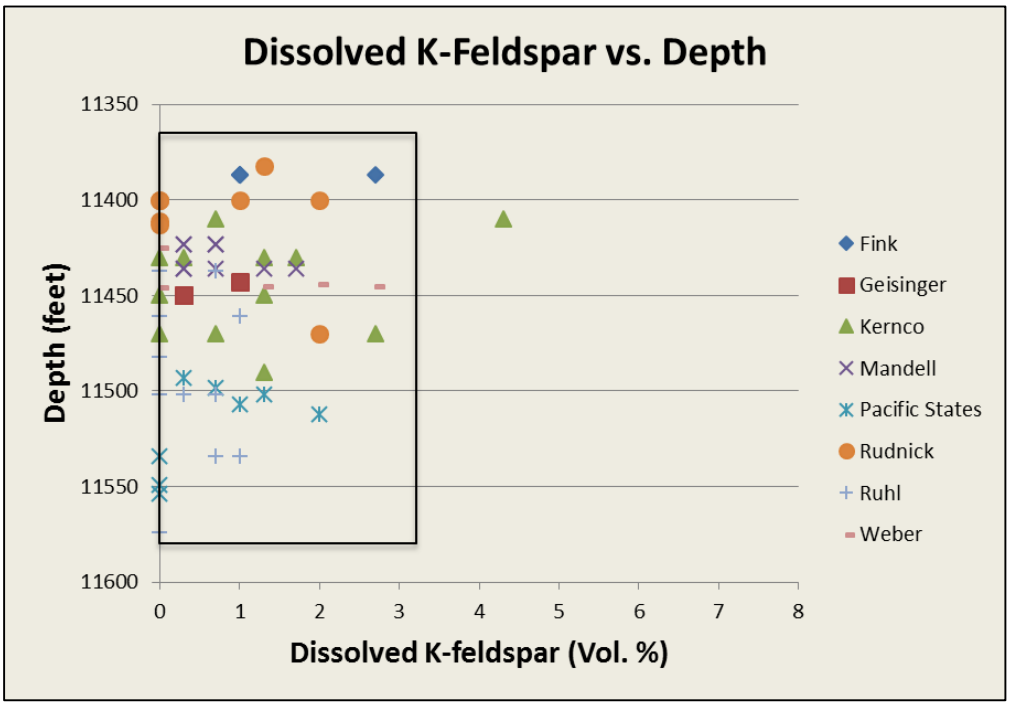


Figure 59: Plot of percent dissolved K-feldspar volume vs. depth in feet.

While the development of secondary porosity through dissolution in sandstones has been well documented (Rowsell and de Swardt, 1974; Hayes, 1977, 1979; Schmidt et al, 1977; Schmidt and McDonald, 1979), the overall importance of this process in the development of porosity remains unresolved. Many (e.g. Bjorlykke, 1984, Boles, 1984; Bjorlykke and Jahren 2012; Hayes and Boles, 1991) suggest that marine sandstones porosity development is due to a redistribution of primary porosity, while others (e.g. McBride, 1987; Milliken, 1988; Harris, 1989; Wilkinson et al., 2001) suggest a significant transfer of dissolved material out of the system, especially aluminum. Theoretical models have been developed in order to settle the difference in the development of porosity and suggest that only limited amounts of dissolved materials, especially aluminum, are exported out of the system (Lundegard et al., 1984; Bjorlykke, 1984; Hanor, 1984; Walter, 1986; Giles, 1987; Stoessell, 1987; Bjorlykke et al., 1988; Hutcheon and Abercrombie, 1990; Hayes and Boles, 1991). Thus, these models propose that as the temperature rises during burial, aluminum solubility increases only slightly. In order for aluminum-silicates to dissolve, there must be a nearby aluminum sink or the pore fluids would quickly become supersaturated and dissolution would end. This generally assumes that there is not enough movement of water through the rocks at deep depths to remove aluminum through fluid flow unless large volumes of fresh water, which is not saturated with aluminum, flows through the rocks, as in a fresh water aquifer (Bjorlykke and Jahren, 2012). Experiments on the other hand have produced conflicting results suggesting that deep burial diagenesis rather than meteoric flushing is responsible for export of dissolved material, especially aluminum, out of the system (Crossey et al, 1986; MacGowan and Surdam, 1988; Harris, 1989; Surdam et al., 1989; Fein, 1991; Thyne, 2001; Thyne et al., 2001).

Mass transfer of aluminum in the Rio Bravo Vedder Sandstones was analyzed by comparing the volumes of kaolinite cement present to the volumes of kaolinite cement that would have formed if all aluminum liberated by dissolution of feldspars precipitated as kaolinite. The results suggest an overall export of aluminum from the sandstones (Figure 49 -Figure 52)

as there is less kaolinite present than is predicted from the observed dissolution of feldspar. In addition, the calculations do not take into account albitization of plagioclase, dissolution of other alumino-silicates, secondary porosity for which the precursor mineral could not be determined, or any secondary porosity that may have been destroyed through subsequent compaction (Taylor, 2007; Nguyen, 2014; Nguyen, in press). All of these potentially would have released additional aluminum into the pore fluids. Therefore, export of aluminum from the Vedder Sandstones is likely. These results agree with the work of Harris (1989) and suggest that dissolution can occur without fresh water. The Rio Bravo water is diluted seawater so some fresh water entered the system, however, there was not flushing by large volumes of fresh water either from shale diagenesis or from meteoric input.

Laumontite cement has been documented within a number of reservoirs in the San Joaquin basin (e.g. Bloch et al., 1993; Bloch and Helmond, 1995; Noh and Boles, 1993; Taylor, 2007), however, no laumontite was observed in the Oligocene Vedder Sandstones at the Rio Bravo Oil Field. Studies at the nearby Greeley (Nguyen, 2014; Nguyen, in press) and Wasco (Olabisi, 2015) oil fields suggests that laumontite precipitation occurs between 130 to 135°C on the east side of the basin. The lack of laumontite at the Rio Bravo Oil Field suggests that the sandstones were never buried deeply enough for laumontite to precipitate, thus the Oligocene Vedder Sandstones are currently at or near their maximum burial depth.

Hydrocarbons migrated into available pore space during late diagenesis (Figure 43). Late pyrite cement occurs in association with hydrocarbons in oversize pores and other secondary porosity (Figure 16 c, d). Late pyrite may have formed as iron in the pore waters reacted with sulfur liberated from continuing maturation of the hydrocarbons (Nguyen 2014; Nguyen, in press). This is possible because hydrocarbons do not displace all of the pore water from the reservoir (Syed, 1981).

SUMMARY

The Oligocene Vedder Sandstones at the Rio Bravo oil field are composed of shallow marine sandstones that are arkosic to lithic arenites. The sandstones contain abundant quartz, plagioclase and potassium feldspars, and minor rock fragments. Common accessory minerals include biotite, muscovite, zircon, hornblende, rutile, garnet, epidote, and magnetite/titanomagnetite. Reservoir quality of the Oligocene Vedder Sandstones at the Rio Bravo oil field has been controlled by several diagenetic features: compaction, cementation, deformation, dissolution, recrystallization, and replacement of minerals. These diagenetic processes significantly altered the reservoir quality by reducing porosity through compaction and cementation or enhancing porosity through dissolution.

Porosity within the Vedder Sandstones ranges from trace amounts to 31% and is controlled by compaction, cementation, and alteration of grains. Mechanical and chemical compaction is evidenced by long and interpenetrating grain contacts, fractured and broken framework grains, sutured quartz grains, deformed ductile grains, and the presence of pseudomatrix. Compaction impacted porosity and permeability through grain rearrangement, fracturing, and deformation of labile grains.

Cementation played a smaller role in affecting reservoir quality. Kaolinite cement is present in the majority of samples and occurs as scattered pore-lining and pore-filling cement, which formed as an alteration product of feldspar grains. Carbonate cement is also present in the majority of samples and forms as poikilotopic pore-filling cement that occurs throughout multiple stages of diagenesis. Zeolite cement is present in small amounts and is common among many of the samples containing significant volcanic grains. Composite images of SEM-BSE and CL images reveals quartz overgrowths present in very minor amounts.

Alteration of detrital grains and cement is widespread throughout the Vedder Sandstones. Illite-smectite or illite-chlorite, and chlorite commonly form from alteration of volcanics and biotite grains. SEM-EDS analysis reveals extensive albitization of both

plagioclase and potassium feldspars grains throughout the majority of uncemented samples. Dissolution of feldspar grains and alteration of rock fragments caused a slight compositional change in the Vedder Sandstones, resulting in more quartz rich sandstone.

Compaction, cementation, and alteration have significantly reduced porosity and permeability in the Vedder Sandstones, however, this reduction was reversed to some extent through the generation of secondary porosity during later diagenesis. The development of secondary porosity through dissolution of framework-grains created an open pore network to facilitate the migration and accumulation of hydrocarbons.

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APPENDIX I – POINT COUNT DATA

Table 1: Point count data for Well: Fink

Depth (ft)	Qtz	K-spar	Plag	RF	Acc Min	Carb	Matrix	Pseudo	Clay Cem	Sec Inter ø	Inter ø	Intra ø	Total ø
11387	26.3	11.0	18.3	4.3	1.7	1.3	5.3	5.3	2.0	3.3	17.0	0.7	21.0
11388	17.0	13.0	15.7	8.0	0.3	28.7	5.7	2.3	0.0	3.3	2.0	0.0	5.3
11389	30.3	7.7	23.7	10.0	1.7	1.0	1.0	0.0	0.0	9.7	8.0	2.7	20.3
11390	27.3	6.3	17.7	9.0	0.7	3.0	0.7	0.0	4.3	6.3	16.3	0.7	23.3

Table 2: Point count data for Well: Geisinger

Depth (ft)	Qtz	K-spar	Plag	RF	Acc Min	Carb	Matrix	Pseudo	Clay Cem	Sec Inter ø	Inter ø	Intra ø	Total ø
11443	33.0	15.3	15.7	9.0	1.0	0.7	2.7	0.7	6.0	1.7	6.0	3.7	11.3
11450	30.0	7.7	6.7	17.0	0.0	5.0	0.7	0.0	4.3	2.0	20.0	0.3	22.3
11451	30.3	11.3	5.0	9.7	0.0	11.3	0.0	2.3	2.3	2.7	21.7	0.3	24.7

Table 3: Point count data for Well: Kernco

Depth (ft)	Qtz	K-spar	Plag	RF	Acc Min	Carb	Matrix	Pseudo	Clay Cem	Sec Inter ø	Inter ø	Intra ø	Total ø
11410	28.0	13.0	18.0	6.3	1.3	2.7	4.3	5.0	0.7	1.3	15.7	0.7	17.7
11410	19.0	12.7	16.0	9.3	1.0	11.3	2.7	5.3	0.0	9.3	5.0	4.0	18.3
11430	18.7	13.3	23.7	1.3	5.3	4.0	18.3	4.3	3.7	1.3	1.3	0.3	3.0
11430	21.3	13.0	15.7	8.3	1.7	11.0	7.3	6.0	2.3	6.0	2.0	1.3	9.3
11430	18.7	8.3	18.3	2.7	1.3	1.3	3.7	27.0	8.7	0.3	6.7	0.0	7.0
11430	26.7	14.3	20.7	6.0	0.7	1.7	10.0	5.0	1.7	9.3	1.0	0.7	11.0
11450	22.0	14.3	24.3	5.7	0.3	0.7	15.3	6.0	4.0	2.7	0.7	1.0	4.3
11450	21.0	11.0	12.3	5.0	0.0	46.7	0.0	0.0	0.0	0.7	0.0	0.0	0.7
11470	24.0	9.0	18.0	7.7	0.0	0.0	18.3	2.0	0.0	10.7	2.0	2.3	15.0
11470	12.0	7.3	15.3	3.3	0.7	51.7	0.0	0.0	0.0	0.0	2.7	0.0	2.7
11470	25.3	12.7	21.3	5.3	0.7	0.0	8.7	4.0	0.3	4.0	6.0	5.0	16.0
11490	20.3	13.0	23.0	4.7	1.3	0.3	3.3	0.7	18.7	5.0	6.7	1.0	11.7

Table 4: Point count data for Well: Mandell

Depth (ft)	Qtz	K-spar	Plag	RF	Acc Min	Carb	Matrix	Pseudo	Clay Cem	Sec Inter ø	Inter ø	Intra ø	Total ø
11423	31.0	11.7	21.7	3.3	6.0	0.3	2.7	0.0	1.3	5.3	10.0	1.7	17.0
11423	29.7	16.0	23.7	6.7	0.3	0.0	0.7	6.0	0.7	3.0	6.3	3.0	12.3
11423	30.3	9.3	23.7	5.3	1.3	1.7	9.7	0.0	3.0	5.7	6.7	0.7	13.0
11423	29.3	15.0	23.0	10.0	0.3	1.3	1.0	6.0	0.3	3.3	6.7	2.0	12.0
11436	27.0	10.3	19.3	6.7	1.0	1.7	8.7	0.3	0.3	4.7	14.3	1.0	20.0
11436	33.3	14.0	23.3	8.7	1.0	1.7	0.0	2.7	0.0	2.7	6.0	2.7	11.3
11436	27.0	9.3	21.7	7.7	1.7	0.7	8.7	0.3	0.3	4.3	15.0	1.3	20.7
11436	30.7	12.3	20.0	4.0	2.0	2.3	10.3	0.7	0.3	3.3	12.0	0.7	16.0
11436	33.7	13.3	21.0	8.0	0.7	1.7	0.3	4.0	0.0	2.0	11.3	1.3	14.7

Depth in feet; Compositional data in percent; Otz = Quartz; K-spar = Potassium feldspar; Plag = Plagioclase feldspar; RF = Rock fragments; Acc Min = Accessory minerals; Carb = Carbonate cement; Matrix = Clay matrix; Pseudo = Pseudomatrix; Clay Cem = one or a combination of kaolinite, illite, smectite; Sec ø = Secondary porosity; Inter ø = Intergranular porosity; Intra ø = Intragranular porosity;Total ø = Total porosity.

Table 5: Point count data for Well: Pacific States

Depth (ft)	Qtz	K-spar	Plag	RF	Acc Min	Carb	Matrix	Pseudo	Clay Cem	Sec Inter ø	Inter ø	Intra ø	Total ø
11493	19.7	10.3	21.0	3.7	1.3	4.0	9.0	0.3	0.3	1.7	24.3	1.3	27.3
11498	27.0	13.7	27.7	5.3	1.0	8.0	0.7	0.3	0.3	8.3	12.7	1.3	22.3
11502	25.0	9.0	23.3	4.0	2.3	2.7	2.3	1.3	1.0	2.7	21.7	0.7	25.0
11507	24.0	8.0	19.7	3.7	3.0	4.0	1.7	3.7	1.3	2.3	24.0	1.0	27.3
11512	26.0	12.0	17.0	8.7	0.7	5.3	0.7	6.7	1.3	6.7	9.7	2.3	18.7
11534	25.0	9.3	18.3	3.7	0.0	38.7	0.0	1.7	0.0	0.0	0.0	0.0	0.0
11549	23.3	2.0	14.0	0.3	17.3	7.0	12.7	0.0	6.7	0.7	4.3	0.3	5.3
11554	24.7	8.3	16.3	20.0	0.3	11.0	0.7	3.0	1.3	2.0	6.7	1.3	10.0

Table 6: Point count data for Well: Rudnick

Depth (ft)	Qtz	K-spar	Plag	RF	Acc Min	Carb	Matrix	Pseudo	Clay Cem	Sec Inter ø	Inter ø	Intra ø	Total ø
11382	30.3	12.0	16.3	9.0	0.3	0.0	11.7	4.0	0.7	5.7	5.3	1.7	12.7
11401	16.7	12.0	19.0	5.7	1.0	8.7	25.0	1.7	1.0	1.0	4.0	0.0	5.0
11402	20.7	15.7	18.0	6.3	1.0	9.0	9.0	2.0	3.0	9.7	2.7	0.7	13.0
11404	14.3	6.0	18.0	2.3	0.0	41.0	2.7	5.0	5.7	0.3	1.0	0.0	1.0
11405	20.7	15.3	20.0	5.3	0.7	9.0	7.3	5.3	2.3	3.7	2.0	2.0	7.7
11411	18.7	5.0	23.3	3.0	0.0	0.0	33.7	7.7	1.0	2.0	0.3	0.3	2.7
11413	32.3	10.0	17.7	18.7	2.3	0.7	1.3	4.3	0.0	2.0	7.3	1.0	10.3
11477	28.0	11.7	16.3	6.0	0.0	5.3	5.3	1.7	2.3	7.7	7.3	1.3	16.3

Table 7: Point count data for Well: Ruhl

Depth (ft)	Qtz	K-spar	Plag	RF	Acc Min	Carb	Matrix	Pseudo	Clay Cem	Sec Inter ø	Inter ø	Intra ø	Total ø
11437	16.7	7.3	23.3	10.7	0.7	2.3	7.0	2.3	1.3	3.7	22.0	1.0	26.7
11437	26.7	6.0	14.0	6.0	1.7	4.7	4.7	2.0	0.3	9.3	18.0	3.7	31.0
11461	22.3	6.3	22.0	5.3	1.3	0.7	9.3	0.7	1.7	3.3	17.0	1.0	21.3
11461	21.3	3.0	8.7	2.3	1.3	55.3	0.0	0.0	1.3	0.3	0.3	0.0	0.7
11482	16.7	8.3	16.0	6.3	11.3	30.3	0.0	2.7	3.3	0.0	0.7	0.0	0.7
11482	16.3	6.0	11.0	13.3	0.0	29.3	5.3	1.0	5.0	0.3	8.3	0.0	8.7
11482	23.0	6.7	15.7	11.7	0.7	35.3	0.0	1.0	0.3	0.3	1.0	0.0	1.3
11502	31.0	8.0	4.3	8.0	0.0	33.0	0.3	0.3	2.0	0.3	4.3	0.0	4.7
11502	30.0	9.7	17.0	3.7	0.3	20.7	0.0	0.3	0.7	0.3	10.7	0.0	11.0
11502	32.3	12.7	7.3	8.0	0.0	23.0	0.0	0.0	1.3	0.0	10.7	1.0	11.7
11502	36.7	9.7	7.3	6.3	0.0	27.0	0.3	0.3	2.0	0.0	3.3	0.3	3.7
11534	32.0	11.0	3.7	3.7	2.0	21.0	0.0	0.0	0.7	2.3	15.0	1.0	18.3
11534	43.0	14.3	4.0	5.7	0.0	23.7	0.0	0.0	1.0	0.7	3.3	1.0	5.0
11574	16.7	11.7	21.7	2.0	0.7	19.0	5.7	13.0	0.0	0.0	2.7	0.3	3.0
11574	18.7	11.0	16.7	2.0	0.0	16.0	9.3	5.0	2.3	10.7	0.7	0.7	12.0
11574	27.3	9.3	10.7	7.0	1.7	11.0	0.0	9.7	1.0	11.7	3.7	0.0	15.3

Table 8: Point count data for Well: Weber

Depth (ft)	Qtz	K-spar	Plag	RF	Acc Min	Carb	Matrix	Pseudo	Clay Cem	Sec Inter ø	Inter ø	Intra ø	Total ø
11425	28.3	8.7	19.7	1.0	1.3	0.0	22.7	5.7	0.0	1.3	2.3	0.3	4.0
11444	24.3	13.3	16.0	10.3	0.7	0.0	13.7	3.7	0.0	6.0	10.0	0.7	16.7
11445	24.3	14.3	17.7	3.0	0.3	17.0	0.0	12.7	0.0	5.0	3.0	0.0	8.0
11445	25.0	12.0	26.7	0.7	3.0	0.0	7.0	4.3	1.7	7.3	4.3	3.3	15.0
11446	32.0	13.0	5.7	12.7	0.0	29.7	1.3	0.0	0.0	0.3	0.0	0.0	0.3

Depth in feet; Compositional data in percent; Otz = Quartz; K-spar = Potassium feldspar; Plag = Plagioclase feldspar; RF = Rock fragments; Acc Min = Accessory minerals; Carb = Carbonate cement; Matrix = Clay matrix; Pseudo = Pseudomatrix; Clay Cem = one or a combination of kaolinite, illite, smectite; Sec ø = Secondary porosity; Inter ø = Intergranular porosity; Intra ø = Intragranular porosity; Total ø = Total porosity.

