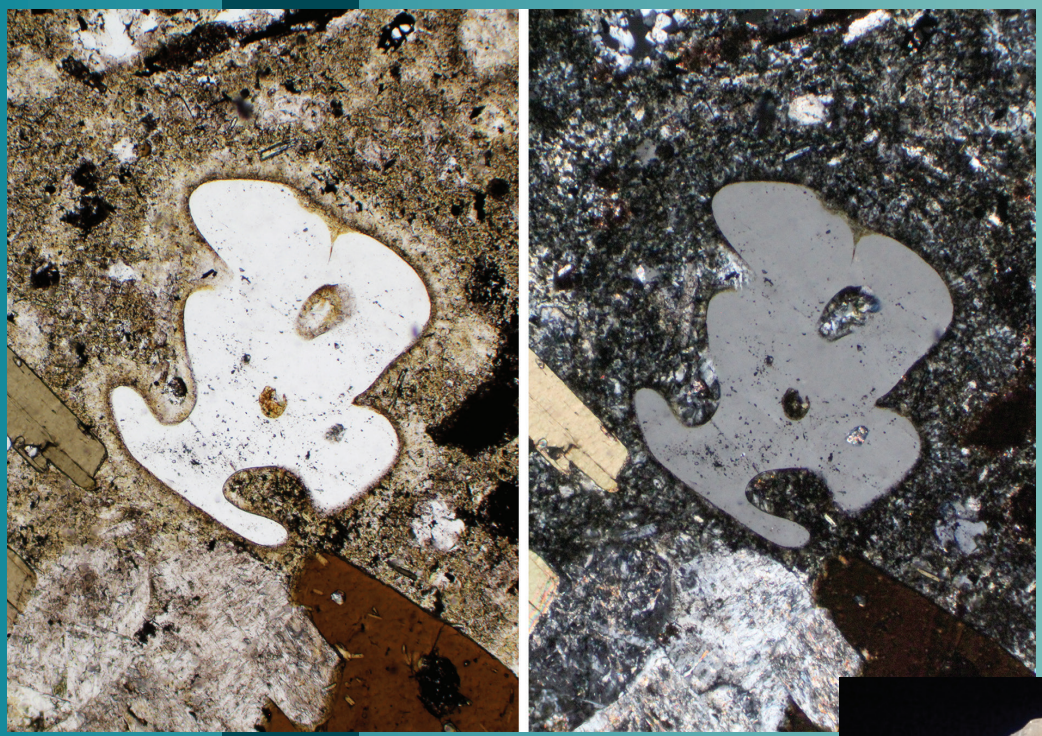
GRAINS:
QUARTZ AND SILICA





CHAPTER 1

QUARTZ AND SILICA

Quartz (SiO_2) is the most abundant mineral in terrigenous sedimentary rocks and is exceedingly durable (surviving multiple generations of weathering and deposition). Quartz and silica occur in many varieties—true quartz in the form of megaquartz, chert, microquartz, or chalcedony and various other forms of silica, mainly opal (opal-A and opal-CT [cristobalite]).

Major characteristics:

Color: Typically clear, but cloudy and colored varieties occur where crystals are especially rich in water or mineral inclusions. In thin section, these colors are rarely seen, although red and pale brown varieties related to included hematite and limonite are sometimes found.

Common crystal habit: Hexagonal, bipyramidal.

Pleochroism: None.

Cleavage/fracture: No cleavage, but fractures and healed fractures can be common.

Relief and optic sign: Low; uniaxial (+).

Birefringence: First-order (in a 30-μm section) typically first-order white and gray to pale straw yellow.

Other: No twinning; may contain trains of water, gas or mineral inclusions including ones, such as rutile and tourmaline needles, that may provide clues to grain provenance. Optical behavior varies based on deformation history; grains can have undulatory (undulose or sweeping) or nonundulatory (nonundulose or straight) extinction. Quartz grains commonly have syntaxial quartz overgrowths that form diagenetically.

Minerals that may have similar appearance and distinguishing differences:

Feldspars: Commonly show some cleavage, more alteration (vacuolization, sericitization, partial to complete dissolution), presence of characteristic twinning patterns and are biaxial. Can be differentiated by staining.

Apatite: Normally lower birefringence, has a higher relief and is uniaxial (-).

Gypsum and barite: Both have birefringence similar to quartz, but barite has slightly higher relief and gypsum has lower relief; both gypsum and barite have strong cleavage.

Zeolites: Numerous zeolite minerals can be confused with fibrous varieties of quartz. Most of the common zeolite minerals are biaxial (+/) and most have somewhat lower birefringence than quartz.