APPENDIX II – CONTACT INDEX AND TIGHT-PACKING INDEX

Table 9: Contact index and tight-packing index of the Vedder sandstones.

Well	Depth (ft)	CI	TPI
Fink-1	11,387-1	2.7	1.8
	11,387-2	N/A	N/A
	11,387-4	3.3	1.9
	11,387-5	3.6	1.9
Geisinger	11,443-1	N/A	N/A
	11,450-1	2.2	1.6
	11,450-3	1.9	1.3
Kernco 61-34	11,410-2	3.0	1.9
	11,410-6	N/A	N/A
	11,430-2	N/A	N/A
	11,430-3	N/A	N/A
	11,430-7	N/A	N/A
	11,430-8	N/A	N/A
	11,450-2	N/A	N/A
	11,450-5	N/A	N/A
	11,470-1	N/A	N/A
	11,470-4	N/A	N/A
	11,470-5	2.5	1.6
	11,490-1	2.8	1.7
Mandell 3	11,423-1	3.9	2.1
	11,423-2	3.4	1.8
	11,423-4	3.8	2.4
	11,423-5	3.1	1.8
	11,436-7	3.2	1.9
	11,436-8	3.3	2.2
	11,436-10	2.8	1.8
	11,436-13	3.7	2.2
	11,436-11	3.4	1.9
Pacific States	11,493	1.9	1.3
	11,498	2.2	1.4
	11,502	2.7	1.7
	11,507	2.5	1.5
	11,512	2.0	1.3
	11,534-55	N/A	N/A
	11,549-55	N/A	N/A
	11,554-60	2.8	1.6
Rudnick	11,382-400	2.1	1.4
	11,400-1	N/A	N/A
	11,400-2	N/A	N/A
	11,400-4	N/A	N/A
	11,400-5	2.1	1.4
	11,470-7	N/A	N/A
	11,411	2.4	1.5
	11,413	3.4	1.6

Well	Depth (ft)	CI	TPI
Ruhl-1	11,437-3	2.5	1.5
	11,437-5	2.0	1.4
	11,461-2	2.1	1.4
	11,461-3	N/A	N/A
	11,482-2	N/A	N/A
	11,482-3	N/A	N/A
	11,482-4	N/A	N/A
	11,502-1	N/A	N/A
	11,502-2	N/A	N/A
	11,502-3	N/A	N/A
	11,502-4	N/A	N/A
	11,534-1	2.1	1.5
	11,534-2	N/A	N/A
	11,574-1	N/A	N/A
	11,574-2	N/A	N/A
	11,574-3	N/A	N/A
Weber	11,425-4	N/A	N/A
	11,444-2	N/A	N/A
	11,445-1	N/A	N/A
	11,445-7	4.1	1.8
	11,446-6	N/A	N/A

CI = Contact Index

TPI = Tight-Packing Index

N/A = Not evaluated

APPENDIX III – MASS BALANCE DATA

Table 10: Mass balance data of the Vedder Sandstones

Number of points counted	# of dissolved plagioclase counted (raw)	# of dissolved K-feldspar counted (raw)	# of kaolinite counted (raw)	Actual Kaolinite %(from point counts)	Expected kaolinite % (0% microporosity)	expected kaolinite % (40% microporosity)	Export or Import for 40% microporosity
300	3	3	4	1.3	1.2	1.9	Export
300	3	3	0	0.0	1.2	1.9	Export
300	13	8	0	0.0	4.2	6.9	Export
300	12	1	6	2.0	2.8	4.6	Export
300	10	1	18	6.0	2.3	3.9	Import
300	2	1	13	4.3	0.6	1.0	Import
300	4	1	7	2.3	1.0	1.7	Import
300	2	2	2	0.7	0.8	1.3	Export
300	16	13	0	0.0	5.6	9.4	Export
300	0	1	11	3.7	0.2	0.3	Import
300	10	5	7	2.3	3.0	5.0	Export
300	1	0	2	0.7	0.2	0.4	Import
300	12	4	0	0.0	3.3	5.4	Export
300	4	3	0	0.0	1.4	2.3	Export
300	0	0	1	0.3	0.0	0.0	Import
300	16	8	0	0.0	4.8	8.0	Export
300	0	0	0	0.0	0.0	0.0	Neutral
300	21	2	1	0.3	4.9	8.1	Export
300	6	4	0	0.0	2.0	3.3	Export
300	7	1	1	0.3	1.7	2.8	Export
300	12	2	2	0.7	2.9	4.9	Export
300	10	1	0	0.0	2.3	3.9	Export
300	11	2	1	0.3	2.7	4.5	Export
300	7	5	1	0.3	2.4	3.9	Export
300	11	1	0	0.0	2.6	4.3	Export
300	6	4	1	0.3	2.0	3.3	Export
300	5	2	1	0.3	1.4	2.4	Export
300	6	2	0	0.0	1.6	2.7	Export
300	4	1	1	0.3	1.0	1.7	Export
300	17	0	1	0.3	3.7	6.1	Export
300	4	4	3	1.0	1.5	2.6	Export
300	5	3	2	0.7	1.6	2.6	Export
300	19	6	4	1.3	5.1	8.5	Export
300	0	0	0	0.0	0.0	0.0	Neutral
300	0	0	20	6.7	0.0	0.0	Import
300	7	0	4	1.3	1.5	2.5	Export
300	13	4	2	0.7	3.5	5.8	Export
300	2	0	3	1.0	0.4	0.7	Import
300	15	6	0	0.0	4.3	7.1	Export
300	1	0	0	0.0	0.2	0.4	Export
300	12	3	2	0.7	3.1	5.2	Export
300	4	0	0	0.0	0.9	1.4	Export
300	7	0	0	0.0	1.5	2.5	Export
300	3	4	0	0.0	1.3	2.2	Export
300	10	0	0	0.0	2.2	3.6	Export
300	21	2	1	0.3	4.9	8.1	Export
300	5	3	5	1.7	1.6	2.6	Export
300	1	0	0	0.0	0.2	0.4	Export
300	0	0	0	0.0	0.0	0.0	Neutral
300	0	0	0	0.0	0.0	0.0	Neutral
300	1	0	1	0.3	0.2	0.4	Export
300	0	0	1	0.3	0.0	0.0	Import
300	0	0	0	0.0	0.0	0.0	Neutral
300	1	2	2	0.7	0.6	0.9	Export
300	1	0	6	2.0	0.2	0.4	Import
300	2	2	1	0.3	0.8	1.3	Export
300	0	3	3	1.0	0.5	0.8	Import
300	1	0	0	0.0	0.2	0.4	Export
300	17	12	7	2.3	5.7	9.5	Export
300	15	10	0	0.0	4.9	8.2	Export
300	2	0	0	0.0	0.4	0.7	Export
300	8	6	0	0.0	2.7	4.6	Export
300	8	4	0	0.0	2.4	4.0	Export
300	13	8	5	1.7	4.2	6.9	Export
300	0	0	0	0.0	0.0	0.0	Neutral

APPENDIX IV – SANDSTONE PETROGRAPHY DATA

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SC

THIN SECTION: Fink-1 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,387-1

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: very poor

COMPACTION: CI: 2.7 TPI: 1.8

SIZE: Fine to coarse

ANGULARITY: Subangular to subround

SIZE ____ COMMENTS ____

1. Quartz (79) 26.33%
- Monocrystalline
- Polycrystalline |||
- Microphanerite |
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic ||

2. K-Feldspar (33) 11%
- Microcline ~~||||~~ |
- Orthoclase
- Sanadine
- Microphanerite |
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

3. Plagioclase (55) 18.33%
- Microphanerite |
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

Altering to clay ~~||||~~
MymeKite present

4. Volcanics

5. Microphanerites

6. Accessory Minerals (5) 1.66%
- Glauconite ||
- Biotite |||

Chlorite present
hornblende present

7. Carbonate Cement (4) 1.33%
- Poikilotopic calcite |
- Blocky calcite |||

8. Pseudomatrix (32) 10.66% ~~||||~~ ~~||||~~ ~~||||~~

Matrix: ~~||||~~ ~~||||~~ ~~||||~~ |

___ Clay-Altered Grains

9. Clay Cement (6) 2%
- Kaolinite Cement ||||
- ? Illite ||

10. Intragranular Porosity (2) .66%
- Quartz |
- K-Feldspar
- Plaigioclase |

VRF: Q, K, P
PRF: Q, K, P

11. Intergranular Porosity (51) 17%
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ |
- Grain-edge dissolution

Primary Porosity

Other

12. Other (23) 7.66
- organics / pyrite ~~||||~~ ||||
- RF ~~||||~~ ~~||||~~ |

Chert |

COMMENTS:
Poikilotopic & blocky calcite present throughout lots of ϕ However still clay Matrix remains. Some areas of high compaction resulting in Pseudomatrix. Kaolinite cement is present.

PARAGENESIS:
Biotite → chlorite

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q |	vrfQ	prfQ
K |	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |||	vrfQ	prfQ
K |||	vrfK	prfK
P ||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ____

(10) 3.33%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZl

THIN SECTION: Fink-1 11,387-3
FORMATION (AGE): Rio Bravo, Miocene
LOCATION: Rio Bravo
DEPTH: 11,387-2

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION: N/A

SIZE: Fine Sand
ANGULARITY: Sub angular

		SIZE	COMMENTS
1. Quartz 51	Monocrystalline Polycrystalline ||| Microphanerite Volcanic Rock Fragment | Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		Quartz → calcite: ||| Altered Quartz: || Poly Altered: |
2. K-Feldspar 39	Microcline — Altered Microcline: | Orthoclase Sanadine Microphanerite | Volcanic Rock Fragment Sedimentary Metamorphic		Orthoclase → pseudo: |||| Orthoclase → calcite: 𝍸𝍸 || Altered ortho: 𝍸 |||
3. Plagioclase 47	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Plag → Calcite: 𝍸𝍸𝍸 ||| plag → pseudo: || Plag Altering: 𝍸 |
4. Volcanics 11	|||		Volcanic → pseudo: 𝍸 Volcanic → calcite: |||
5. Microphanerites			
6. Accessory Minerals 1	biotite | Muscovite Epidote	Garnet	
7. Carbonate Cement 86	𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸 ||| Murky carbonate: |||		
8. Matrix/ Pseudomatrix 24	17 𝍸𝍸𝍸 | 7 ||||	Clay Rim on grain: | Biotite: |||	
Clay-Altered Grains			
9. Clay Cement			
10. Intragranular Porosity	Quartz K-Feldspar Plaigioclase	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 6	Fractures || Fracture-induced dissolution Oversize/elongate pores || Grain-edge dissolution		Primary Porosity oversize pore from dissolution || Other
12. Other 25	organics/pyrite 𝍸𝍸 | shale: || R.F. |		Carbonate Shale clast 𝍸𝍸 Chert: |

COMMENTS: Lots of carbonate and clay matrix, Fracturing through thin section. Large Shale clasts present. Small amounts of glauconite, clay laminations Volcanics → pseudomatrix. Offset of Fracture @ 8, 70.5 of shale clast.
- Sample was prepared crappy. Hard to distinguish grains.

Not a lot of φ. Clay Rims on grains probably diagenetic

PARAGENESIS: Calcite deposited first then squashed biotite grain around calcite. @ 36, 76.5
Dissolution of grains → clay → carbonate?
Fracturing → carbonate? evidence of this in fracture of $CaCO_3$ rhomb @ 8, 70.5 between Shale clast
carbonate → oil emplacement?
Carbonate → Clay ([illegible])

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q |||	vrfQ	prfQ
K |||	vrfK	prfK
P |||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P |	vrfP	prfP
OTHER 10		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Fink
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,387-4

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING:

COMPACTION: CI: 3.3 TPI: 1.9

SIZE:

ANGULARITY: subangular

		SIZE	COMMENTS
1. Quartz 91	Monocrystalline Polycrystalline ||| Microphanerite Volcanic Rock Fragment || Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic |		Altered to sericite: ||
2. K-Feldspar 23	Microcline |||| Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altered to sericite: || Altered to I/S?: |
3. Plagioclase 68	Microphanerite Volcanic Rock Fragment ||| Sedimentary Metamorphic		Altered to sericite: 卌 卌 |||
4. Volcanics 13	卌 卌 |||		
5. Microphanerites			
6. Accessory Minerals 5	Epidote || tourmaline biotite |||	Chlorite	
7. Carbonate Cement 3	|||		
8. Matrix/ Pseudomatrix 3	||| Biotite → chlorite |		
___Clay-Altered Grains			
9. Clay Cement			
10. Intragranular Porosity 8	Quartz | K-Feldspar || Plaigioclase 卌	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 24	Fractures Fracture-induced dissolution Oversize/elongate pores 卌 卌 卌 卌 |||| Grain-edge dissolution	Primary Porosity Other	
12. Other 30	organics/pyrite: 卌 Rock frag: 卌 卌 卌	Phosphate: ||| Chert: 卌	Myrmekite: |

COMMENTS:

Lots of Φ. Hardly any clay compared to previous. Some glauconite and carbonates. Clay rims possibly mixed layer I/S. A lot of plag grains are undergoing sericitization. Zeolite growth? 39,80ish on plag grain. Lots of good overgrowths on grains. Lots of biotite. Some chlorite.

PARAGENESIS:

Dissolution → clay infiltration I/S?
Calcite → squashing of biotite

Lots of Φ due to $CaCO_3$ dissolution? Some small patches
Calcite protected grains from high compaction.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q 卌 卌 卌	vrfQ	prfQ
K 卌	vrfK	prfK
P 卌 |	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER 29		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: FinK-1 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,387-5

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: very poorly sorted
SIZE: Very fine to fine Sand

COMPACTION: CI: 3.6 TPI: 1.9
ANGULARITY: Angular to subangular

		SIZE	COMMENTS
1. Quartz (60) 27.33%	Monocrystalline Polycrystalline || Microphanerite Volcanic Rock Fragment || Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic ||| Chalcedony |	.24mm - .08mm	Altering to clay |||
2. K-Feldspar (19) 6.33%	Microcline Orthoclase Sanadine Microphanerite | Volcanic Rock Fragment Sedimentary Metamorphic	.16 - .18mm	
3. Plagioclase (99) 18.33%	Microphanerite Volcanic Rock Fragment |||| Sedimentary Metamorphic	.28 - .1mm	Plag altering to sericite || Altering to calcite | Altering to clay ||
4. Volcanics (9) 3%	|||||||||		
5. Microphanerites			
6. Accessory Minerals (15) 5%	? Red Mustery | Glauconite	Chlorite |||||||| Biotite ||| ? Mica || Muscovite |	
7. Carbonate Cement (9) 3%	Blocky calcite poikilotopic calcite ||	Dolomite | Blocky calcite ||||	
8. Pseudomatrix		Matrix: ||	
Clay-Altered Grains			
9. Clay Cement (13) 4.3%	||| Kaolinite ||||	Illite? ||	

10. Intragranular Porosity (2) .46%	Quartz K-Feldspar | Plaigioclase |	VRF: Q K P		PRF: Q K P	
11. Intergranular Porosity (49) 16.33%	Fractures Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution	? Primary Porosity ||||||| (No clay around grains)			
12. Other (28) 9.33%	RF |||||||||| organics/pyrite |||||| Chert ||	Other Dissolved clay |			

COMMENTS: Good pic of Kaolinite 11.5, 76.2 Some clay coatings, quartz overgrowths, chlorite is present throughout p is growing over quartz mostly. Lost of muscovite biotite. Some plag highly albitized. Dolomite crystals present. Some poikilotopic + blocky calcite.

PARAGENESIS:
Chlorite forming after dissolution of clay?
Plag → Calcite → late diagenetic?
Biotite → Chlorite

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ||||	vrfQ	prfQ
K ||	vrfK	prfK
P |||||||||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(19) 6.33%

(50)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Geisinger
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,443-1

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate
COMPACTION: N/A too big would be bias
SIZE: Conglomerate
ANGULARITY: Subangular - subround

		SIZE	COMMENTS
1. Quartz (99) 33%	Monocrystalline Polycrystalline ||||| Microphanerite Volcanic Rock Fragment | Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic ||		
2. K-Feldspar (46) 15.3%	Microcline ||| Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altering:| Altering to Kaolinite: |
3. Plagioclase (47) 15.6%	Microphanerite | Volcanic Rock Fragment Sedimentary Metamorphic		Altering to sericite: || Alter to calcite: || Altered: |
4. Volcanics (3) 1%	|||		
5. Microphanerites			
6. Accessory Minerals (1) .33%	Biotite: |		
7. Carbonate Cement (2) .66%	||		
8. Matrix/ Pseudomatrix (10) 3.3%	||||| ||		
Clay-Altered Grains			
9. Clay Cement (18) 6%	Kaolinite: |||||||||||		
10. Intragranular Porosity (11) 3.6%	Quartz | K-Feldspar | Plaigioclase ||||||	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (18) 6%	Fractures Fracture-induced dissolution Oversize/elongate pores |||||||||||| Grain-edge dissolution	Primary Porosity Other	
12. Other (40) 13.3%	Mafic/organics: ||| R.F: ||||||||||||||||	Bone: ||| chert: |||||	Shale: |||

COMMENTS:
Very large grains. Sample was prepared very poorly. Hard to distinguish grains. Little cement or clay. Lots of porosity. Very unconsolidated sample. Kaolinite cement throughout (lots)
- Part clay has high birefringence possibly chlorite?

PARAGENESIS: @ 31.5, 79ish
Calcite first then pseudo biotite. good pic

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ||	vrfQ	prfQ
K ||	vrfK	prfK
P |	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER _____
(5) 1.6%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SK

THIN SECTION: Geisinger-2 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,450-1

PROJECT: Thesis

ROCK NAME: Lithic Arenite
POINT COUNTS: 300

SORTING: Poor

COMPACTION: CI: 2.2 TPI: 1.6

SIZE: Medium to coase sand

ANGULARITY: Subround to Rounded

SIZE COMMENTS

1. Quartz (90) 30%
- Monocrystalline
- Polycrystalline ~~||||~~ ||||
- Microphanerite
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic |

2. K-Feldspar (23) 7.66%
- Microcline ||
- Orthoclase
- Sanadine
- Microphanerite
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

3. Plagioclase (18) 6.66%
- Microphanerite ||
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

4. Volcanics (4) 1.3% ||||

5. Microphanerites

6. Accessory Minerals

7. Carbonate Cement (15) 5% Blocky Calcite ~~||||~~ ~~||||~~ ~~||||~~

8. Pseudomatrix (2) .66% Matrix ||

Clay-Altered Grains

9. Clay Cement (13) 4.3% Kaolinite ~~||||~~ ~~||||~~ |||

10. Intragranular Porosity (1) .33%
- Quartz |
- K-Feldspar
- Plaigioclase

VRF: Q K P — PRF: Q K P

11. Intergranular Porosity (60) 20.0%
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~
- Grain-edge dissolution |

Primary Porosity

Other

12. Other (66) 22% Chert ~~||||~~ ~~||||~~ ~~||||~~ RF ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ||| organics, pyrite |||

COMMENTS: Good pic of Kaolinite. Lots of Kaolinite, Very unconsolidated, Coarse grained, Calcite cement patches throughout. Lots of ∅ + rock fragments.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |||	vrfQ	prfQ
K		vrfK	prfK
P ||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER

(6) 2%

(10) →

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SL

THIN SECTION: Geisinger - 2 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,450-3

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION: CI: 1.9 TPI: 1.3

SIZE: Medium to Coarse Sand
ANGULARITY: Subround to Round

		SIZE	COMMENTS
1. Quartz (91) 30.3%	Monocrystalline Polycrystalline ~~||||~~ ~~||||~~ Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic ||		
2. K-Feldspar (34) 11.33%	Microcline |||| Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (14) 5%	Microphanerite Volcanic Rock Fragment | Sedimentary Metamorphic		
4. Volcanics (6) 2%	~~||||~~ |		
5. Microphanerites			
6. Accessory Minerals			
7. Carbonate Cement (34) 11.33%	Blocky Calcite ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ |||	Dolomite |	
8. Pseudomatrix (7) 2.33%		Matrix ~~||||~~ ||	
Clay-Altered Grains			
9. Clay Cement (7) 2.33%	Kaolinite ~~||||~~ ||		
10. Intragranular Porosity	Quartz K-Feldspar Plaigioclase |	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (65) 21.66%	Fractures Fracture-induced dissolution Oversize/elongate pores ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ Grain-edge dissolution	Primary Porosity Other	
12. Other (32) 10.66%	Chert ~~||||~~ || RF ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ |||	organics/pyrite |	

COMMENTS:
Blocky calcite occuring during possibly late diagenesis
Lots of ϕ. Little clay Matrix. Some Matrix
turned into Kaolinite. Very Similar to #8 but
less grain contact.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q ||||	vrfQ	prfQ
K |	vrfK	prfK
P |||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER

6

(14)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Kemco 61-34 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,410-2

PROJECT: thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poorly Sorted

COMPACTION: CI: 3.0 TPI: 1.9

SIZE: Fine to Medium Sand w/ Really lg. grains Randomly

ANGULARITY: Subangular

		SIZE	COMMENTS
1. Quartz (81) 28%	Monocrystalline Polycrystalline |||| Microphanerite || Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic |		Altering to clay |
2. K-Feldspar (39) 13%	Microcline ~~||||~~ Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (49) 18%	Microphanerite ~~||||~~ Volcanic Rock Fragment Sedimentary Metamorphic		Altering to clay | Albatized |
4. Volcanics (5) 1.66%	~~||||~~		
5. Microphanerites			
6. Accessory Minerals (4) 1.33%	Hornblende | Zeolite | Biotite |	Zircon Muscovite |	
7. Carbonate Cement (8) 2.66%	Calcite ~~||||~~ |||		
8. Pseudomatrix (28) 9.33%	~~||||~~ ~~||||~~ ~~||||~~	Matrix: ~~||||~~ ~~||||~~ |||	
___Clay-Altered Grains			
9. Clay Cement (2) .66%	||		
10. Intragranular Porosity (2) .66%	Quartz K-Feldspar | Plaigioclase	Dissolution of clay |	VRF: Q K P — PRF: Q K P
11. Intergranular Porosity (47) 15.66%	Fractures Fracture-induced dissolution Oversize/elongate pores ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ || Grain-edge dissolution		Primary Porosity Other
12. Other (23) 7.66%	Pyrite/Organics ~~||||~~ | RF ~~||||~~ ~~||||~~ ||||	Phosphate || Chert |	Myrmekite |

COMMENTS:

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |	vrfQ	prfQ
K |	vrfK	prfK
P ||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ____________

(4) 1.33%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Kenco
FORMATION (AGE): Yeddar
LOCATION: Rio Bravo
DEPTH: 11,410-6

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate
COMPACTION: N/A

SIZE: Fine to Med sand
ANGULARITY: subround

		SIZE	COMMENTS
1. Quartz (58) 19.3%	Monocrystalline Polycrystalline |||| Microphanerite | Volcanic Rock Fragment | Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic |||		Quartz → calcite |
2. K-Feldspar (38) 12.6%	Microcline Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic ||		Altering to clay: |||| Alter to carbonate: ||||
3. Plagioclase (48) 16%	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altering to clay: || Alter to carbonate: || Altered: ||
4. Volcanics (27) 9%	|||| |||| |||		Alter to clay: |||| ||||
5. Microphanerites			
6. Accessory Minerals (3) 1%	Glauconite | Muscovite | Chlorite |		
7. Carbonate Cement (34) 11.3%	|||| |||| |||| |||| ||||		
8. Matrix/ Pseudomatrix (26) 8.6%	|||| |||| ||||		Pseudo biotite: |||
Clay-Altered Grains			
9. Clay Cement			
10. Intragranular Porosity (12) 4%	Quartz | K-Feldspar |||| Plagioclase ||||	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (15) 5%	Fractures Fracture-induced dissolution Oversize/elongate pores |||| |||| Grain-edge dissolution |	Primary Porosity Other	
12. Other (11) 3.6%	pyrite/organics |||| |||| R.F. |	Phosphate: |	

COMMENTS:

Patches of carbonate cement & dolomite rhombs. Porosity is patchy & varies throughout. Dirty sample. Lots of clay.
— Glauconite present growing on phosphate

good! fic.

PARAGENESIS:

Did phosphate or glauconite come first?

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q |||| ||||	vrfQ	prfQ
K |||| ||||	vrfK	prfK
P |||| ||||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(28) 9.3%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SUnnuh

THIN SECTION: Kernco 61-34 (Stained)
PROJECT: Thesis
FORMATION (AGE): Oligocene
LOCATION: Rio Bravo
ROCK NAME: Arkosic Wacke
DEPTH: 11,430-2
POINT COUNTS: 300

SORTING: Moderate to poorly sorted
COMPACTION: N/A

SIZE: Fine sand to some large grains
ANGULARITY: Angular to subangular

		SIZE	COMMENTS
1. Quartz (56) 18.6%	Monocrystalline Polycrystalline | Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic ||		Altering to clay ~~||||~~ ~~||||~~
2. K-Feldspar (40) 14%	Microcline | Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altered to Kaolinite | Altered to clay ~~||||~~ ~~||||~~
3. Plagioclase (67) 24.7	Microphanerite ||| Volcanic Rock Fragment | Sedimentary Metamorphic		Altering to dolomite | Altering to clay ~~||||~~ ~~||||~~ || Altering to sericite |
4. Volcanics .33%	|		
5. Microphanerites			
6. Accessory Minerals (16) 5.3%	Dolomite Rhomb ~~||||~~ ||| Dolomite Altering to clay |||	Biotite to clay ||| Biotite ||	
7. Carbonate Cement (12) 4%	Dolomite ~~||||~~ ~~||||~~ ||		
8. Pseudomatrix			
Clay-Altered Grains			
9. Clay ~~Cement~~ Matrix (79) 28%	Smectite? ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ |||	Kaolinite ~~||||~~ ~~||||~~ |	
10. Intragranular Porosity (1) .33%	Quartz K-Feldspar Plaigioclase	Clay |	VRF: Q K P — PRF: Q K P
11. Intergranular Porosity (4) 1.3%	Fractures || Fracture-induced dissolution | Oversize/elongate pores | Grain-edge dissolution		Primary Porosity Other
12. Other (16) 5.3%	Pyrite/organics ~~||||~~ ~~||||~~ ||| Rock Fragment |	Shale clast ||	

COMMENTS:

Oil clusters throughout, & tend to have an affinity to accumulate more on dolomite cement. Dolomite rhombs are growing over clay & detrital minerals. Some sericite cement, Kaolinite & possible smectite. Plag → sericite

PARAGENESIS:

Dissolution → clay → precipitation dolomite

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q |||	vrfQ	prfQ
K |	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(4) = 1.3%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Kemco
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,430-3

PROJECT: Thesis

ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor

COMPACTION: N/A

SIZE: Fine sand

ANGULARITY: Subangular - Subround

		SIZE	COMMENTS
1. Quartz (64) 21.3%	Monocrystalline Polycrystalline //// Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic |		Altering to matrix: |
2. K-Feldspar (37) 13%	Microcline | Orthoclase Sanadine Microphanerite Volcanic Rock Fragment || Sedimentary Metamorphic		Altering to calcite: | Altering to clay: //// Altering: ||
3. Plagioclase (42) 15.6%	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altering: //// Altering to calcite: ///
4. Volcanics (15) 5%	////		Volcanic to Matrix: ////
5. Microphanerites			
6. Accessory Minerals (5) 1.6%	Chlorite | Biotite | Muscovite |		Red Mystery ||
7. Carbonate Cement (33) 11%	//// //// //// //// ////		
8. Matrix/ Pseudomatrix (40) 13.3%	//// //// //// //// //// ////		Biotite pseudo: //// ///
Clay-Altered Grains			
9. Clay Cement Kaolinite? (7) 2.3%	//// ||		
10. Intragranular Porosity (4) 1.3%	Quartz K-Feldspar || Plaigioclase |	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (6) 2%	Fractures Fracture-induced dissolution Oversize/elongate pores //// Grain-edge dissolution	Primary Porosity Other	
12. Other (22) 7.3%	Punc/concavies: //// /// R/F: //// ///	phosphate: ////	

COMMENTS:

Clay from dissolution of unstable grains.
Lots of pseudomatrix.
Sporadic carborate throughout
Weird Red Clay (Hematite?) laminations @ 36, 73

SEM to see what auth. clays are present?

PARAGENESIS:

Biotite → chlorite
carborate/dolomite first then clay/dissolution of grains evidence @ 12,695.
Also clay coats the carborates among sample

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ////	vrfQ	prfQ
K |	vrfK	prfK
P ////	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(18) 6%

(18)

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SZL

THIN SECTION: Kerncole1 - 34 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,430 - 7

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION: N/A

SIZE: Very fine Sand
ANGULARITY: Subangular to Round

SIZE ____ COMMENTS ____

1. Quartz (56) 18.66%
- Monocrystalline
- Polycrystalline ||
- Microphanerite
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic

2. K-Feldspar (25) 8.33%
- Microcline
- Orthoclase
- Sanadine
- Microphanerite |
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

3. Plagioclase (55) 18.33%
- Microphanerite
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

4. Volcanics (2) .66% ||

5. Microphanerites

6. Accessory Minerals (4) 1.33% — Biotite ||| — Muscovite |

7. Carbonate Cement (4) 1.33% — Calcite ||||

8. Pseudomatrix (92) 卌卌 — Matrix: 卌卌卌卌卌卌卌卌卌卌卌卌卌卌卌卌|

___Clay-Altered Grains___

9. Clay Cement (26) 30.66% — Kaolinite || — ? 卌卌卌卌||||

10. Intragranular Porosity
- Quartz
- K-Feldspar
- Plaigioclase

VRF: Q K P — PRF: Q K P

11. Intergranular Porosity (20) 6.66%
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores 卌卌卌卌
- Grain-edge dissolution

Primary Porosity
Other

12. Other (15) 5% — pyrite/organics: 卌|||| — RF: ||||

COMMENTS: the only Φ porosity is through microfractures that run throughout. Lots of clay matrix, some that is very iron rich.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P |	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ____
(1) .33%

PARAGENESIS:

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Kernco
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,430-8
SORTING: Poor
SIZE: Med - Fine sand

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: N/A
ANGULARITY: sub rounded

SIZE ____ COMMENTS ____

1. Quartz (80) 26.6%
- Monocrystalline
- Polycrystalline |||| |||| ||||
- Microphanerite ||||
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic ||

Comments: Altering: || ; Poly Altering: |

2. K-Feldspar (43) 14.3%
- Microcline ||
- Orthoclase
- Sanadine
- Microphanerite
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

Comments: Altering to clay: |||| |||| | ; Altered: ||

3. Plagioclase (62) 20.6%
- Microphanerite
- Volcanic Rock Fragment |
- Sedimentary
- Metamorphic

Comments: Altering to clay: || ; Altered: |||| |||

4. Volcanics |||| ||| (10) 3.3%

Comments: Altering: || ; Altered to sericite: |

5. Microphanerites

6. Accessory Minerals (2) .66%
- Hornblend: |
- Red Mystery?: |

7. Carbonate Cement |||| (5) 1.6%

8. Matrix/Pseudomatrix |||| |||| |||| |||| |||| |||| |||| |||| |||| (48) 16%

Comments: Pseudo Biotite: |||

___Clay-Altered Grains___

9. Clay Cement || (2) .66%

10. Intragranular Porosity (2) .66%
- Quartz
- K-Feldspar ||
- Plaigioclase

VRF: Q, K, P — PRF: Q, K, P

11. Intergranular Porosity (3) 1%
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores ||
- Grain-edge dissolution

Primary Porosity
Other: Dissolution of clay: |

12. Other (15) 5%
- pyrite/organics: ||||
- R.F. ||||
- Chert: |||
- Shale: ||

COMMENTS:
Lots of detrital & authigenic clays. A lot of dissolution of feldspar grains. Some porosity due to grain plucking. Other due to shrinkage & dissolution of matrix. Some small amounts of carbonate. Some dolomite rhombs present.

PARAGENESIS:
Dissolution → Pyrite/organics

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |||| |||| ||||	vrfQ	prfQ
K		vrfK	prfK
P |||| ||||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ____

(28) 9.3%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Kernco 61 34
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,450-2

PROJECT: Thesis
ROCK NAME: Arkosic Wacke
POINT COUNTS: 300

SORTING: Poorly
COMPACTION: N/A

SIZE: Fine Sand
ANGULARITY: sub angular - sub round

SIZE ___ COMMENTS ___

1. Quartz (68) 22%
Monocrystalline
Polycrystalline ||||
Microphanerite granitic |||
Volcanic Rock Fragment
Quartz Arenite
Other Sedimentary
Metaquartzite
Other Metamorphic ||

2. K-Feldspar (43) 14.3
Microcline ||
Orthoclase
Sanadine
Microphanerite
Volcanic Rock Fragment
Sedimentary
Metamorphic
ortho altered: |||| ||||

3. Plagioclase (73) 24.3
Microphanerite |
Volcanic Rock Fragment
Sedimentary
Metamorphic
Altering to clay: |||
Altered to clay: |||

4. Volcanics (10) 3.3% |||| ||||

5. Microphanerites

6. Accessory Minerals (1) .33%
Muscovite |

7. Carbonate Cement (2) .66
||

8. Matrix/Pseudomatrix (64) 21.3%
|||| |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| ||||
|||| |||| ||||
pseudo Biotite: |||
___Clay-Altered Grains

9. Clay Cement (12) 4%
? |||| |||| ||

10. Intragranular Porosity (3) 1%
Quartz
K-Feldspar ||
Plaigioclase |
VRF: Q K P
PRF: Q K P

11. Intergranular Porosity (2) .66%
Fractures |
Fracture-induced dissolution
Oversize/elongate pores
Grain-edge dissolution |
Primary Porosity
Other

12. Other (16) 5.3%
pyrite/organics: ||||||
RF: |||| ||
Chert: ||

COMMENTS:
Very dirty sample. Some fracturing throughout
porosity is patchy throughout.
Some phosphate bones throughout.
Some areas are highly compacted.