Provenance indicators:

Quartz can occur as single crystals or polycrystalline aggregates that may provide clues to the provenance of the grains, but quartz is common to most rock types other than basalts (Table 1.1). Semicomposite and polycrystalline quartz can be found in metamorphic and plutonic rocks as well as hydrothermal vein deposits and fractures. For metamorphic quartz, the size of the crystals may represent increasing metamorphic grade; larger crystals form under higher temperatures and pressures (Fig. 1.1).

Grain size can make provenance determination more difficult. With decreasing grain size, the ability to see undulatory quartz or polycrystalline/composite grains becomes more difficult. Since crystal sizes within polycrystalline grains may be large, grains formed from their breakdown may not exhibit polycrystallinity or undulatory extinction.

Chert and opaline silica can be found in either sedimentary or volcanic rocks — in the former as direct precipitates and in the latter as recrystallized glass.

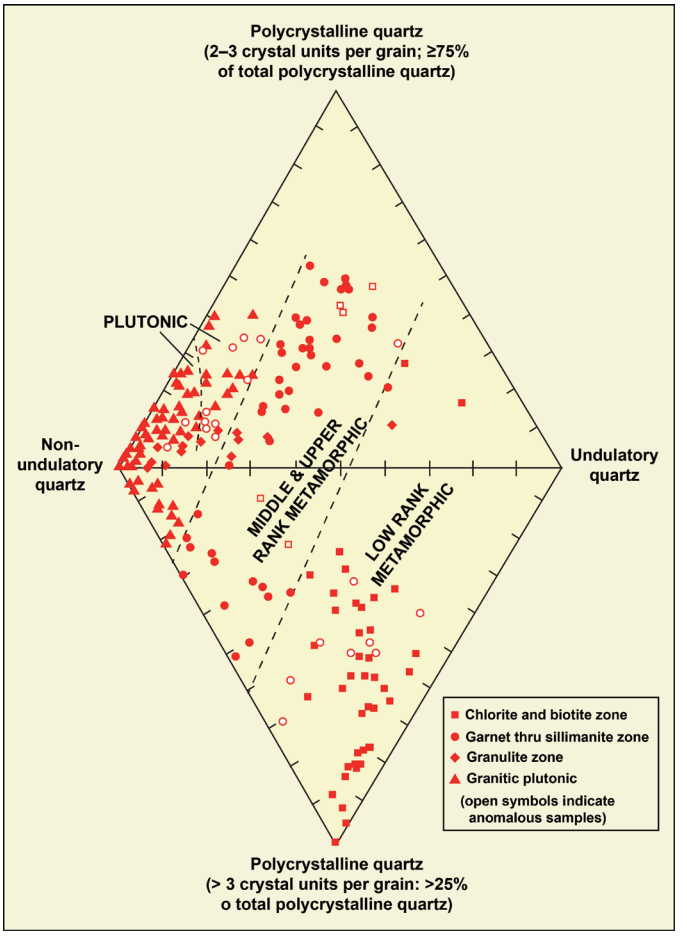


Figure 1.1: Plot of modern beach sands and their source terranes shows how the amount of nonundulatory, undulatory and polycrystalline quartz grains and the number of crystals in polycrystalline grains can help determine quartz provenance (from Basu et al., 1975).

Common inclusions and provenance –

Amphiboles (actinolite and others): metamorphic, intermediate to mafic igneous rocks and skarn deposits.

Apatite: felsic to intermediate volcanic rocks, skarns, carbonatites, calcium-rich metamorphic rocks, pegmatites and hydrothermal vein deposits.

Chlorite: fracture fills in low to medium grade metamorphic rocks, skarns and pegmatites.

Iron oxides (hematite, goethite and others): very common, and they form in a variety of environments ranging from anoxic (magnetite) to highly oxidizing (hematite, goethite) and low (goethite), medium (hematite) to high temperature (magnetite) conditions.

Sillimanite: metamorphic rocks.

Titanium minerals (such as rutile, titanite, anatase and others): metamorphic rocks, pegmatites and hydrothermal vein deposits.

Tourmaline: pegmatites.

Zircon: common in igneous and metamorphic rocks.