PARAGENESIS:

Dissolution of grain → clay

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION
Q vrfQ prfQ
K vrfK prfK
P vrfP prfP

GRAIN-EDGE DISSOLUTION
Q ||| vrfQ prfQ
K || vrfK prfK
P ||| vrfP prfP

OVERSIZE/ELONGATE PORES
Q vrfQ prfQ
K vrfK prfK
P vrfP prfP

OTHER ___

(8) 2.66%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Kernco
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,450-5

PROJECT: thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor

COMPACTION: N/A

SIZE: Medium Sand

ANGULARITY: Angular - Subround

		SIZE	COMMENTS
1. Quartz 62 (20.6%)	Monocrystalline Polycrystalline ||||| Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic |||		quartz → dolomite: |||
2. K-Feldspar 32 (10.6%)	Microcline | Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		ortho → dolomite: ~~||||~~ ~~||||~~ |||
3. Plagioclase 36 (12%)	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		plag → dol: ~~||||~~ ~~||||~~
4. Volcanics 8 (2.6%)	~~||||~~ |||		
5. Microphanerites			
6. Accessory Minerals			
7. Carbonate Cement 140 (46.6%)	Dolomite: [tally marks]		
8. Matrix/ Pseudomatrix			
Clay-Altered Grains			
9. Clay Cement 1 .33%	Kaolinite: |		
10. Intragranular Porosity	Quartz K-Feldspar Plaigioclase	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity	Fractures Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution	Primary Porosity Other	
12. Other 14 4.6%	pyrite/organics: ~~||||~~ | R.F.: ~~||||~~	Chert: ||	

COMMENTS:

Dolomite throughout whole sample.

PARAGENESIS:

calcite → dolomite?

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION			
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION			
Q ||	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES			
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER			

2 (.6%)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Kenco
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,470-1

PROJECT: Thesis
ROCK NAME: Arkosic Wacke
POINT COUNTS: 300

SORTING: Poorly Sorted
COMPACTION: N/A

SIZE: Fine sand
ANGULARITY: Angular - subround

		SIZE	COMMENTS
1. Quartz (72) 24%	Monocrystalline Polycrystalline 𝍸||| Microphanerite | Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic |||		Altered to clay: |||
2. K-Feldspar (67) 8.3%	Microcline || Orthoclase Sanadine Microphanerite Volcanic Rock Fragment | Sedimentary Metamorphic		ortho altered to clay: 𝍸|||||
3. Plagioclase (54) 18%	Microphanerite | Volcanic Rock Fragment Sedimentary Metamorphic		Altered to clay: 𝍸𝍸|||
4. Volcanics (22) 7.3%	𝍸𝍸𝍸|		Altered to clay: 𝍸|
5. Microphanerites			
6. Accessory Minerals	Muscovite:		
7. Carbonate Cement			
8. Matrix/ Pseudomatrix (62) 20.6	𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸 |		pseudo biotite: |||| Chlorite pseudo: | Shale pseudo: |
___Clay-Altered Grains			
9. Clay Cement			
10. Intragranular Porosity (7) 2.3%	Quartz | K-Feldspar || Plaigioclase ||||	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (6) 2%	Fractures Fracture-induced dissolution Oversize/elongate pores 𝍸| Grain-edge dissolution	Primary Porosity Other	
12. Other (20) 6.6%	Pyrite/organics: 𝍸𝍸| R.F. |	chert: 𝍸 Phosphate: |	Fossil: |

COMMENTS:
lots of volcanics, very dirty sample. Zoned Plagioclase
Phosphates present. Sporadic porosity in sample
Lot of volcanics have altered to clay matrix.

PARAGENESIS:
Biotite → chlorite

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q 𝍸𝍸||	vrfQ	prfQ
K 𝍸	vrfK	prfK
P 𝍸|||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(32) 10.6%

(19)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Kernco 61-34 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,470-4

PROJECT: Thesis

ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor

COMPACTION: N/A

SIZE: Very Fine Sand

ANGULARITY: Subround to Round

		SIZE	COMMENTS
1. Quartz (36) 12%	Monocrystalline Polycrystalline Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		
2. K-Feldspar (22) 7.33%	Microcline Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (46) 15.33%	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		
4. Volcanics (4) 1.33%			
5. Microphanerites			
6. Accessory Minerals (2) .66%	Iron clast	Muscovite	
7. Carbonate Cement (155) 51.66%	Dolomite		
8. Pseudomatrix			
___Clay-Altered Grains			
9. Clay Cement			
10. Intragranular Porosity	Quartz K-Feldspar Plaigioclase	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (8) 2.66%	Fractures Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution	Primary Porosity Other	
12. Other (27) 9%	pyrite/organics RF		

COMMENTS:

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER	______	

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Kemco
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,470-5

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate
COMPACTION: CI: 2.5 TPI: 1.6

SIZE: Medium sand
ANGULARITY: Subangular - Subround

		SIZE	COMMENTS
1. Quartz 76	Monocrystalline		
	Polycrystalline ~~||||~~ |||		
	Microphanerite		
	Volcanic Rock Fragment			
	Quartz Arenite		
	Other Sedimentary		
	Metaquartzite		
	Other Metamorphic ||||		
2. K-Feldspar 30	Microcline			Altering to clay: ||
	Orthoclase		
	Sanadine		
	Microphanerite		
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
3. Plagioclase 64	Microphanerite		Altering: ~~||||~~ ||
	Volcanic Rock Fragment			Altered to clay: ||||
	Sedimentary		
	Metamorphic		
4. Volcanics 5	|||		Altering: ||
5. Microphanerites			
6. Accessory Minerals 2	Muscovite: | Biotite: |		
7. Carbonate Cement			
8. Matrix/Pseudomatrix	26 ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~			Pseudo Biotite: |||| Pseudo Muscovite: | Pseudo Shale: |
12 Clay-Altered Grains	~~||||~~ |||		
9. Clay Cement (1)	Kaolinite: |		
10. Intragranular Porosity 15	Quartz || K-Feldspar | Plaigioclase ~~||||~~ ~~||||~~ ||	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 18	Fractures Fracture-induced dissolution Oversize/elongate pores ~~||||~~ ~~||||~~ ~~||||~~ ||| Grain-edge dissolution	Primary Porosity Other	
12. Other	14 Plant/organics: ~~||||~~ ~~||||~~ |||| 10 RYF: ~~||||~~ ~~||||~~	Chert: | Shale: |	Phosphate: ||

COMMENTS:
Dirty sample but clean enough to try compaction. Lots of dissolution of all grains.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q ||||	vrfQ	prfQ
K |	vrfK	prfK
P ~~||||~~ |||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER
15

PARAGENESIS:
Possible siderite clay in sample?
Clay first then Kaolinite. @ 33, 75

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Kennedy-34
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,490-1

PROJECT: Thesis

ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Very Poor
SIZE: Fine Sand

COMPACTION: CI: 2.8 - TPI: 1.7
ANGULARITY: Subangular - Subrounded

	SIZE	COMMENTS
1. Quartz (61) 20.33%	Monocrystalline Polycrystalline ||| Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic	
2. K-Feldspar (39) 13%	Microcline | Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic	
3. Plagioclase (65) 23%	Microphanerite |||| - granitic Volcanic Rock Fragment Sedimentary Metamorphic	
4. Volcanics (2) .66%	||	
5. Microphanerites		
6. Accessory Minerals (4) 1.33%	Biotite || Muscovite |	hornblende |
7. Carbonate Cement (1) .33%	|	
8. Pseudomatrix (12) 4%	||	Matrix:
Clay-Altered Grains		
9. Clay Cement (56) 18.66%		
10. Intragranular Porosity (3) 1%	Quartz K-Feldspar | Plaigioclase |	Clay |
11. Intergranular Porosity (20) 6.66%	Fractures Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution	Primary Porosity Other
12. Other (21) 7%	RF: Pyrite/organics:	Chert ||

COMMENTS:
Lots of clay Altered grains that are squashed between grains protecting from compaction + touching of Fwg, some Calcite cement throughout. Grains w/ no clay protection show high amounts of fracturing. Lots of grain dissolution.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ||||	vrfQ	prfQ
K |||	vrfK	prfK
P |||||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(12) 4%

(7)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Mandell-3 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,423-1

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Very Poor
SIZE: Medium Sand

COMPACTION: CI: 3.9. TPI: 2.1
ANGULARITY: Angular to subround

	SIZE	COMMENTS
1. Quartz (89)	Monocrystalline Polycrystalline II Microphanerite IIII Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic	Altering to Muscovite I Altering to clay II
2. K-Feldspar (35)	Microcline I Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic	Altering to clay III
3. Plagioclase (60)	Microphanerite IIII Volcanic Rock Fragment Sedimentary Metamorphic	Altering to clay IIII
4. Volcanics (9)	IIII IIII	
5. Microphanerites (1)	I	
6. Accessory Minerals (18)	Chlorite III Muscovite IIII Dolomite II	Biotite w/ organics IIII I Glauconite → clay I Biotite → clay II Zircon I
7. Carbonate Cement (1)	I	
8. Pseudomatrix		
Clay-Altered Grains		
9. Clay ~~Cement~~ Matrix (12)	Dark clay? IIII III	Smectite? III Kaolinite? I
10. Intragranular Porosity (5)	Quartz II K-Feldspar I Plaigioclase II	VRF: Q K P PRF: Q K P
11. Intergranular Porosity (30)	Fractures I Fracture-induced dissolution Oversize/elongate pores IIIIIIIII Grain-edge dissolution	Primary Porosity IIII IIII
12. Other (16)	organics/fungi IIII IIII Phosphate II	Other Dissolution of clay IIII I RF = I

COMMENTS: ϕ porosity has been formed by dissolution of clays as well as dissolution of FWG's. Lots of clay rims around FWG's. Some biotite deformed & altered to pseudomatrix. Lots of. Biotite is altering to chlorite. Biotite altering to clay is squeezing b/w FWG. Glauconite is present

PARAGENESIS:
Compaction → fracturing → clays → dissolution
Fracturing → albitization
chlorite → dissolution → clay → oil

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P I	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q IIII IIII	vrfQ	prfQ
K	vrfK	prfK
P IIII	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER (16)		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Mardell
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,423-2

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION: CI: 3.4 TPI: 1.8

SIZE: upper fine to lower Medium sand
ANGULARITY: Subangular-Subround

		SIZE	COMMENTS
1. Quartz 85	Monocrystalline Polycrystalline //// Microphanerite ////		
2. K-Feldspar 47	Microcline //// Orthoclase Sanadine Microphanerite \ Volcanic Rock Fragment Sedimentary Metamorphic		Altered: ||
3. Plagioclase 49	Microphanerite || Volcanic Rock Fragment Sedimentary Metamorphic		Altered: ||
4. Volcanics 5	///		
5. Microphanerites			
6. Accessory Minerals 1	glauconite: |		
7. Carbonate Cement			
8. Matrix/ Pseudomatrix 18	|| //// //// ////		Biotite pseudo: || Muscovite pseudo: |
Clay-Altered Grains			
9. Clay Cement 2	Kaloinite: ||		
10. Intragranular Porosity 9	Quartz | K-Feldspar || Plaigioclase ////	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 19	Fractures Fracture-induced dissolution Oversize/elongate pores //// //// //// //// Grain-edge dissolution	Primary Porosity Other	
12. Other 9 / 15	pyrite/organics: //// //// RF.: //// ////	Phosphate: | Chert: ||	

COMMENTS:
This is a poorly Made sample had to distinguish a lot of grains. Zoned of pseudomatrix, some residual oil left. Lots of rock fragments

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ///	vrfQ	prfQ
K	vrfK	prfK
P ////	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER 9		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Mandell-3
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,423-4
SORTING: Moderately Sorted
SIZE: Medium sand

PROJECT: Thesis
ROCK NAME: Sub Arkose Arenite
POINT COUNTS: 300
COMPACTION: CI: 3.8 TPI: 2.4
ANGULARITY: Sub-angular - sub-round

		SIZE	COMMENTS
1. Quartz 92	Monocrystalline		Quartz w/ chlorite I @ 74,11
	Polycrystalline 𝍸		
	Microphanerite		
	Volcanic Rock Fragment I		
	Quartz Arenite		
	Other Sedimentary		
	Metaquartzite		
	Other Metamorphic II		
2. K-Feldspar 28	Microcline I		
	Orthoclase		
	Sanadine		
	Microphanerite I		
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
3. Plagioclase 71	Microphanerite II		Plag → Sericite 𝍸
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
4. Volcanics 6	𝍸I		
5. Microphanerites			
6. Accessory Minerals 4	Muscovite II		
	glauconite II		
7. Carbonate Cement 5	𝍸		
8. Matrix/ Pseudomatrix 29	𝍸 𝍸 𝍸 𝍸 𝍸 IIII		
Clay-Altered Grains			
9. Clay Cement 9	𝍸 IIII		
10. Intragranular Porosity 2	Quartz	VRF: Q	PRF: Q
	K-Feldspar I	K	K
	Plaigioclase I	P	P
11. Intergranular Porosity 20	Fractures		
	Fracture-induced dissolution	Primary Porosity	
	Oversize/elongate pores 𝍸 𝍸 𝍸		
	Grain-edge dissolution	Other 𝍸	
12. Other	8 organics/pyrite: 𝍸III	Chert:	
	10 RF: 𝍸 𝍸		

COMMENTS:
sporatic carbonate throughout. lots of dissolution v volcanics.
- plag grain w/ inclusion 72,12

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q 𝍸III	vrfQ	prfQ
K	vrfK	prfK
P 𝍸IIII	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER 17		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Mandell
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,423-5

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION: C1:3.1 TP1:1.8

SIZE: Fine sand
ANGULARITY: Subangular

		SIZE	COMMENTS
1. Quartz 88	Monocrystalline Polycrystalline |||| Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic|		
2. K-Feldspar 45	Microcline || Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altering:|
3. Plagioclase 69	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altered:|| Alter to sericite:|| Alter to calcite:|
4. Volcanics 13	||||||		Altered:||||
5. Microphanerites			
6. Accessory Minerals 1	Biotite:| Hornblende		
7. Carbonate Cement 4	||||		
8. Matrix/ Pseudomatrix 3 ||| 18 |||||||| Clay-Altered Grains			Pseudo Biotite:||||| Biotite>chlorite:|
9. Clay Cement 1	Kaolinite:|		
10. Intragranular Porosity 6	Quartz K-Feldspar| Plaigioclase||||	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 20	Fractures Fracture-induced dissolution Oversize/elongate pores |||||||||||||||||||| Grain-edge dissolution		Primary Porosity Other
12. Other 17	Pyrite/organics:| R.F.: |||||||||||||||||		Phosphate:| Bone:| Chert:||

COMMENTS:
Most chlorite out of all samples present. Small amounts of carbonate. Tons of biotite in this sample.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q|||	vrfQ	prfQ
K|	vrfK	prfK
P||||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		
10		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Mandell-3(Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,436-7

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING:
COMPACTION: Cl : 3.2 TPI : 1.9
SIZE: fine Sand
ANGULARITY: Subangular to subround

		SIZE	COMMENTS
1. Quartz (79) 27%	Monocrystalline Polycrystalline |||| Microphanerite || Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		Altered |||
2. K-Feldspar (31) 10.33%	Microcline Orthoclase Sanadine Microphanerite || Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (58) 19.33%	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altered |||| |||| Altered to sericite |
4. Volcanics (1) .33%	|		
5. Microphanerites			
6. Accessory Minerals (3) 1%	Biotite | Glauconite | Chlorite |		
7. Carbonate Cement (5) 1.66%	||||		
8. Pseudomatrix (1) .33%	|		
Clay-Altered Grains			
9. Clay Cement (27) 9%	Kaolinite ||||| ||||| ||||| ||||		
10. Intragranular Porosity (3) 1%	Quartz K-Feldspar || Plagioclase |	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (43) 14.33%	Fractures | Fracture-induced dissolution ||||| ||||| ||||| |||| Oversize/elongate pores Grain-edge dissolution	Primary Porosity Other	
12. Other (33) 11%	RF: ||||| ||||| ||| pyrite/organics: |||| |||	chert |||| Altered chert ||	

COMMENTS:
Plagioclase grains are highly altered and some highly fractured. Some fractured plag grains have been healed over. Lots of clay altered shale? fragments. Some $CaCO_3$'s in slide

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ||||	vrfQ	prfQ
K |||	vrfK	prfK
P ||||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(14) 4.66%

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SZ

THIN SECTION: Mandell
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,436-8
SORTING: Moderate
SIZE: fine to medium sand

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: CI: 3.3 TPI: 2.2
ANGULARITY: Subangular

		SIZE	COMMENTS
1. Quartz (100)	Monocrystalline Polycrystalline //// Microphanerite // Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic /		
2. K-Feldspar (42)	Microcline /// Orthoclase Sanadine Microphanerite / Volcanic Rock Fragment Sedimentary Metamorphic		Altered: //
3. Plagioclase (70)	Microphanerite //// Volcanic Rock Fragment Sedimentary Metamorphic		Altered to sericite: // Altering: /
4. Volcanics (14)	//// //// ///		
5. Microphanerites			
6. Accessory Minerals (3)	Biotite: ///		
7. Carbonate Cement (5)	////		
8. Matrix/ Pseudomatrix (8)	///		pseudo Biotite: // pseudo chlorite: /
Clay-Altered Grains			
9. Clay Cement			
10. Intragranular Porosity (8)	Quartz K-Feldspar / Plagioclase ////	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (18)	Fractures / Fracture-induced dissolution Oversize/elongate pores //// //// /// Grain-edge dissolution	Primary Porosity Other	
12. Other (24)	punte/organics: //// R.F.: //// //// ///	Phosphate: //// Chert: ////	

COMMENTS:
Some glauconite, muscovite

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ////	vrfQ	prfQ
K	vrfK	prfK
P ////	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(8)

(27)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SU

THIN SECTION: Mandell-3 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,436-10

PROJECT: thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate

COMPACTION: CI: 2.8 TPI: 1.8

SIZE: Fine to Medium Sand

ANGULARITY: Subangular - Subround

		SIZE	COMMENTS
1. Quartz (81) (27%)	Monocrystalline		Altered I
	Polycrystalline ~~IIII~~ IIII		
	Microphanerite II		
	Volcanic Rock Fragment		
	Quartz Arenite		
	Other Sedimentary		
	Metaquartzite		
	Other Metamorphic I		
2. K-Feldspar (28) (9.33%)	Microcline		
	Orthoclase		
	Sanadine		
	Microphanerite I		
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
3. Plagioclase (65) 21.66%	Microphanerite		Altered I
	Volcanic Rock Fragment		Albitized III
	Sedimentary		
	Metamorphic		
4. Volcanics (9) 3%	~~IIII~~ IIII		
5. Microphanerites			
6. Accessory Minerals (5) 1.66%	Biotite III		Muscovite I
	Chlorite I		
	Glauconite		
7. Carbonate Cement (2) .66%	Dolomite II		
8. Pseudomatrix (2) .66%	II		Matrix:
___Clay-Altered Grains			
9. Clay Cement (26) 8.66%	~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~		
	Kaolinite I		
10. Intragranular Porosity (4) 1.33%	Quartz	VRF: Q	PRF: Q
	K-Feldspar II	K	K
	Plaigioclase II	P	P
11. Intergranular Porosity (45) 15%	Fractures		
	Fracture-induced dissolution	Primary Porosity	
	Oversize/elongate pores ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~ ~~IIII~~		
	Grain-edge dissolution	Other	
12. Other (20) 6.66%	RF: ~~IIII~~ ~~IIII~~ IIII		Phosphate I
	pyrite/organics: IIII		Chert I

COMMENTS:

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ~~IIII~~ I	vrfQ	prfQ
K II	vrfK	prfK
P IIII	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER	______	

(13) 4.33%

8

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: S2l

THIN SECTION: Handell - 3 (stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,436-13
SORTING: Moderate to poorly Sorted
SIZE: Fine Sand

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: Cl: 3.7 - TPI: 2.2
ANGULARITY: Subangular to Subround

		SIZE	COMMENTS
1. Quartz (92) 30.66%	Monocrystalline Polycrystalline ||||| Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		
2. K-Feldspar (37) 12.33%	Microcline | Orthoclase Sanadine Microphanerite || Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (60) 20.%	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altered |||||| Altering to sericite
4. Volcanics (2) .66%	||		
5. Microphanerites			
6. Accessory Minerals (6) 2%	Chlorite | Biotite | Epidote |	Muscovite |||	
7. Carbonate Cement (7) 2.33%	Dolomite |||||		
8. Pseudomatrix (2) .66%	||		
Clay-Altered Grains			
9. Clay Cement (32) 10.66%	||||| ||||| ||||| ||||| Kaolinite |		
10. Intragranular Porosity (2) .66%	Quartz K-Feldspar | Plaigioclase |	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (36) 12%	Fractures Fracture-induced dissolution | Oversize/elongate pores ||||| ||||| ||||| ||||| Grain-edge dissolution	Primary Porosity Other	
12. Other (14) 4.66%	RF ||||| Dyntic organics |	Chert |||	

COMMENTS:

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ||||	vrfQ	prfQ
K |	vrfK	prfK
P ||||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(10) 3.33%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Mandell
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,436-11
SORTING: Moderate
SIZE: Medium Sand

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: CI: 3.4 TPI: 1.9
ANGULARITY: Subangular

SIZE COMMENTS

1. Quartz (101) 33.6%
   - Monocrystalline
   - Polycrystalline ||||| |
   - Microphanerite
   - Volcanic Rock Fragment
   - Quartz Arenite
   - Other Sedimentary
   - Metaquartzite
   - Other Metamorphic |

2. K-Feldspar (40) 13.3%
   - Microcline ||||| |
   - Orthoclase
   - Sanadine
   - Microphanerite |
   - Volcanic Rock Fragment
   - Sedimentary
   - Metamorphic

   Altering to Kaolinite: |

3. Plagioclase (63) 21%
   - Microphanerite |
   - Volcanic Rock Fragment
   - Sedimentary
   - Metamorphic

4. Volcanics (10) 3.3% ||||| || — Pseudo: |||

5. Microphanerites

6. Accessory Minerals (2) .66%
   - Biotite: |
   - Muscovite: |

7. Carbonate Cement (5) 1.6% |||||

8. Matrix/Pseudomatrix (13) 4.3% | ||||| ||| — Pseudo Biotite: |||||
   ___Clay-Altered Grains

9. Clay Cement

10. Intragranular Porosity (4) 1.3%
   - Quartz
   - K-Feldspar
   - Plaigioclase ||||

   VRF: Q K P — PRF: Q K P

11. Intergranular Porosity (34) 11.3%
   - Fractures
   - Fracture-induced dissolution
   - Oversize/elongate pores ||||| ||||| ||||| ||||| ||||| ||||| ||||
   - Grain-edge dissolution

   Primary Porosity
   Other

12. Other (22) 7.3%
   - pyrite/organics:
   - R.F.: ||||| ||||| |||
   - Phosphate: |||||
   - Chert: ||

COMMENTS:
Small amounts of chlorite, Kaolinite & biotite, lots of porosity w/ little clay.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |||	vrfQ	prfQ
K		vrfK	prfK
P ||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER
(6) 2%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SM

THIN SECTION: PS-21 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,493

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate
COMPACTION: Cl: 1.9 TPI: 1.3

SIZE: Very Fine sand w/some larger coarse grains
ANGULARITY: Angular - Subangular

		SIZE	COMMENTS
1. Quartz (59) 19.66%	Monocrystalline Polycrystalline ||| Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		
2. K-Feldspar (31) 10.33%	Microcline || Orthoclase Sanadine Microphanerite || Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (63) 21%	Microphanerite ||| Volcanic Rock Fragment Sedimentary Metamorphic		Altered ||
4. Volcanics (2) .66%	||		
5. Microphanerites			
6. Accessory Minerals (3) 1%	Muscovite || Biotite |		Glauconite-present Hornblende present
7. Carbonate Cement (12) 4%	Dolo. //////		
8. Pseudomatrix (1) .33%	|		Matrix
Clay-Altered Grains			
9. Clay Cement (27) 9%	? //////// Kaolinite |		
10. Intragranular Porosity (4) 1.33%	Quartz K-Feldspar | Plaigioclase |||	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (73) 24.33%	Fractures Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution	Primary Porosity Other	
12. Other (20) 16.66%	RF //// pyrite/organics ////	Chert || Myrmekite ||	

COMMENTS:

PARAGENESIS:
Clay → shrinkage of fwg, dissolution

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P |	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q |||	vrfQ	prfQ
K	vrfK	prfK
P |	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER
(5) 1.66%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SU

THIN SECTION: PS
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,498

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING:

COMPACTION: CI: 2.2 TPI: 64

SIZE:

ANGULARITY:

		SIZE	COMMENTS
1. Quartz 81	Monocrystalline Polycrystalline //// Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic ///		
2. K-Feldspar 41	Microcline //// Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altered: //
3. Plagioclase 53	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altering to carbonate: /// Altered to sericite: //
4. Volcanics 5	////		
5. Microphanerites			
6. Accessory Minerals 3	Chlorite: // Muscovite: /		
7. Carbonate Cement 23	//// //// //// ///		
8. Matrix/ Pseudomatrix // /			Pseudo Biotite → chlorite: /
Clay-Altered Grains			
9. Clay Cement	Kaolinite: /		
10. Intragranular Porosity	Quartz K-Feldspar Plaigioclase ////	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 38	Fractures Fracture-induced dissolution Oversize/elongate pores //// //// //// //// //// Grain-edge dissolution	Primary Porosity Other	
12. Other + 10	Pyrite/organics: //// //// Rt: ////	Bone: / Chert: /	

COMMENTS:
Carbonates & clays are mostly dissolved. Lots of porosity. Kaolinite present. Chlorite present in small amounts

PARAGENESIS:
Which are first?
carbonate → chlorite 28, 78
Chlorite → $CaCO_3$? 9, 70
★ Albitization → chlorite healing fracture? PIC @ 40, 69

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ////	vrfQ	prfQ
K /	vrfK	prfK
P //// ////	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER 25		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SLL

THIN SECTION: Pacific Section 21 (stained) PROJECT: Thesis
FORMATION (AGE):
LOCATION:
DEPTH: 11,502 ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
SORTING: Poorly Sorted COMPACTION: CI: 2.7 TPI: 1.7
SIZE: fine to Medium Sand ANGULARITY: Subangular to subrounded

		SIZE	COMMENTS
1. Quartz (75) 25%	Monocrystalline Polycrystalline |||| Microphanerite | Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		
2. K-Feldspar (27) 9%	Microcline ||| Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (70) 23.33%	Microphanerite Volcanic Rock Fragment || Sedimentary Metamorphic		Altering to clay |
4. Volcanics (2) .666%	||		
5. Microphanerites			
6. Accessory Minerals (7) 2.3%	Muscovite | Hornblende Biotite ||||		Glauconite Brown Mystery | 33, 68
7. Carbonate Cement (8) 2.666%	Calcite |||||| Poikilotopic |		
8. Pseudomatrix (11) 3.666%	|||||		Matrix ||||
Clay-Altered Grains			
9. Clay Cement (3) 1%	Kaolinite ||| _____		
10. Intragranular Porosity (2) .466%	Quartz K-Feldspar | Plaigioclase |	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (65) 21.666%	Fractures Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution	Primary Porosity Other	
12. Other (22) 7.33%	RF ||||||||| pyrite/organics ||||||||		Chert ||

COMMENTS:
Albatized plag grains, Abundant Kaolinite cement present throughout. Some pseudomatrix Some blocky & poikilotopic carbonate cement throughout.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ||	vrfQ	prfQ
K |||	vrfK	prfK
P |||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER _____		

(8) 2.666%

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SZL

THIN SECTION: PS-21 11,507 (stained) PROJECT: Thesis
FORMATION (AGE): Vedder
LOCATION: Rio Bravo ROCK NAME: Arkosic Arenite
DEPTH: 11,507 POINT COUNTS: 300
SORTING: Moderate Sorting COMPACTION: CI: 2.5 TPI: 1.5
SIZE: Fine to Medium Sand ANGULARITY: Subangular to Rounded

		SIZE	COMMENTS
1. Quartz (72) 24%	Monocrystalline Polycrystalline //// Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		
2. K-Feldspar (24) 8%	Microcline Orthoclase Sanadine Microphanerite /// Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (59) 19.66%	Microphanerite / Volcanic Rock Fragment Sedimentary Metamorphic		Altering to clay/
4. Volcanics (2) .66%	//		
5. Microphanerites			
6. Accessory Minerals (8) 2.66%	Chlorite //// Muscovite /// _____	Biotite / _____ _____	
7. Carbonate Cement (12) 4%	Dolomite //// //// _____		
8. Pseudomatrix (5) 1.66%		Matrix ////	
Clay-Altered Grains			
9. Clay Cement (15) 5%	//// Kaolinite //	Sericite //	

10. Intragranular Porosity (3) 1%	Quartz K-Feldspar // Plaigioclase /	VRF: Q K P	PRF: Q K P		
11. Intergranular Porosity (72) 24%	Fractures Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution	Primary Porosity Other			
12. Other (21) 7%	punk/organics //// RF //// ///	Myrmekite / Chert /			

COMMENTS:
Kaolinite cement is patches throughout. Clay matrix & rims remain on majority of grains.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q //	vrfQ	prfQ
K /	vrfK	prfK
P ///	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER _____
(7) 2.33%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Pacific States
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,512

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: moderate
*COMPACTION: → lots of ∅, $CaCO_3$ & pseudo Cl: 2.0 TPI: 1.3

SIZE: Upper fine to Medium sand
ANGULARITY: Subround

		SIZE	COMMENTS
1. Quartz (78) 26%	Monocrystalline Polycrystalline |||| Microphanerite | Volcanic Rock Fragment | Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		Altered: |
2. K-Feldspar (36) 12%	Microcline | Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altering: |
3. Plagioclase (51) 17%	Microphanerite || Volcanic Rock Fragment | Sedimentary Metamorphic		Altered: ||||
4. Volcanics (10) 3.3%	||||||		Altered: |
5. Microphanerites			
6. Accessory Minerals (2) .66%	Biotite: | Muscovite: |		
7. Carbonate Cement (16) 5.3	||||||||||		
8. Matrix/ Pseudomatrix (22) 7.3%	|| ||||||||||		Biotite pseudo: ||||
Clay-Altered Grains			
9. Clay Cement (4) 1.3%	Kaolinite: ||||		
10. Intragranular Porosity (7) 2.3%	Quartz K-Feldspar || Plaigioclase ||||	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (29) 9.6%	Fractures Fracture-induced dissolution Oversize/elongate pores |||||||||||||||||||| Grain-edge dissolution		Primary Porosity Other
12. Other (25) 8.3%	punte/organics |||||||||| R.F: ||||||||||	Chert: |	

COMMENTS:
Small amounts of carbonate. Sedimentary Rock fragments throughout. Lots of ∅, lots of shale fragments deformed into pseudomatrix. Residual oil left behind. Small amounts of chlorite, & kaolinite clay coats & calcite protect grain compaction.

PARAGENESIS:
Phosphate → Kaolinite
Chlorite glauc → Biotite
SRF → chlorite?
Dolomite → pseudo?

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ||||	vrfQ	prfQ
K |||	vrfK	prfK
P |||||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER
(20) 6.6%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SRL

THIN SECTION: Pacific States
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,534-55
SORTING: Moderate
SIZE: Medium Sand

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: N/A
ANGULARITY: Subangular-Subround

SIZE ____ COMMENTS ____

1. Quartz 77
- Monocrystalline
- Polycrystalline 𝍸𝍸 (Altering: |)
- Microphanerite
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic |

2. K-Feldspar 28
- Microcline |||| (Altering to $CaCO_3$: ||||)
- Orthoclase
- Sanadine
- Microphanerite
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

3. Plagioclase 55
- Microphanerite (Altering to $CaCO_3$: 𝍸 ||||)
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

4. Volcanics 5 ||| (Altered: ||)

5. Microphanerites

6. Accessory Minerals ____ ____

7. Carbonate Cement [many tally marks]

8. Matrix/Pseudomatrix 5 || (Biotite pseudo: |||)

___Clay-Altered Grains___

9. Clay Cement ____

10. Intragranular Porosity
- Quartz
- K-Feldspar
- Plaigioclase

VRF: Q K P PRF: Q K P

11. Intergranular Porosity
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores |
- Grain-edge dissolution

Primary Porosity

Other

12. Other
10 pyrite/organics: 𝍸 |||||
6 R.F.: 𝍸 |

COMMENTS:
Lots of carbonate cement. Same amounts of glauconite grains. No porosity in sample

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ____

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: Shmuh

THIN SECTION: Pacific States 21 (Stained)
PROJECT: Thesis
FORMATION (AGE): Oligocene
LOCATION: Rio Bravo
ROCK NAME: Arkosic Arenite
DEPTH: 11,549 - 11,555
POINT COUNTS: 300
SORTING: Very poorly sorted
COMPACTION: N/A
SIZE: Fine to Medium silt w/ some larger grains in Matrix
ANGULARITY: Angular to subangular

	SIZE	COMMENTS
1. Quartz (70) 23.9%	Monocrystalline 53 Polycrystalline ++++ ++++ ||| Microphanerite Volcanic Rock Fragment | Quartz Arenite Other Sedimentary Metaquartzite | Other Metamorphic |	Chert ++++ | Altering to clay |
2. K-Feldspar (6) 1.9%	Microcline 5 Orthoclase | Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic	
3. Plagioclase (42)	Microphanerite || Volcanic Rock Fragment Sedimentary Metamorphic	Alter to Illite/Smectite ++++ ++++ Alter to chlorite | Alter to Dolomite ||| Alter to clay? |
4. Volcanics .32% (1)	|	
5. Microphanerites		
6. Accessory Minerals 12	chlorite ++++ ||| Muscovite |	Biotite | Hornblende Apatite || Glauconite-present
7. Carbonate (11) 3.55% Cement	Dolomite ++++ ++++ ++++ ++++ |	
8. Pseudomatrix		
Clay-Altered Grains		
9. Clay Matrix ~~Cement~~ (77) 24.9%	Illite/Smectite: 38 chlorite : 19	Kaolinite: 20
10. Intragranular (1) Porosity .32%	Quartz | K-Feldspar Plaigioclase	VRF: Q K P PRF: Q K P
11. Intergranular (13) Porosity 4.2%	Fractures || Fracture-induced dissolution || Oversize/elongate pores Grain-edge dissolution ||	Primary Porosity Other Shrinking: ++++ |
12. Other 17.8% (55)	Glauconite: ++++ ++++ ++++ ++++ | pyrite/organics: 32	Phosphate: 11

COMMENTS:
Quartz grains are floating in a detrital clay Matrix. Partial dolomitization occuring & shrinking of grains which is creating porosity around the grains. Clays w/in the sample are carbonate. Chlorite is infilling fractures among grains. Rutile crystals in some quartz grains. Microfractures are also present among sample. Lots of glauconite. Quartz looks healed over in fractures.

PARAGENESIS:
Clay → shrinkage Fracturing → Chlorite infilling fractures of Mostly quartz grains. → Dolomitization → Migration of oil. Good Pic of this process #

Oil on dolomite # 23,79 Dolomitization possibly before Pic #'s 10 of dol'n of 3 grain.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q |	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q |	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(2) .64%

out of 309 counts

(59)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Pacific States
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,554 - 11,560
SORTING: Poor
SIZE: Medium sand

PROJECT: Thesis
ROCK NAME: Lithic Arenite
POINT COUNTS: 300
COMPACTION: CI: 2.8 TPI: 1.6
ANGULARITY: Subround

SIZE ___ COMMENTS ___

1. Quartz (74)
- Monocrystalline
- Polycrystalline |||||||||||
- Microphanerite
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic |

2. K-Feldspar (25)
- Microcline |
- Orthoclase
- Sanadine
- Microphanerite |
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

3. Plagioclase (49)
- Microphanerite — Altering to calcite: ||
- Volcanic Rock Fragment
- Sedimentary — Altering: |
- Metamorphic

4. Volcanics (29) |||||||||||||||||||| — Altering: ||||

5. Microphanerites

6. Accessory Minerals (1) Biotite: |

7. Carbonate Cement (33) |||||||||||||||||||||||||

8. Matrix/Pseudomatrix (11) || — Biotite pseudo: |
|||||||
Clay-Altered Grains

9. Clay Cement (4) Kaolinite: ||||

10. Intragranular Porosity (4)
- Quartz
- K-Feldspar
- Plaigioclase ||||

VRF: Q, K, P — PRF: Q, K, P

11. Intergranular Porosity (20)
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores ||||||||||||||||||||
- Grain-edge dissolution

Primary Porosity

Other

12. Other (44) Pyrite/organics: |||| ; R.F.: |||||||||||||||||||||||| ; Phosphate: |||| ; Chert: |||| ; Shale: |

COMMENTS:
Lots of porosity, Some carbonates in minor amounts Kaolinite cement. Lots of rock fragments. Volcanics are altering to pseudo zeolite

*Maybe too many r.f., carbonate, P pseudo for CI. P T.P.I to be valuable?