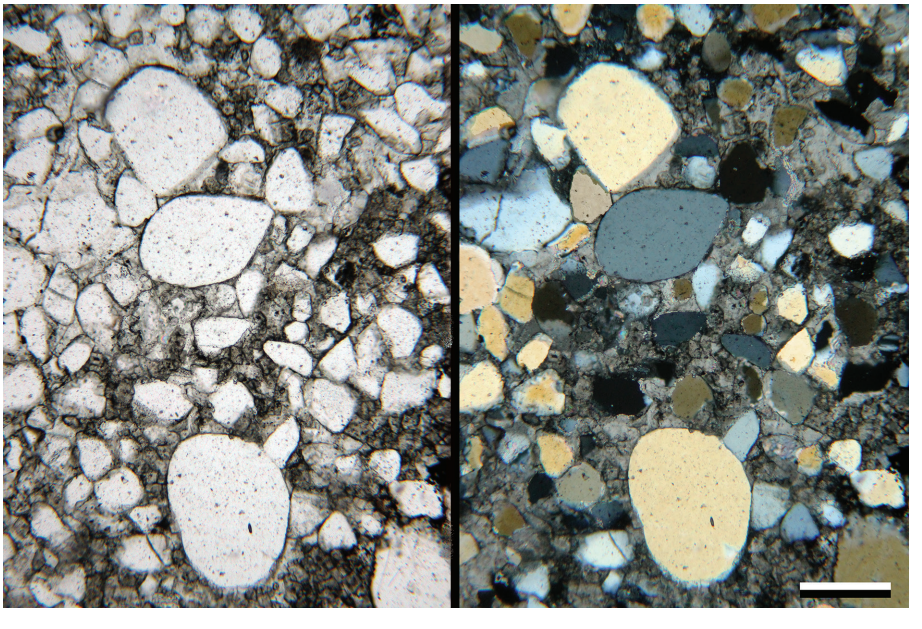
Hydrocarbons, bitumen and methane: trapped during growth of the quartz crystals from fluids containing organics. These can sometimes be used to reconstruct basin temperature and fluid histories.

Table 1.1: Overview of quartz types, characteristics and provenance (adapted from Krynine, 1946 and Folk, 1980).

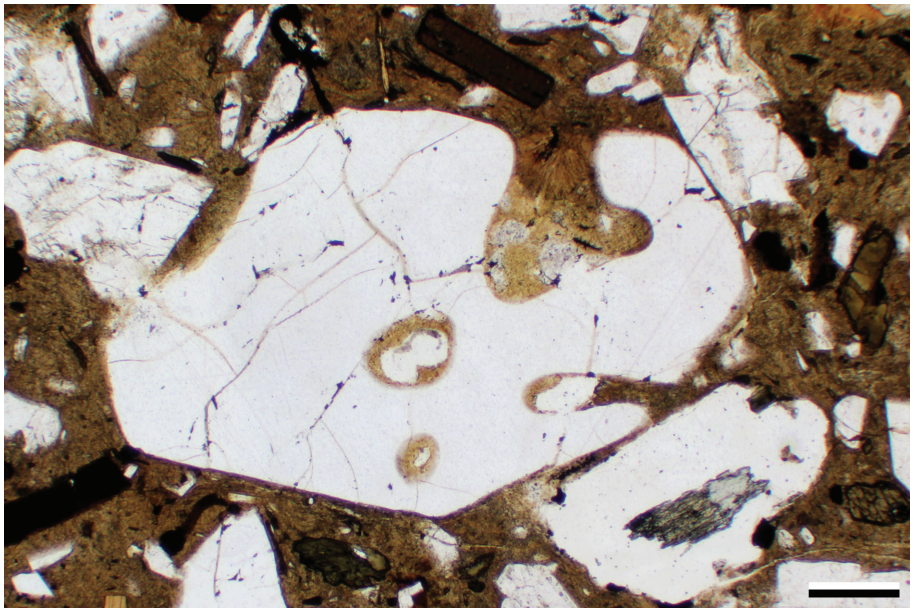
Quartz Types / Source	Extinction Characteristics	Other Features
Common or plutonic (granitic or many others)	Unit (straight) to slightly undulatory	Some vacuoles and/or microlites; subequant to xenomorphic grains
Vein or pegmatitic	Unit or semi-composite to undulatory, possible shearing	Abundant vacuoles, possible vermicular chlorite; comb structure common; typically found in large clasts
Volcanic	Unit (straight)	Euhedral bipyramidal shapes, round corners, and straight sides with embayments; virtually no inclusions; posible negative crystals
Schistose metamorphic	Unit to slightly undulatory	Elongate composite grains with straight borders; common mica inclusions
Stretched metamorphic	Strongly undulatory; subunit borders crenulate, granulate or smooth	Elongate, lenticular-shaped crystal sub-units; some microlites and vacuoles
Recrystallized metamorphic	Unit to slightly undulatory	Straight boundaries between equant inter-locking grains in a mosaic; some microlites or vacuoles

Mid. Ordovician Lander Sandstone, Johnson Co., Wyoming

Well-rounded, medium-sized quartz grains in a very fine grained, bimodal quartzarenite (interpreted to be an eolian deposit). In cross-polarized light, most of the grains exhibit unit (nonundulatory) extinction—i.e., the entire grain goes to extinction at the same time. The range of birefringence colors (gray to yellow) in the cross-polarized light photomicrograph is slightly "high" for a standard thickness (30 μm) thin section; thus, this section is slightly thicker than standard.



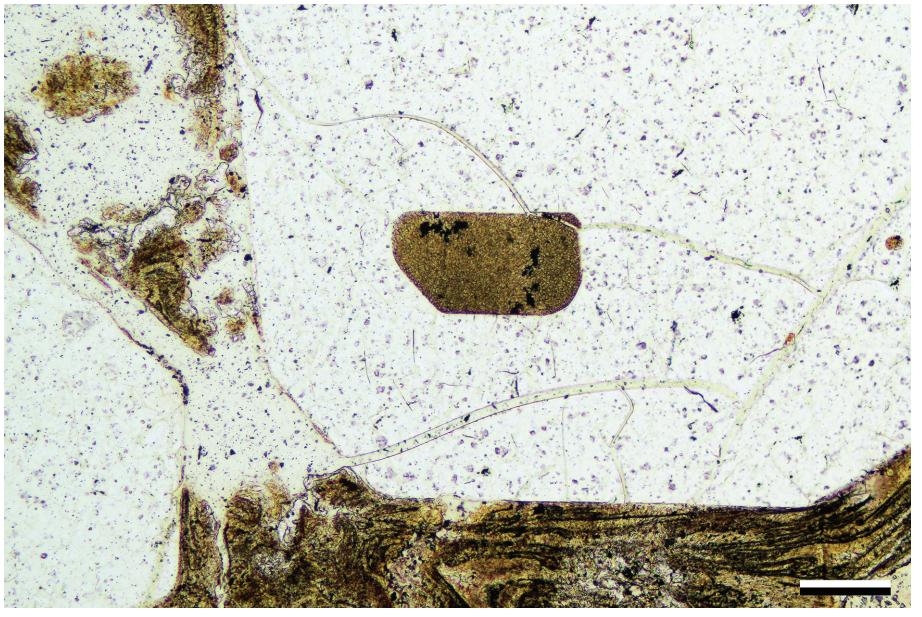
PPL | XPL, Scale bar = 0.20 mm



Paleogene Needles Range Fm., Millard Co., Nevada

A volcanic quartz grain with euhedral, bipyramidal outline. Euhedral shape, embayments, unit extinction and scarcity of inclusions are all indicative of an extrusive igneous (volcanic) provenance, but none, by itself, is conclusive evidence. This crystal started out as β-quartz, a hexagonal, high-temperature polymorph (573–870°C) of quartz. β-quartz is not stable at surface temperatures, and it inverts to α-quartz upon cooling.

PPL, Scale bar = 0.36 mm



Neogene Yellowstone Tuff, Park Co., Wyoming

A higher magnification view of a volcanic quartz crystal. This grain has unit extinction, a euhedral outline and a large "negative crystal" or vacuole. The vacuole (or hole) has the same crystallographic orientation as the complete quartz grain, hence the term "negative crystal". This feature is common but not ubiquitous in volcanic quartz crystals.

PPL, KFS, Scale bar = 0.14 mm



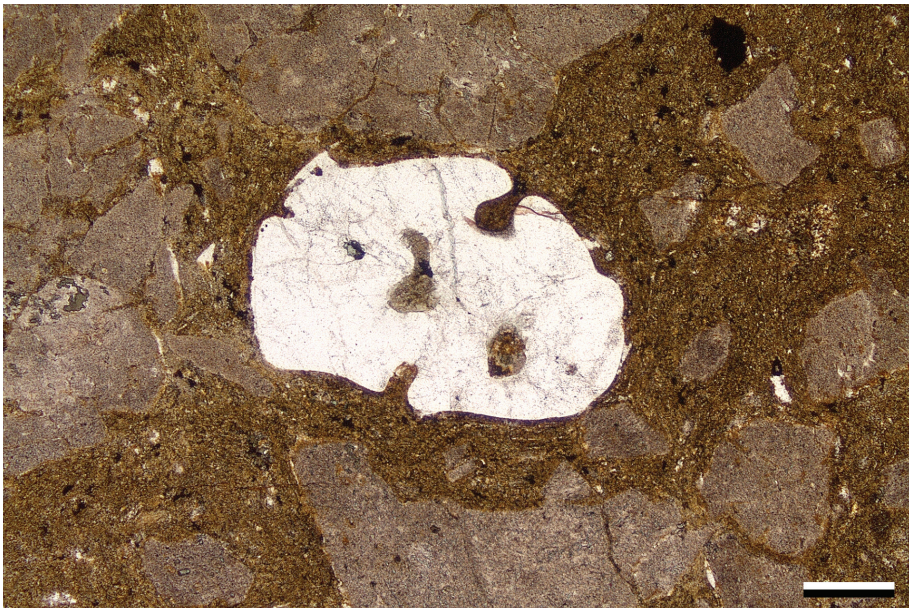
Cenozoic monzonite intrusive, Clark Co., Nevada