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION
- Q — vrfQ — prfQ
- K — vrfK — prfK
- P — vrfP — prfP

GRAIN-EDGE DISSOLUTION
- Q ||| — vrfQ — prfQ
- K — vrfK — prfK
- P ||| — vrfP — prfP

OVERSIZE/ELONGATE PORES
- Q — vrfQ — prfQ
- K — vrfK — prfK
- P — vrfP — prfP

OTHER ___

(6)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Rudnick
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,382 - 11,400

PROJECT: Thesis

ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poorly Sorted

COMPACTION: CI: 2.1 TPI: 1.4

SIZE: Medium Sand

ANGULARITY: Subround

SIZE ___ COMMENTS ___

1. Quartz (91) 30.9%
- Monocrystalline
- Polycrystalline ||||| |
- Microphanerite |
- Volcanic Rock Fragment |||
- Quartz Arenite
- Other Sedimentary
- Metaquartzite ||
- Other Metamorphic ||||| |

2. K-Feldspar (36) 11.8%
- Microcline ||||
- Orthoclase
- Sanadine
- Microphanerite
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

Altering to sericite: |
Altering: |

3. Plagioclase (49) 16.1%
- Microphanerite
- Volcanic Rock Fragment |
- Sedimentary
- Metamorphic

4. Volcanics (17) 5.5% ||||| ||||| ||||| ||

5. Microphanerites

6. Accessory Minerals (1) .32%
- Muscovite: |

7. Carbonate Cement

8. Matrix/Pseudomatrix (48) ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| |

Shale pseudo: |

Clay-Altered Grains

9. Clay Cement (2)
- Kaolinite: ||

10. Intragranular Porosity (5) .65%
- Quartz
- K-Feldspar ||
- Plaigioclase |||

VRF: Q K P

PRF: Q K P

11. Intergranular Porosity (16) 5.2%
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores ||||| ||||| |||||
- Grain-edge dissolution

Primary Porosity

Other |

12. Other (19) 6.2%
- Punk/organics: ||||| |
- RF: ||||| |||||

Chert: ||
Phosphate: |

*Plag overgrowth @ 8, 73.2

COMMENTS:
Plag overgrowth observed. Lots of Ø w/ clay left behind.
Lots of Volcanics.
Kaolinite present.
clay protected grains from compaction & after dissolution. TPI is very low, or grains are too big and would create a bias.

PARAGENESIS:
Lots of Plag & Qtz overgrowths.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |||||	vrfQ	prfQ
K ||	vrfK	prfK
P ||||| |||||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ___
(17) 5.5%

Total: 300

(13)

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SZL

THIN SECTION: Rud-1 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,400-1

PROJECT: Thesis

ROCK NAME: Arkosic Wacke
POINT COUNTS: 300

SORTING: Poor

COMPACTION: N/A

SIZE: Fine Sand

ANGULARITY: Angular to subangular

SIZE ____ COMMENTS ____

1. Quartz (50) 16.666%
   - Monocrystalline
   - Polycrystalline |
   - Microphanerite
   - Volcanic Rock Fragment
   - Quartz Arenite
   - Other Sedimentary
   - Metaquartzite
   - Other Metamorphic

2. K-Feldspar (36) 12%
   - Microcline |
   - Orthoclase
   - Sanadine
   - Microphanerite |
   - Volcanic Rock Fragment
   - Sedimentary
   - Metamorphic

3. Plagioclase (57) 19%
   - Microphanerite ||| — Altering to clay |
   - Volcanic Rock Fragment
   - Sedimentary
   - Metamorphic

4. Volcanics (5) 1.666% ||||

5. Microphanerites

6. Accessory Minerals (1) .33% Biotite |

7. Carbonate Cement (26) 8.666%
   - Calcite |||| |||| |||| |||| ||||
   - Dolomite |

8. Pseudomatrix |||| (80) 26.666 Matrix: |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| ||

___Clay-Altered Grains___

9. Clay Cement (3) 1%
   - Kaolinite |||

10. Intragranular Porosity
    - Quartz
    - K-Feldspar
    - Plaigioclase
    - VRF: Q K P
    - PRF: Q K P

11. Intergranular Porosity (12) 4%
    - Fractures
    - Fracture-induced dissolution
    - Oversize/elongate pores |||| |||| ||
    - Grain-edge dissolution
    - Primary Porosity
    - Other

12. Other (27) 9%
    - Pyrite/organics |||| |||| |
    - RE |||| ||||
    - Chert |||

COMMENTS:
Lots of Matrix, Poorly sorted. Nothing special about this one.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |	vrfQ	prfQ
K	vrfK	prfK
P ||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ____

(3) 1%

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SZ

THIN SECTION: Rudnick
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,400-2

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION: N/A

SIZE: Fine Sand
ANGULARITY: Subangular

		SIZE	COMMENTS
1. Quartz 62	Monocrystalline Polycrystalline ||| Microphanerite ||| Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		Altered to calcite: |
2. K-Feldspar 47	Microcline | Orthoclase Sanadine Microphanerite | Volcanic Rock Fragment Sedimentary Metamorphic		Altering: |||
3. Plagioclase 5%	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altering: || Alter to calcite: |||
4. Volcanics 10	|||| ||||		
5. Microphanerites			
6. Accessory Minerals	_____ _____ _____	_____ _____ _____	
7. Carbonate Cement 27	|||| |||| |||| |||| |||| ||||		
8. Matrix/ Pseudomatrix 27	|||| |||| |||| |||| |||| ||||		Biotite pseudo: ||||
Clay-Altered Grains 6	|		
9. Clay Cement 9	|||| ||||		
10. Intragranular Porosity 2	Quartz K-Feldspar | Plaigioclase |	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 8	Fractures || Fracture-induced dissolution Oversize/elongate pores |||| | Grain-edge dissolution	Primary Porosity Other	
12. Other	+ Pyrite/organics: |||| | 9 R.F.: |||| ||||	3 Chert: |||	

COMMENTS:
Dirty sample. Some $CaCO_3$ clasts, clay coatings on grains. Some Kaolinite throughout.

PARAGENESIS:
Feldspar → Kaolinite

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ||||	vrfQ	prfQ
K |||	vrfK	prfK
P |||| ||||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER _____		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Rudnick-1 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,400-4

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Very Poor
SIZE: Very fine Sand

COMPACTION: N/A
ANGULARITY: Subangular to subround

		SIZE	COMMENTS
1. Quartz (43) 14.33%	Monocrystalline Polycrystalline | Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic |		
2. K-Feldspar (18) 6%	Microcline Orthoclase Sanadine Microphanerite || Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (54) 18%	Microphanerite || Volcanic Rock Fragment Sedimentary Metamorphic		
4. Volcanics (3)	||		
5. Microphanerites			
6. Accessory Minerals	_____ _____ _____	_____ _____ _____	
(123) 7. Carbonate Cement 41%	~~||||~~ _____		
(23) 8. Pseudomatrix 7.66%	~~||||~~	Matrix: ~~||||~~	
Clay-Altered Grains			
(17) 9. Clay Cement 5.66%	~~||||~~ _____		
10. Intragranular Porosity	Quartz K-Feldspar Plaigioclase	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (3) 1%	Fractures Fracture-induced dissolution Oversize/elongate pores ||| Grain-edge dissolution	Primary Porosity Other	
12. Other (15) 5%	RF |||| pynk/organics ~~||||~~ |||		

COMMENTS:

Band of carbonate running through. Very cool

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P |	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER	_____	

(1) .33%

56

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZe

THIN SECTION: Rudnick
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,400-5
SORTING: Poor
SIZE:

PROJECT: thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: Lots of clay may not be able to use? CI: 2.1 TPI: 1.40
ANGULARITY: Subangular

Category	Type	SIZE	COMMENTS
1. Quartz 62	Monocrystalline; Polycrystalline ||; Microphanerite |; Volcanic Rock Fragment; Quartz Arenite; Other Sedimentary; Metaquartzite; Other Metamorphic ||		Altering: ||
2. K-Feldspar 46	Microcline |; Orthoclase; Sanadine; Microphanerite |; Volcanic Rock Fragment; Sedimentary; Metamorphic		Altering to clay: |||
3. Plagioclase 60	Microphanerite; Volcanic Rock Fragment; Sedimentary; Metamorphic		Altering: 𝍸 ||||; Altering 2 calcite:	
4. Volcanics 8	𝍸 |||		Altered:	
5. Microphanerites			
6. Accessory Minerals 1	Biotite:			
7. Carbonate Cement 27	𝍸𝍸𝍸𝍸𝍸 ||		
8. Matrix/Pseudomatrix 22	𝍸𝍸𝍸𝍸 ||		Biotite pseudo: ||||; Biotite → chlorite pseudo: |||
16 ___Clay-Altered Grains	𝍸 ||||		
9. Clay Cement 7	𝍸; Kaolinite: ||		
10. Intragranular Porosity 6	Quartz; K-Feldspar |; Plaigioclase 𝍸		VRF: Q, K, P; PRF: Q, K, P
11. Intergranular Porosity 6	Fractures; Fracture-induced dissolution; Oversize/elongate pores 𝍸 |; Grain-edge dissolution		Primary Porosity; Other
12. Other	16 Pink/organics: 𝍸𝍸𝍸 |; 8 RF: 𝍸 |||		Bone: ||; Chert: ||

COMMENTS:
Lots of dissolution, matrix, pseudo, carbonate
may not have good compaction index?

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q |||	vrfQ	prfQ
K ||	vrfK	prfK
P 𝍸	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER ||	______	

PARAGENESIS:
Fracturing → pyrite 40, 78

(15)

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SH

THIN SECTION: Rudnick -1 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,400 - 7

PROJECT: Thesis
ROCK NAME: Arkosic Wacke
POINT COUNTS: 300

SORTING: Very Poor
SIZE: Very fine sand

COMPACTION: N/A
ANGULARITY: Subangular - Subrounded

		SIZE	COMMENTS
1. Quartz (56) 18.66%	Monocrystalline Polycrystalline | Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		Altering |
2. K-Feldspar (15) 5%	Microcline Orthoclase Sanadine Microphanerite | Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (74) 25.33%	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		
4. Volcanics (2) .66%	||		
5. Microphanerites			
6. Accessory Minerals (3) 1%	hornblende 		Muscovite Biotite ||
7. Carbonate Cement	 		
8. Pseudomatrix (124) 41.33% hornblende → clay |	(20)	Matrix: 101	
Clay-Altered Grains			
9. Clay Cement (3) 1%	||| 		
10. Intragranular Porosity (1) .33%	Quartz K-Feldspar Plaigioclase	Clay |	VRF: Q K P PRF: Q K P
11. Intergranular Porosity (1) .33%	Fractures Fracture-induced dissolution Oversize/elongate pores | Grain-edge dissolution		Primary Porosity Other
12. Other 4.33%	(13) pyrite/organics |||| RF: ||||		

COMMENTS:
Lots of matrix, pseudomatrix. little K-spar. Probably dissolved P crushed into pseudo P clay

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q||	vrfQ	prfQ
K	vrfK	prfK
P||||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(6) 21.

(57)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZC

THIN SECTION: Rudnick
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,411

SORTING: Poor

SIZE:

PROJECT: Thesis

ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

COMPACTION: CI: 2.4 TPI: 1.5

ANGULARITY: Subangular - Subround

		SIZE	COMMENTS
1. Quartz 97	Monocrystalline		
	Polycrystalline 𝍸𝍸 𝍸𝍸		Poly altering: |
	Microphanerite |		
	Volcanic Rock Fragment		
	Quartz Arenite		
	Other Sedimentary		
	Metaquartzite		
	Other Metamorphic ||||		
2. K-Feldspar 30	Microcline		Altering to clay: |
	Orthoclase		Altered: |
	Sanadine		
	Microphanerite		
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
3. Plagioclase 53	Microphanerite |||		Altering: 𝍸𝍸 𝍸𝍸
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
4. Volcanics 35	𝍸𝍸 𝍸𝍸 𝍸𝍸 𝍸𝍸 𝍸𝍸 𝍸𝍸 𝍸𝍸		Altered: 𝍸𝍸
5. Microphanerites			
6. Accessory Minerals 1	Biotite: |		
	Garnet:		
7. Carbonate Cement 2	Dolomite: ||		
8. Matrix/ Pseudomatrix 4 / 13	||||		Biotite pseudo: |||
	𝍸𝍸 𝍸𝍸 |||		
___Clay-Altered Grains___			
9. Clay Cement			
10. Intragranular Porosity 3	Quartz	VRF: Q	PRF: Q
	K-Feldspar	K	K
	Plaigioclase |||	P	P
11. Intergranular Porosity 22	Fractures		
	Fracture-induced dissolution	Primary Porosity	
	Oversize/elongate pores 𝍸𝍸 𝍸𝍸 𝍸𝍸 𝍸𝍸 ||		
	Grain-edge dissolution	Other	
12. Other	4 Pyrite/organics: ||||	Phosphate: |	Bone: |
	21 R.F.: 𝍸𝍸 𝍸𝍸 𝍸𝍸 𝍸𝍸 |	7 Chert: 𝍸𝍸 ||	

COMMENTS:

Lots of volcanics, Possible bauxite? lots of deformed Shale clasts forming a clay Matrix. Dolomite rhombs in Ø. Starting to grow or leftover from dissolution?

PARAGENESIS:

Dolomite filling in Ø @ 38,71

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q ||	vrfQ	prfQ
K	vrfK	prfK
P ||||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER

6

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: S Ulrich

THIN SECTION: Rud-1 11,413 Stained
FORMATION (AGE): Oligocene
LOCATION: Rio Bravo
DEPTH: 11,413

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate to poorly sorted
COMPACTION: CI: 3.4 TPI: 1.6

SIZE: Medium to coarse sand .32 - .44
ANGULARITY: subround to subangular

		SIZE	COMMENTS
1. Quartz (84)	Monocrystalline 71 Polycrystalline ~~||||~~ |||| Microphanerite Volcanic Rock Fragment | Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		Quartz Overgrowth | Chert ~~||||~~
2. K-Feldspar (35)	Microcline Orthoclase || Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altering to clay ~~||||~~ || Altering to calcite ||||
3. Plagioclase (49)	Microphanerite | Volcanic Rock Fragment Sedimentary 36 Metamorphic		Altering to sericite ~~||||~~ Altering to Kaolinite ~~||||~~ |||| Altering to Calcite
4. Volcanics 5.3% (16)	~~||||~~ ~~||||~~ ~~||||~~ |		
5. Microphanerites			
6. Accessory Minerals .6% (2)	Biotite ||		
7. Carbonate Cement 5.3% (16)	Calcite: ~~||||~~ ~~||||~~ ~~||||~~ |		
8. Pseudomatrix 1.6% (5)	~~||||~~		
___Clay-Altered Grains			
9. Clay Cement 6% (18)	Biotite Altering to clay: || ~~||||~~ ~~||||~~ ~~||||~~ |		clay coatings very common
10. Intragranular Porosity 1.3% (4)	Quartz || K-Feldspar | Plaigioclase	Dissolved grain can't tell: |	VRF: Q K P — PRF: Q K P
11. Intergranular Porosity 7.3% (22)	Fractures Fracture-induced dissolution Oversize/elongate pores |||| Grain-edge dissolution		Primary Porosity ~~||||~~ ~~||||~~ ~~||||~~ | Other Dissolved clay: ||
12. Other 7% (21)	Shale || hydrocarbon/Pyrite ~~||||~~ ~~||||~~ ||	Phosphate pellets/Bone ~~||||~~ ||	

COMMENTS:
Compaction & calcite bands run throughout. Calcite is cement replacing grains mostly plagioclase. Lots of clay coatings & volcanics w/ possible zeolites. Porosity is mostly primary throughout thin section. Sorting varies throughout as well as ϕ & perm. due to cement & compaction bands.

PARAGENESIS:
Feldspar grains partially replaced by calcite. Calcite cement band goes throughout slide

*Also possible zeolites in sample.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION			
Q |	vrfQ	prfQ	
K ||	vrfK	prfK	
P	vrfP	prfP	
GRAIN-EDGE DISSOLUTION			
Q ~~||||~~ ||||	vrfQ	prfQ	
K |||	vrfK	prfK	
P |||	vrfP |	prfP	
OVERSIZE/ELONGATE PORES			
Q	vrfQ	prfQ	
K	vrfK	prfK	
P ||||	vrfP	prfP	
OTHER (23) 7.6%			

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SU

THIN SECTION: Ruhl-1 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,437-3

PROJECT: Thesis

ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate Sorting
SIZE: Very fine - Fine Sand

COMPACTION: CI: 2.5 TPI: 1.5
ANGULARITY: Subround to Rounded

SIZE ___ COMMENTS ___

1. Quartz (50) 16.66%
- Monocrystalline
- Polycrystalline |||
- Microphanerite
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic ||

2. K-Feldspar (22) 7.33%
- Microcline |
- Orthoclase
- Sanadine
- Microphanerite |||
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

3. Plagioclase (70) 23.33%
- Microphanerite ||
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

Altering to clay ||||

4. Volcanics (7) 2.33% |||| ||

5. Microphanerites

6. Accessory Minerals (2) .66%
- Biotite: |
- Muscovite: |

7. Carbonate Cement (7) 2.33%
- Calcite Blocky |||| |
- Dolomite |

8. Pseudomatrix (28) 9.33% |||| ||

Matrix: |||| |||| |||| |||| ||||

Clay-Altered Grains

9. Clay Cement (4) 1.33% ||||

10. Intragranular Porosity (3) 1%
- Quartz ||
- K-Feldspar
- Plaigioclase |

VRF: Q, K, P

PRF: Q, K, P

11. Intergranular Porosity (66) 22%
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| |||| ||
- Grain-edge dissolution

Primary Porosity

Other

12. Other (30) 10%
- RF: |||| |||| |||| ||||
- Pyrite/organics ||||

Phosphate |

COMMENTS:
Noticing that Carbonates either Calcite or dolomite have an affinity for oil to cluster around. Squashed grains in some areas of tighter packing, Clay rims on Fwg.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q ‖	vrfQ	prfQ
K	vrfK	prfK
P |||| |||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P		vrfP	prfP

OTHER ___

(11) 3.66%

(33)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Ruhl-1
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,437-5