A deeply (monstrously) embayed volcanic quartz crystal within a monzonite porphyry. Embayed quartz crystals are common in acidic volcanics and have been ascribed to quartz disequilibrium with the melt causing the crystals to be reabsorbed (dissolution). Embayments normally have rounded edges. Like most volcanic quartz, this grain has unit extinction and few inclusions. Even though this is a source rock, it contains oddly shaped and rounded grains that can be liberated during weathering.

PPL | XPL, Scale bar = 0.26 mm

Paleocene, Rajasthan, India

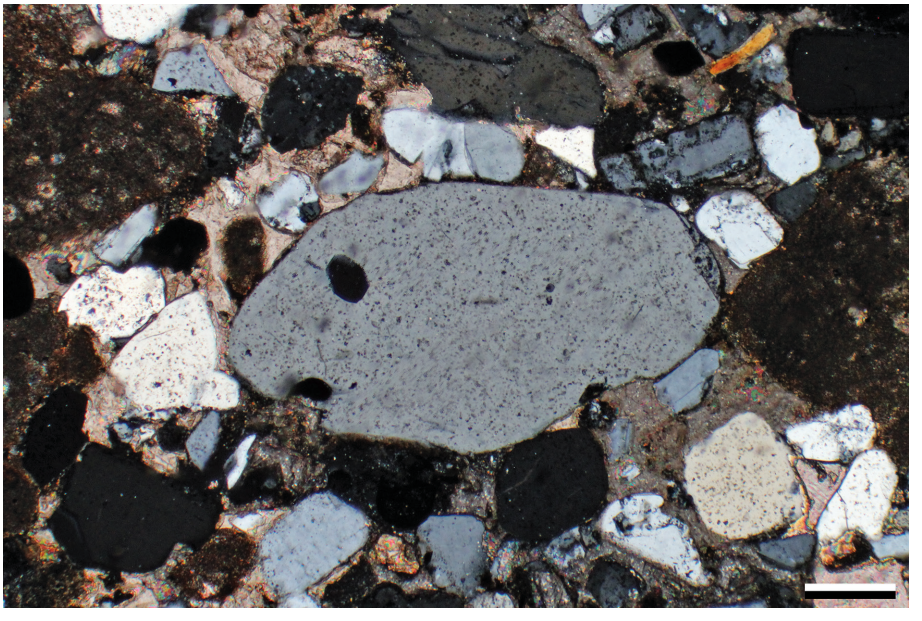
An embayed quartz crystal (pyroclast) within a crystal tuff. The embayments are not crystallographically controlled, suggesting that they result from magmatic corrosion. The corrosion occurs during changes in melt composition. Some embayments may form as partial inclusions, but it is not interpreted to be the case here. The quartz crystal is surrounded by devitrified volcanic glass and stretched pumice. The matrix has taken a stain from the sodium cobaltinitrite, suggesting that the alteration product of the glass includes K-feldspar.



PPL, KFS, Scale bar = 0.49 mm

Paleogene Vieja Gp., Presidio Co., Texas

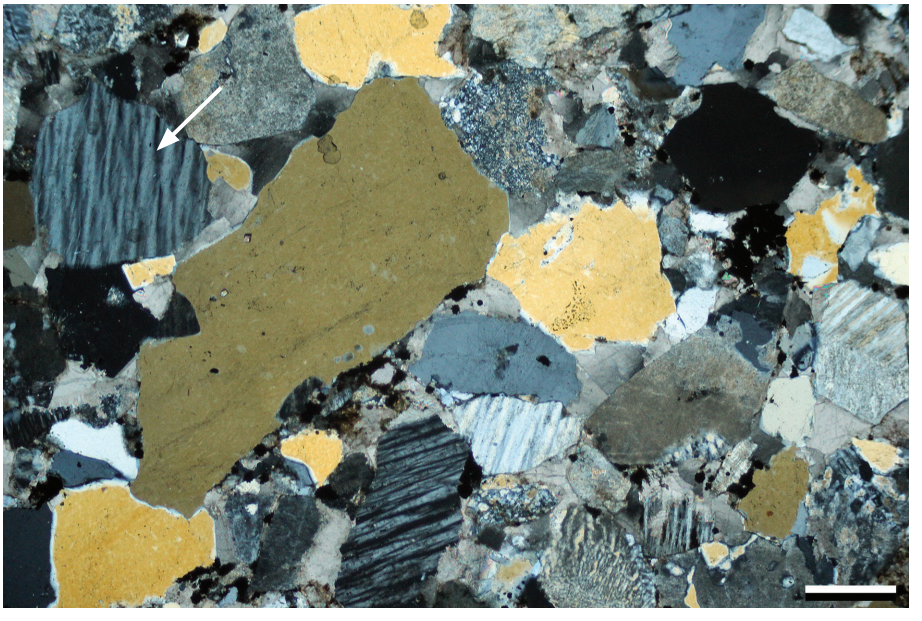
A single crystal, unit extinction, detrital quartz grain ("common quartz" or "normal igneous quartz" of Krynine, 1946). The grain goes to complete extinction under crossed polarizers with less than one degree of stage rotation. Such quartz is supplied by many types of source rocks and may be selectively concentrated during weathering and transportation. This grain may have been derived from a volcanic source as indicated by the embayments.



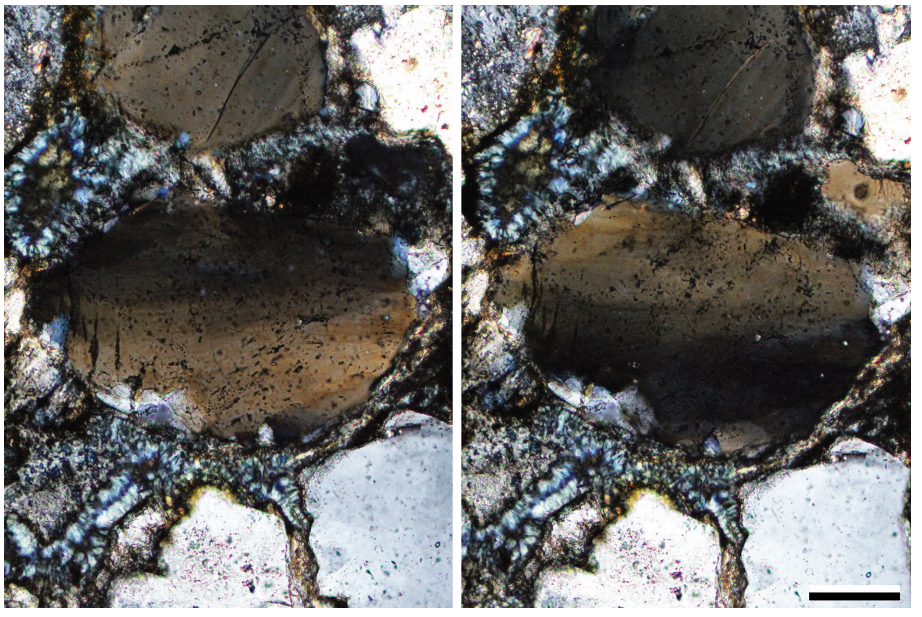
XPL, Scale bar = 0.26 mm

Up. Pennsylvanian – Lo. Permian Granite Wash, southern Oklahoma

An example of a thin section that was cut thicker than normal (i.e., > 30 μm). Instead of the gray to pale yellow birefringence expected for quartz, many of the quartz grains are deep yellow. Conversely, if the thin section is too thin, then the highest quartz birefringence colors might only be light gray. Thus, one has to "adjust one's expectations" to accurately identify these grains in thin section. Many of the other grains in this sample are microcline feldspars, recognizable because of their twinning (example indicated by white arrow).