PROJECT: Thesis

ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poorly sorted

COMPACTION: CI: 2.0 TPI: 1.4

SIZE: fine to Medium sand

ANGULARITY: Subangular

		SIZE	COMMENTS
1. Quartz 80	Monocrystalline		
	Polycrystalline |||		
	Microphanerite		
	Volcanic Rock Fragment		
	Quartz Arenite		
	Other Sedimentary		
	Metaquartzite		
	Other Metamorphic			
2. K-Feldspar 18	Microcline		
	Orthoclase		
	Sanadine		
	Microphanerite		
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
3. Plagioclase 42	Microphanerite		Plag → sericite	
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
4. Volcanics 3	|||		
5. Microphanerites			
6. Accessory Minerals 5	Biotite |||		
	Muscovite ||		
7. Carbonate Cement 14	~~||||~~ ~~||||~~ ||||		
8. Matrix/ 14	~~||||~~ ~~||||~~ ||||		
Pseudomatrix 6	~~||||~~			
___Clay-Altered Grains			
9. Clay Cement 1				
10. Intragranular Porosity 11	Quartz		VRF: Q K P	PRF: Q K P
	K-Feldspar		
	Plaigioclase ~~||||~~		
dissolved grain	other: ~~||||~~		
11. Intergranular Porosity 54	Fractures		
	Fracture-induced dissolution	Primary Porosity	
	Oversize/elongate pores ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ ||||		
	Grain-edge dissolution ||	Other |||	
12. Other	5 organics/pyrite: ~~||||~~	Phosphate		
	15 R.F. ~~||||~~ ~~||||~~ ~~||||~~	Chert |||	

COMMENTS:

Clay coatings on all grains.
Some glauconite/chlorite.
Kaolinite present.
fracturing of quartz grain w/ Muscovite in between grain
Sporatic $CaCO_3$ in sample
Rutile needles

PARAGENESIS:

22.2 ; 25

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q ~~||||~~ ~~||||~~	vrfQ	prfQ
K ||	vrfK	prfK
P ~~||||~~ ~~||||~~ ~~||||~~		vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ________

28

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Ruhl-1 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,461-2

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate
COMPACTION: CI: 2.1 TPI: 1.4

SIZE: Medium Sand
ANGULARITY: Subangular to subround

SIZE ___ COMMENTS ___

1. Quartz 67
- Monocrystalline
- Polycrystalline ||||| |||| — Altered poly 1
- Microphanerite | — Altered 1
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic

2. K-Feldspar 19
- Microcline
- Orthoclase
- Sanadine
- Microphanerite |
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

3. Plagioclase 66
- Microphanerite | — Altered |||
- Volcanic Rock Fragment — Altered to sericite 1
- Sedimentary
- Metamorphic

4. Volcanics (3) 1% |||

5. Microphanerites

6. Accessory Minerals (4) 1.33%
- Chlorite 1
- Muscovite 1
- Glauconite
- Hornblende 1
- Biotite 1

7. Carbonate Cement (2) .66%
- Dolomite ||

8. Pseudomatrix (2) .66% || — Matrix:

___Clay-Altered Grains___

9. Clay Cement (33) 11%
- ||||| ||||| ||||| ||||| ||||| |||
- Kaolinite |||||

10. Intragranular Porosity (3) 1%
- Quartz
- K-Feldspar |
- Plaigioclase ||

VRF: Q, K, P — PRF: Q, K, P

11. Intergranular Porosity (51) 17%
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||
- Grain-edge dissolution

Primary Porosity

Other

12. Other (40) 13.33%
- RF ||||| ||||||
- Punk/organics ||||| ||||| ||||| ||||| ||||| |||

COMMENTS:
Lots of residual oil. Lots of porosity. Lots of clay altered grains w/ oil covering deformed biotite grains

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |||||	vrfQ	prfQ
K ||	vrfK	prfK
P |||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ___

(10) 3.33%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Ruhl-1
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,461.5

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION: N/A

SIZE:
ANGULARITY: Subangular to Subround

		SIZE	COMMENTS
1. Quartz 64	Monocrystalline Polycrystalline |||| Microphanerite Volcanic Rock Fragment || Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic |		
2. K-Feldspar 9	Microcline Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase 24	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		
4. Volcanics |			
5. Microphanerites			
6. Accessory Minerals 4	Muscovite: | Biotite: | Glauconite: ||		
7. Carbonate Cement 166			
8. Pseudomatrix			
Clay-Altered Grains			
9. Clay Cement 4	||||		
10. Intragranular Porosity	Quartz K-Feldspar Plaigioclase	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 1	Fractures Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution |	Primary Porosity Other	
12. Other	14 organics/pyrite: |||| |||| |||| 6 RF: |||| |	Chert: | 3 fossil: |||	

COMMENTS:

- Carbonate cement throughout both calcite & Dolomite.
- Dolomite & calcite are partially replacing f.w. grains.
- Zircon present @ 63.5, 34.5

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P |	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		
|		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Ruhl
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,482-2
SORTING: Poor
SIZE: fine to Conglomerate

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: N/A
ANGULARITY: Subround

SIZE ___ COMMENTS ___

1. Quartz (50) 16.6%
- Monocrystalline
- Polycrystalline |||||
- Microphanerite
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary |
- Metaquartzite
- Other Metamorphic ||

2. K-Feldspar (25) 8.3%
- Microcline
- Orthoclase
- Sanadine
- Microphanerite
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

Altering to $CaCO_3$: ||||

3. Plagioclase (48) 16%
- Microphanerite ||
- Volcanic Rock Fragment |
- Sedimentary
- Metamorphic

Altering to $CaCO_3$: ||||| ||||| |
Altering: |

4. Volcanics (7) 2.3% |||

Volcanic → chlorite: |||
Altering: |

5. Microphanerites

6. Accessory Minerals (34) 11.3%
- Glauconite: ||||| ||||| ||||| |||||
- Chlorite: ||||| ||||
- Hornblend: |

Glauc to Chlorite: ||||

7. Carbonate Cement (91) 30.3% ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| |

8. Matrix/Pseudomatrix (8) 2.6% ||||| |||

Pseudoglauc: |

Clay-Altered Grains

9. Clay Cement (10) 3.3% ||||| |||||

10. Intragranular Porosity
- Quartz
- K-Feldspar
- Plaigioclase

VRF: Q K P

PRF: Q K P

11. Intergranular Porosity (2) .66%
- Fractures |
- Fracture-induced dissolution
- Oversize/elongate pores |
- Grain-edge dissolution

Primary Porosity

Other

12. Other (25) 8.3%
- organics/pyrite: ||||
- R.F.: ||||| ||||| |||
- Chert: ||||| |

COMMENTS:

Lots of glauconite, dolomite cement, chlorite filling in fractured grains.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ___

PARAGENESIS:

Glauconite → chlorite
fracturing + infilling of chlorite in fractures
Glauconite → organics/pyrite

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Ruhl-1 (stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,482-3

PROJECT: Thesis
ROCK NAME: Lithic Arenite
POINT COUNTS: 300

SORTING: Very Poor
SIZE: Fine to Medium Sand

COMPACTION: N/A
ANGULARITY: Subrounded

		SIZE	COMMENTS
1. Quartz (49) 16.33%	Monocrystalline Polycrystalline Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic	.12 - .40 mm	
2. K-Feldspar (18) 6%	Microcline Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic	.14 - .26mm	
3. Plagioclase (33) 11%	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic	.12 - .32mm	
4. Volcanics (14) 4.66%			
5. Microphanerites			
6. Accessory Minerals			
7. Carbonate Cement Dolomite (88) 29.33			
8. Pseudomatrix (19) 6.33%		Matrix	
Clay-Altered Grains			
9. Clay Cement (15) 5%			

10. Intragranular Porosity	Quartz	VRF: Q	PRF: Q
	K-Feldspar	K	K
	Plaigioclase	P	P
11. Intergranular Porosity (25) 8.33%	Fractures		
	Fracture-induced dissolution		Primary Porosity
	Oversize/elongate pores		
	Grain-edge dissolution		Other
12. Other (38) 12.66%	RF pyrite/organics	phosphate Chert	

COMMENTS:
Lots of carbonate cement along w/ clay altered grains throughout. Dolomitization occuring on Numerous grains. Lots of dissolution of grains.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(1) 1%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Ruhl-1
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,482-4

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION:

SIZE: Medium sand
ANGULARITY: Subangular - subround

SIZE ____ COMMENTS ____

1. Quartz 69
- Monocrystalline
- Polycrystalline 卌卌 ||
- Microphanerite
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite ||||
- Other Metamorphic |

2. K-Feldspar 20
- Microcline
- Orthoclase
- Sanadine
- Microphanerite
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

3. Plagioclase 47
- Microphanerite |
- Volcanic Rock Fragment |
- Sedimentary
- Metamorphic

4. Volcanics 14 卌卌 ||||

5. Microphanerites

6. Accessory Minerals 2
- Biotite |
- Muscovite |

7. Carbonate Cement 106 (tally marks)

8. Matrix/Pseudomatrix ||| 3

___Clay-Altered Grains___

9. Clay Cement | 1

10. Intragranular Porosity
- Quartz
- K-Feldspar
- Plaigioclase

VRF: Q, K, P
PRF: Q, K, P

11. Intergranular Porosity
- Fractures
- Fracture-induced dissolution
- Oversize/elongate pores
- Grain-edge dissolution |||

Primary Porosity

Other

12. Other
- 4 Organics/Pyrite - ||||
- 21 R.F. 卌卌卌卌 |
- 9 Chert 卌 ||||

COMMENTS:
- RF are most affected by calcification. They seem to be the least stable
- Lots of zoned plagioclase grains

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |	vrfQ	prfQ
K	vrfK	prfK
P |	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ______

(23)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZ

THIN SECTION: Ruhl-1 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,502-1

PROJECT: Thesis

ROCK NAME: Lithic Arenite
POINT COUNTS: 300

SORTING: Poorly Sorted

COMPACTION: N/A

SIZE: Coarse Sand

ANGULARITY: Subround to Rounded

SIZE ______ COMMENTS ______

1. Quartz 93 — 31%
   - Monocrystalline
   - Polycrystalline |||
   - Microphanerite ||
   - Volcanic Rock Fragment
   - Quartz Arenite
   - Other Sedimentary
   - Metaquartzite
   - Other Metamorphic |

   Comments: weird quartz? 24, 77? ||||| ||

2. K-Feldspar (24) — 8%
   - Microcline ||||
   - Orthoclase
   - Sanadine
   - Microphanerite
   - Volcanic Rock Fragment
   - Sedimentary
   - Metamorphic

3. Plagioclase (13) — 4.33%
   - Microphanerite |
   - Volcanic Rock Fragment
   - Sedimentary
   - Metamorphic

   Comments: Altering to sericite |

4. Volcanics (3) — 1% |||

5. Microphanerites

6. Accessory Minerals

7. Carbonate Cement (99) — 33%
   - Dolomite [tally marks]

8. Pseudomatrix (1) — 1%

   Matrix: |

___Clay-Altered Grains___

9. Clay Cement (6) — 2%
   - orange |||||
   - Kaolinite |

10. Intragranular Porosity
    - Quartz
    - K-Feldspar
    - Plaigioclase

    VRF: Q K P — PRF: Q K P

11. Intergranular Porosity (13) — 4.33%
    - Fractures
    - Fracture-induced dissolution
    - Oversize/elongate pores [tally marks]
    - Grain-edge dissolution

    Primary Porosity

    Other

12. Other (46) — 15.33%
    - RF [tally marks]
    - Pyrite/organics |||
    - Chert [tally marks]

COMMENTS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K |	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ______

(1) 1%

PARAGENESIS:

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: RuW-1
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,502-2

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poorly sorted
COMPACTION: N/A

SIZE: Medium sand - Coarse
ANGULARITY: Sub-rounded

SIZE COMMENTS

1. Quartz 90
- Monocrystalline
- Polycrystalline ||||| ||||| (tally)
- Microphanerite ||||| (tally)
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic

calcedony |

2. K-Feldspar 29
- Microcline
- Orthoclase
- Sanadine
- Microphanerite |
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

3. Plagioclase 51
- Microphanerite |
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

Plag → sericite

4. Volcanics 4 ||||

5. Microphanerites

6. Accessory Minerals: Biotite |

7. Carbonate Cement 62 (tally marks)

8. Matrix/ Pseudomatrix |

___Clay-Altered Grains

9. Clay Cement ||

10. Intragranular Porosity
- Quartz
- K-Feldspar
- Plaigioclase

VRF: Q K P — PRF: Q K P

11. Intergranular Porosity 32
- Fractures |
- Fracture-induced dissolution
- Oversize/elongate pores (tally)
- Grain-edge dissolution ||

Primary Porosity

Other

12. Other
15 organics/pyrite (tally)
7 R.F (tally)
9 Chert (tally)
Phosphate |

COMMENTS:
More ϕ than 11,482-4
- Quartz grains are highly fractured
- Myrmekite present
- Some zoned plagioclase grains present

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SZL

THIN SECTION: Rwh1-1 (stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,502-3
SORTING: Well sorted fwg w/ $CaCO_3$ cement
SIZE: Coarse to Very Coarse

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: N/A
ANGULARITY: Subround to Round

	SIZE	COMMENTS
1. Quartz (97) 32.33%	Monocrystalline Polycrystalline |||| Microphanerite Volcanic Rock Fragment | Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic |||	
2. K-Feldspar (38) 12.66%	Microcline |||| Orthoclase Sanadine Microphanerite | Volcanic Rock Fragment Sedimentary Metamorphic	
3. Plagioclase (22) 7.33%	Microphanerite | Volcanic Rock Fragment | Sedimentary Metamorphic	Altering | w/ muscovite flakes 18,71 Altering to sericite |
4. Volcanics (5) 1.66%	||||	
5. Microphanerites		
6. Accessory Minerals		FeO_2 min. present 16,74
7. Carbonate Cement (69) 23%	Dolomite	
8. Pseudomatrix		
Clay-Altered Grains		
9. Clay Cement (4) 1.33%	|| Kaolinite |	
10. Intragranular Porosity (3) 1%	Quartz K-Feldspar || Plaigioclase |	VRF: Q K P
11. Intergranular Porosity (32) 10.66%	Fractures Fracture-induced dissolution Oversize/elongate pores |||| Grain-edge dissolution	Primary Porosity Other
12. Other (30) 10%	RF |||| pyrite/organics |	Phosphate || chert ||||

PRF: Q
K
P

COMMENTS:
Sample is full of dolomite cement along w/ some Fe rich matrix? Very orange/reddish. Very coarse grained sample.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(51)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Rubl-1
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,502-4

PROJECT: Thesis
ROCK NAME: Sub Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate
COMPACTION: N/A

SIZE: Medium to coarse grained
ANGULARITY: Subrounded

		SIZE	COMMENTS
1. Quartz (110) 36.6%	Monocrystalline Polycrystalline //////// Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic ////		Altering to calcite: /// Chert → Kaolinite: /
2. K-Feldspar (29) 9.6%	Microcline // Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altering to calcite: /
3. Plagioclase 22 7%	Microphanerite // Volcanic Rock Fragment Sedimentary Metamorphic		Altering to sericite: / Altering to calcite: /
4. Volcanics (5) 1.6%	////		
5. Microphanerites			
6. Accessory Minerals			
7. Carbonate Cement (81) 27%	//		
8. Matrix/ Pseudomatrix (3) 1%	\ /		pseudo chlorite: /
Clay-Altered Grains			
9. Clay Cement (6) 2%	Kaolinite: //// /		
10. Intragranular Porosity (1) .33%	Quartz K-Feldspar Plaigioclase \	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (10) 3.3%	Fractures Fracture-induced dissolution Oversize/elongate pores //// Grain-edge dissolution	Primary Porosity Other	
12. Other (34) 11.3%	pyrite/organics: // RF.: ////////	Phosphate: //// Chert: //////	

COMMENTS:

Poikilotopic carbonate cement. Small amounts of Kaolinite.

PARAGENESIS:

Phosphate first then carbonate. Good pic.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

5

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SUnnih

THIN SECTION: Ruhl-1 (Stained)
FORMATION (AGE): Oligocene
LOCATION: Rio Bravo Field
DEPTH: 11,534-1

PROJECT: Thesis

ROCK NAME: Sub Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate to well sorted

COMPACTION: CI: 2.1 TPI: 1.5

SIZE: Coarse to very coarse sand

ANGULARITY: Round to well Rounded

		SIZE	COMMENTS
1. Quartz (96) 32%	Monocrystalline I Polycrystalline IIII II Microphanerite I Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		Quartz w/ dolomite rims I remnant
2. K-Feldspar (33) 11%	Microcline Orthoclase IIII Sanadine Microphanerite I Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (11) 3.66%	Microphanerite Volcanic Rock Fragment I Sedimentary Metamorphic		Altered to sericite I
4. Volcanics (6) 2%	IIII I		
5. Microphanerites			
6. Accessory Minerals (6) 2%	Muscovite I Chlorite II Glauconite I	Apatite II	
7. Carbonate Cement (63) 21%	Dolomite IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII III		
8. Pseudomatrix			
___Clay-Altered Grains			
9. Clay Cement (2) .66%	Kaolinite I Sericite I		
10. Intragranular Porosity (3) 1%	Quartz I K-Feldspar II Plaigioclase	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (45) 15%	Fractures Fracture-induced dissolution Oversize/elongate pores IIII IIII IIII IIII IIII Grain-edge dissolution III	Primary Porosity IIII IIII IIII II Other Shrinkage I	
12. Other (28) 9.3%	Phosphate IIII III hydrocarbon/pyrite IIII	Rock fragment/shale IIII chert IIII III	

COMMENTS:

Lots of carbonate cement w/ Dolomite Rohmbs. cement occuding pore space. Texture is mainly of floating grains & point contacts. Lots of primary porosity & oversize pores. K-spars show dissolution w/ intragranular porosity the most. Dolomite rhoms floating. Small amounts of oil shows present. Chlorite is healing over on some quartz grains.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q II	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q III	vrfQ	prfQ
K	vrfK	prfK
P II	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ______

(7) 2.33%

PARAGENESIS:

Fracturing → Dolomite precip. → dissolution → secondary φ → oil Migration.