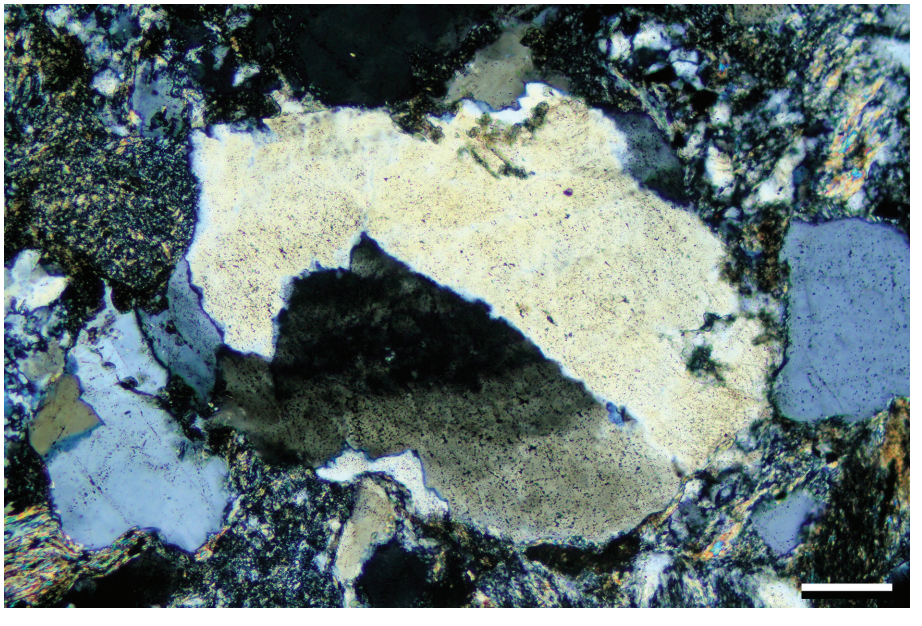
XPL, Scale bar = 0.22 mm



Lo. Cretaceous Patula Arkose, Coahuila, Mexico

This strained quartz grain has strongly undulatory extinction. The difference in stage rotation between the two photomicrographs is 8°, with the extinction zone sweeping from top to bottom. The straining here was produced *in situ* during burial and compaction causing crystal lattice dislocations. However, grains like these are common in source terranes that have undergone substantial deformation or metamorphism (Basu, 1985) and thus can arrive as prestrained detrital grains. The distinction is made by seeing if most or just a few grains show straining and if there is or is not a consistent pattern or fabric of strain features.

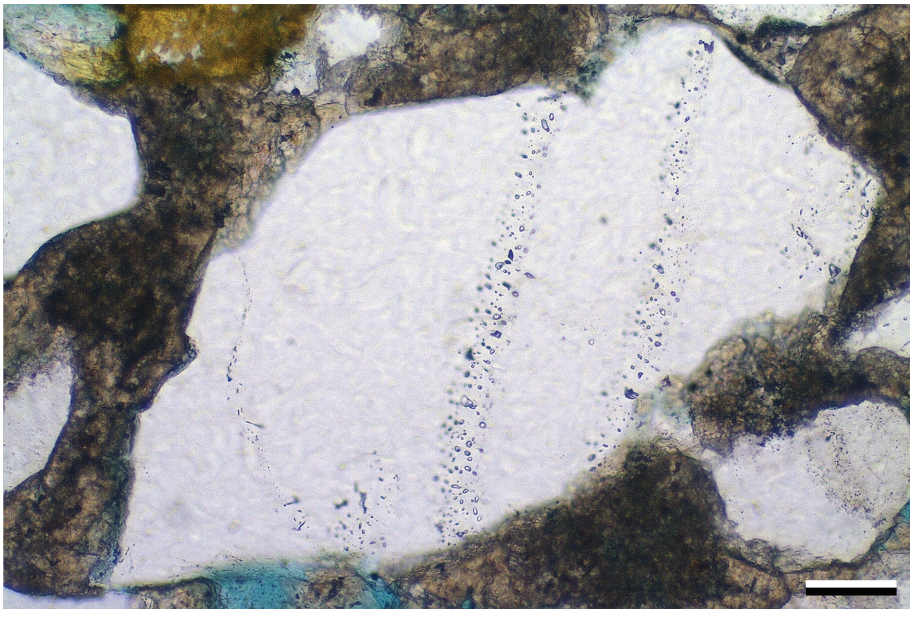
XPL | XPL, Scale bar = 0.10 mm



Silurian Tuscarora Sandstone, Lebanon Co., Pennsylvania

Undulatory extinction in a composite quartz grain. This quartz grain consists of a number of separate quartz crystals. Such grains can be derived from a range of source terranes, including plutonic, metamorphic and hydrothermal.