Chlorite? not sure on timing

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZl

THIN SECTION: Ruhl
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,534-2

PROJECT: Thesis
ROCK NAME: SubArkosic Arenite
POINT COUNTS: 300

SORTING: Well
COMPACTION: N/A

SIZE: Medium
ANGULARITY: Sub rounded

		SIZE	COMMENTS
1. Quartz (129) 43%	Monocrystalline		Poly Quartz → calcite: ||||
	Polycrystalline ||||||||||||		
	Microphanerite		
	Volcanic Rock Fragment		
	Quartz Arenite		
	Other Sedimentary		
	Metaquartzite		
	Other Metamorphic ||		
2. K-Feldspar (43) 14.3%	Microcline ||||||||		
	Orthoclase		
	Sanadine		
	Microphanerite |		
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
3. Plagioclase (12) 4%	Microphanerite |||		
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
4. Volcanics (4) 1.3%	||||		
5. Microphanerites			
6. Accessory Minerals			
7. Carbonate Cement (71) 23.6%	|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||		
8. Matrix/ Pseudomatrix			
Clay-Altered Grains			
9. Clay Cement (3) 1%	Kaolinite: |||		
10. Intragranular Porosity (3) 1%	Quartz	VRF: Q	PRF: Q
	K-Feldspar |||	K	K
	Plaigioclase	P	P
11. Intergranular Porosity (10) 3.3%	Fractures		
	Fracture-induced dissolution	Primary Porosity	
	Oversize/elongate pores ||||||||||		
	Grain-edge dissolution	Other	
12. Other (23) 7.6%	Pyrite/organics	Shell: |	Phosphate: |
	R.F. |||||||||||||	Chert: ||||||||	

COMMENTS:

Poikilotopic calcite cement.
Chert & R.F. tend to alter to Kaolinite.
Most microcline I've had yet in a thin section

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ||	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(2) .66%

PARAGENESIS:

Fracture → calcite

? Chlorite or phosphate? what came first?
Calcite → dissolution

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SU

THIN SECTION: Ruhl-1 (Stained)
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,574-1

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION: N/A

SIZE: Very fine grained sand
ANGULARITY: Angular to sub angular

		SIZE	COMMENTS
1. Quartz (50) 16.66%	Monocrystalline Polycrystalline || Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		
2. K-Feldspar (35) 11.66%	Microcline Orthoclase Sanadine Microphanerite | Volcanic Rock Fragment Sedimentary Metamorphic		
3. Plagioclase (65) 21.66%	Microphanerite ||| Volcanic Rock Fragment Sedimentary Metamorphic		
4. Volcanics (1) .33%	|		
5. Microphanerites			
6. Accessory Minerals (2) .66%	Glauconite → Chlorite | Hornblende |	Zircon Muscovite present	
(57) 7. Carbonate Cement .19	Dolomite //////////		
8. Pseudomatrix (19)	||	Matrix //////////	
___Clay-Altered Grains			
9. Clay Cement (37) 6.33%	//////////		
10. Intragranular Porosity (1) .33%	Quartz K-Feldspar Plaigioclase |	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity (8) 2.66%	Fractures Fracture-induced dissolution Oversize/elongate pores //// Grain-edge dissolution	Primary Porosity Other	
12. Other (25) 8.33%	Dunite/organics ////////// REE ////		

COMMENTS:

Lots of clay-Altered grains along w/ dolomite cement. Some altered biotite grains that altered to clay.

PARAGENESIS:

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SZL

THIN SECTION: Ruhl
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,574-2

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Poor
COMPACTION: N/A

SIZE: fine sand
ANGULARITY: subangular

SIZE ______ COMMENTS ______

1. Quartz (56) 18.6%
- Monocrystalline
- Polycrystalline ||||
- Microphanerite
- Volcanic Rock Fragment
- Quartz Arenite
- Other Sedimentary
- Metaquartzite
- Other Metamorphic |

Poly to calcite: |
Quartz → calcite: ||

2. K-Feldspar (33) 11%
- Microcline
- Orthoclase
- Sanadine
- Microphanerite
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

Altering: ||||
Altering to calcite: |||
Microcline to calcite: |

3. Plagioclase (50) 16.6%
- Microphanerite
- Volcanic Rock Fragment
- Sedimentary
- Metamorphic

Altering: ||||| ||
Altering to calcite: ||||| ||

4. Volcanics

5. Microphanerites

6. Accessory Minerals Zircon

7. Carbonate Cement (48) 16% ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| ||||| |||
↳ Dirty carbonate cement

8. Matrix/ Pseudomatrix (43) 14.3% ||||| ||||| ||||| ||||| ||||| |||
Clay-Altered Grains ||||| |||
Biotite pseudo: ||||| ||

9. Clay Cement (7) 2.3% Kaolinite: ||||| ||

10. Intragranular Porosity (2) .6%
- Quartz
- K-Feldspar |
- Plaigioclase ||

VRF: Q K P
PRF: Q K P

11. Intergranular Porosity (2) .6%
- Fractures ||
- Fracture-induced dissolution
- Oversize/elongate pores
- Grain-edge dissolution

Primary Porosity
Other

12. Other (27) 9%
pyrite/organics: ||||| ||||| |||
R.F.: |||||
Shale: |
Chert: ||||
Phosphate: ||

COMMENTS:
Lots of Matrix, dissolution of grains, carbonate cement. Calcite → dolomite.

PARAGENESIS:
Biotite → chlorite → carbonate?

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q |||||	vrfQ	prfQ
K ||||| |||||	vrfK	prfK
P ||||| |||||	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ______

(32) 10.6%

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: [illegible]

THIN SECTION: Ruhl-1
FORMATION (AGE): Vedder Oligocene
LOCATION: Rio Bravo
DEPTH: 11,574-T3
SORTING: Poor
SIZE: Fine Sand

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: N/A
ANGULARITY: Sub angular

SIZE ______ COMMENTS ______

1. Quartz 82
   - Monocrystalline
   - Polycrystalline
   - Microphanerite
   - Volcanic Rock Fragment
   - Quartz Arenite
   - Other Sedimentary
   - Metaquartzite
   - Other Metamorphic

2. K-Feldspar 28
   - Microcline
   - Orthoclase
   - Sanadine
   - Microphanerite
   - Volcanic Rock Fragment
   - Sedimentary
   - Metamorphic

3. Plagioclase 32
   - Microphanerite
   - Volcanic Rock Fragment
   - Sedimentary
   - Metamorphic

   Skeletal Remains of plag

4. Volcanics 5

5. Microphanerites

6. Accessory Minerals 5
   - Muscovite
   - Zircon
   - Glauconite
   - hornblende
   - Biotite

7. Carbonate Cement 33

8. Matrix/Pseudomatrix 29
   ___Clay-Altered Grains

9. Clay Cement 3

10. Intragranular Porosity
   - Quartz
   - K-Feldspar
   - Plaigioclase

   VRF: Q, K, P
   PRF: Q, K, P

11. Intergranular Porosity 11
   - Fractures
   - Fracture-induced dissolution
   - Oversize/elongate pores
   - Grain-edge dissolution

   Primary Porosity
   Other

12. Other
   19 organics/pyrite
   14 R.F.
   fossil-1
   chert-1

COMMENTS:
Carbonate replacing some grains.
Poikilotopic cement throughout. Some dolomite rohmbs throughout & in shale clasts
Feldspar grains are highly altered

PARAGENESIS:

75, 27

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

GRAIN-EDGE DISSOLUTION

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OVERSIZE/ELONGATE PORES

Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP

OTHER ______

35

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: S Unruh

THIN SECTION: Weber (stained)
FORMATION (AGE): Oligocene
LOCATION: Rio Brava
DEPTH: 11,425-4

PROJECT: Thesis
ROCK NAME: Arkosic Wacke
POINT COUNTS: 300

SORTING: Poorly Sorted
COMPACTION: N/A

SIZE: Fine sand with some larger Medium sand grains
ANGULARITY: Angular to Subangular

		SIZE	COMMENTS
1. Quartz 95	Monocrystalline 69 Polycrystalline III Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic II		Quartz to clay |||||
2. K-Feldspar 26	Microcline Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		K-Spar to clay ||||
3. Plagioclase 59	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altered to Sericite I Altered to clay ||||| |||| | Mymakite I
4. Volcanics III 1% (3)			
5. Microphanerites			
6. Accessory Minerals 1.3% (4)	muscovite III zircon I		
7. Carbonate Cement			
8. Pseudomatrix (93) 31% Clay-Altered Grains	||||	Matrix: 87	Biotite to clay-I Muscovite to clay-I
9. Clay Cement			
10. Intragranular Porosity .33% (1)	Quartz K-Feldspar Plaigioclase \		VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 2.3% (7)	Fractures Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution ||||	Primary Porosity Other
12. Other 8.3% (25)	pyrite / organics |||| |||| |||| |||| |||| | other I		

COMMENTS:

Lots of clay virtually no porosity, primary or secondary. Oil shows w/ in sample. Tight compaction. Small amounts of K-spar grains exist. Clay taking over all sample. Coarse grains are mixed w/ fine sand grains

PARAGENESIS:

The quartz is not forming a framework which implies that the clays were introduced @ the same time as the quartz possibly.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q III	vrfQ	prfQ
K	vrfK	prfK
P I	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

1.3% (4)

SANDSTONE PETROGRAPHY DATA

EXAMINED BY: SL

THIN SECTION: Weber
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,444-2

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: poor
SIZE: Fine sand

COMPACTION: N/A
ANGULARITY: subangular - subround

		SIZE	COMMENTS
1. Quartz 73	Monocrystalline Polycrystalline ||| Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic		Polycrystalline > clay | Altered to clay |
2. K-Feldspar 40	Microcline Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		Altered to clay ++++ ++++ ||||
3. Plagioclase 48	Microphanerite || Volcanic Rock Fragment Sedimentary Metamorphic		Altered to clay ++++ ++++
4. Volcanics 29	++++ ++++ ++++ ++++		Altered to clay ++++ ||||
5. Microphanerites			
6. Accessory Minerals 2	Biotite: | Epidote Muscovite |		
7. Carbonate Cement			
8. Matrix/ Pseudomatrix 41	++++ ++++ ++++ ++++ ++++ ||||		Pseudo Biotite: ++++ ||||
Clay-Altered Grains			
9. Clay Cement			

10. Intragranular Porosity 2	Quartz | K-Feldspar Plaigioclase |	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 30	Fractures ++++ ++++ ++++ ++++ ++++ Fracture-induced dissolution Oversize/elongate pores Grain-edge dissolution	Primary Porosity Other	
12. Other	Punk Inclusions: ++++ |||| RF: ++++ |	fossil: |	

COMMENTS: Lots of clay & dissolved feldspar grains. Residual oil left over. Volcanics present. Lots of fractures throughout (possibly from thin section making)? Small amounts of Kaolinite Clay coats over grains which indicates not authigenic clay?

PARAGENESIS:
Lots of crush & slipped or rotated grains
lots of altered biotite & wavy clay laminations
Detrital clay throughout looks like disaggregated clay clasts & biotite. Clay has high birefringence.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q ++++	vrfQ	prfQ
K ++++	vrfK	prfK
P ++++	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		
18		

(40)

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SZl

THIN SECTION: Weber
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,445-1
SORTING: Poor
SIZE: Very fine to fine sand

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300
COMPACTION: N/A
ANGULARITY: Angular to subangular

		SIZE	COMMENTS
1. Quartz (73) 24%	Monocrystalline		Altered to clay: ||
	Polycrystalline		
	Microphanerite |		
	Volcanic Rock Fragment |		
	Quartz Arenite		
	Other Sedimentary		
	Metaquartzite		
	Other Metamorphic		
2. K-Feldspar (43) 14%	Microcline		ortho alter to clay: 𝍸𝍸𝍸𝍸
	Orthoclase		ortho to calcite: ||
	Sanadine		
	Microphanerite		
	Volcanic Rock Fragment		
	Sedimentary		
	Metamorphic		
3. Plagioclase (53) 17.6%	Microphanerite		Altering to clay: 𝍸
	Volcanic Rock Fragment		Plag → calcite: ||
	Sedimentary		
	Metamorphic		
4. Volcanics (8) 2.6%	𝍸|||		Volcanic → clay: ||
5. Microphanerites			
6. Accessory Minerals (1) .3%	Muscovite |		
7. Carbonate Cement (5) 1.6%	Dolomite Rohmbs: |||		Carbonate clay/Matrix?: 𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸𝍸|
	Calcite? ||		
8. Matrix/Pseudomatrix 12.6% (38)	𝍸𝍸𝍸||	Volcanic pseudo: |	Biotite pseud: 𝍸|||
	Clay-Altered Grains		ortho → clay: 𝍸||||
			Plag → clay: 𝍸
			Muscovite: |
9. Clay → (46)? Not sure where to put b/c its a $CaCO_3$ clay cement. Cement 15.3%			
10. Intragranular Porosity	Quartz	VRF: Q K P	PRF: Q K P
	K-Feldspar		
	Plaigioclase		
11. Intergranular Porosity (9) 3%	Fractures 𝍸||||		
	Fracture-induced dissolution	Primary Porosity	
	Oversize/elongate pores		
	Grain-edge dissolution	Other	
12. Other (9) 3%	Pyrite/organics: 𝍸||	Chert: |	
	R.F.: |		

COMMENTS:
Some patches of calcite throughout. Lots of matrix possibly detrital & authigenic. Grains are very dissolved. Very dirty sample. Uneven distribution of Ø. Lots of clay matrix. Even quartz grains are altered. Some dolomite Rohmbs.

PARAGENESIS:
Dissolution → calcite → dolomite

→ Grains are crushed & rotated quite a bit throughout sample.

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION			
	Q	vrfQ	prfQ
	K	vrfK	prfK
	P	vrfP	prfP
GRAIN-EDGE DISSOLUTION			
	Q |||	vrfQ	prfQ
	K ||||	vrfK	prfK
	P 𝍸|||	vrfP	prfP
OVERSIZE/ELONGATE PORES			
	Q	vrfQ	prfQ
	K	vrfK	prfK
	P	vrfP	prfP
OTHER (15) 5%			

SANDSTONE PETROGRAPHY DATA EXAMINED BY: S. Unruh

THIN SECTION: Weber 11,445-7 (Stained) PROJECT: Thesis
FORMATION (AGE): Vedder, Oligocene
LOCATION: Rio Bravo ROCK NAME: Arkosic Arenite
DEPTH: 11,445-7 POINT COUNTS: 300
SORTING: Moderate to poor COMPACTION: CI: 4.1 TPI: 1.8
SIZE: Medium to coarse sand ANGULARITY: Angular to Subangular

		SIZE	COMMENTS
1. Quartz (75)	Monocrystalline Polycrystalline ||| Microphanerite Volcanic Rock Fragment Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic	.7 x .6mm	Altered to illite: ||| Quartz healed fractures: 1 Quartz Altered to clay: 1
2. K-Feldspar (36) 11.5%	Microcline Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic	1mm x .4mm	Altered to illite? || Altered to Kaolinite: ||
3. Plagioclase (80)	Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic	.8 x .5mm	Altered to Kaolinite: 𝍸 𝍸 || Altered to Illite: 𝍸 | Altered to Sericik: 𝍸 | Albite: 1
4. Volcanics .32% (1)	1		
5. Microphanerites			
6. Accessory Minerals .29% (9)	Biotite: ||| Muscovite: 𝍸 |	phosphate: ||	
7. Carbonate Cement			
8. Pseudomatrix .22% (7)	𝍸 ||		
Clay-Altered Grains			
9. Clay ~~Cement~~ Matrix 10.9% (34)	Illite: 𝍸 𝍸 𝍸 || Kaolinite: 𝍸 Sericite: 1		Biotite Altered to clay: 𝍸 Muscovite Altered to Clay: 1
10. Intragranular Porosity 3.2% (10)	Quartz K-Feldspar 𝍸 | Plagioclase |||	VRF: Q K P	PRF: Q K P
11. Intergranular Porosity 4.2% (13)	Fractures || Fracture-induced dissolution Oversize/elongate pores ||| Grain-edge dissolution		Primary Porosity ||| Dissolution of clay: || Other Shrinkage: ||
12. Other 6.4% (20)	pyrite/hydrocarbons: 𝍸 𝍸 |||| Shale: 1		

COMMENTS:
Lots of clay. Clay preserved grains from compaction. Areas w/ no or little clay have higher compaction & pseudomatrix. Plag. grains show healing of fractures w/ albite. Lots of secondary porosity. Clay Matrix is $CaCO_3$. Very bright

PARAGENESIS:
Clay → grain shrinking → fracturing → dissolution → Secondary ϕ → Migration of oil

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q 𝍸 |	vrfQ	prfQ
K ||	vrfK	prfK
P 𝍸 |||	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

7.0% (22)

313 point counts

SANDSTONE PETROGRAPHY DATA EXAMINED BY: SZR

THIN SECTION: Weber
FORMATION (AGE): Vedder
LOCATION: Rio Bravo
DEPTH: 11,446-6

PROJECT: Thesis
ROCK NAME: Arkosic Arenite
POINT COUNTS: 300

SORTING: Moderate
COMPACTION: N/A

SIZE: Medium to fine sand
ANGULARITY: Subrounded

		SIZE	COMMENTS
1. Quartz (96) 32%	Monocrystalline Polycrystalline //// Microphanerite | Volcanic Rock Fragment /// Quartz Arenite Other Sedimentary Metaquartzite Other Metamorphic //		Poly → calcite: // Qtz → calcite: |
2. K-Feldspar (39) 13%	Microcline | Orthoclase Sanadine Microphanerite Volcanic Rock Fragment Sedimentary Metamorphic		ortho → sericite: | Altered → calcite: ////
3. Plagioclase (17) 5.6%	Microphanerite Volcanic Rock Fragment | Sedimentary Metamorphic		Plag → Calcite: |
4. Volcanics (30) 10%	////		Altered: | Volcanic → Calcite: //
5. Microphanerites			
6. Accessory Minerals			
7. Carbonate Cement (89) 29.6%	Calcite: ////		
8. Matrix/ Pseudomatrix (4) 1.3%	////		
Clay-Altered Grains			
9. Clay Cement			

Poikilotopic ←

10. Intragranular Porosity	Quartz	VRF: Q	PRF: Q
	K-Feldspar	K	K
	Plaigioclase	P	P
11. Intergranular Porosity	Fractures		
	Fracture-induced dissolution	Primary Porosity	
	Oversize/elongate pores		
	Grain-edge dissolution	Other	
12. Other (24) 8%	punk/organics: //// RF: ////	chert: | Phosphate: |	

COMMENTS:

Coarser grained than previous sample. All calcite cement throughout. Better sorting of grains than previous.
Possible quartz cement @ 16.5, 78
Poikilotopic cement throughout, small amounts of matrix left behind

Good for CL for overgrowths?

PARAGENESIS:

Dissolution → calcite
Floating grains w/ calcite surrounding showing dissolution → calcite @ 23, 76

SECONDARY INTERGRANULAR POROSITY

FRACTURE-INDUCED DISSOLUTION		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
GRAIN-EDGE DISSOLUTION		
Q |	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OVERSIZE/ELONGATE PORES		
Q	vrfQ	prfQ
K	vrfK	prfK
P	vrfP	prfP
OTHER		

(1) .3%