XPL, Scale bar = 0.14 mm



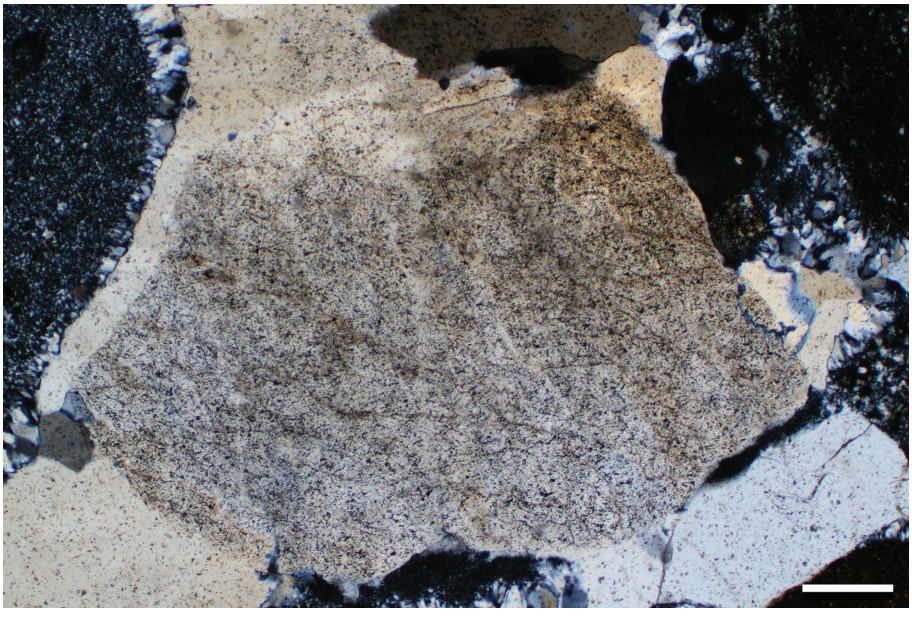
Jurassic Tilje Fm., Norwegian sector, North Sea †

Trails of fluid inclusions (vacuoles) within an otherwise inclusion-free quartz grain. Although aligned, these inclusion trains do not represent Boehm lamellae. The crosscutting of the trails suggests that the vacuoles are secondary and occurred from fluid flow along fractures that were subsequently healed. The quartz grain is surrounded by siderite cement.

PPL, KFS, BDI, Scale bar = 0.07 mm

Lo. Cretaceous Travis Peak Fm., Eastland Co., Texas

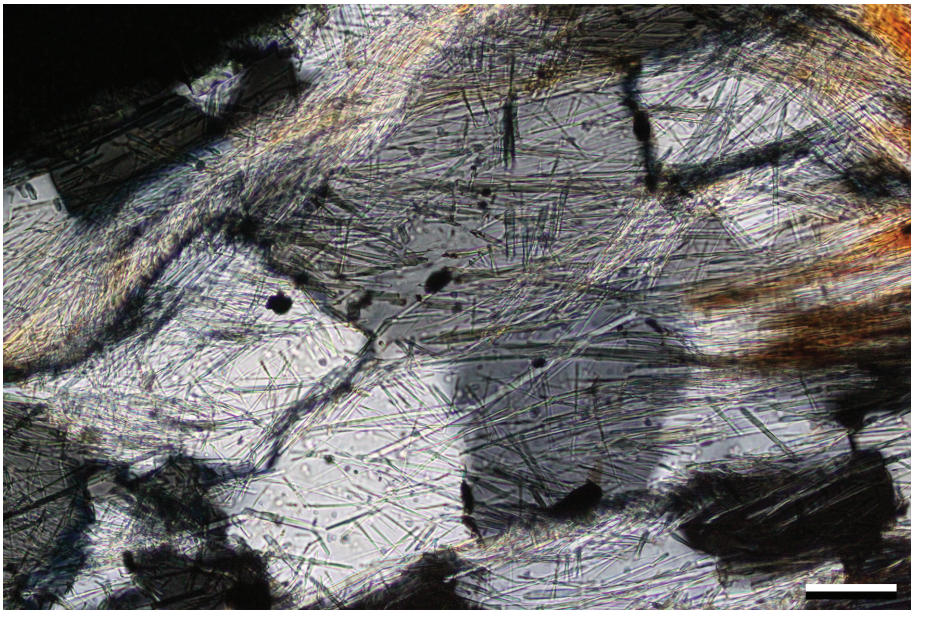
A quartz grain with exceptionally abundant vacuoles (probably liquid-filled inclusions) and semicomposite extinction (Krynine's "hydrothermal" quartz). Such vacuole-rich quartz grains are most commonly derived from hydrothermal-vein sources. The quartz overgrowth (cement) around the upper part of the grain has far fewer inclusions.



XPL, Scale bar = 0.26 mm

Lo. Paleozoic andalucite schist, Carroll Co., New Hampshire

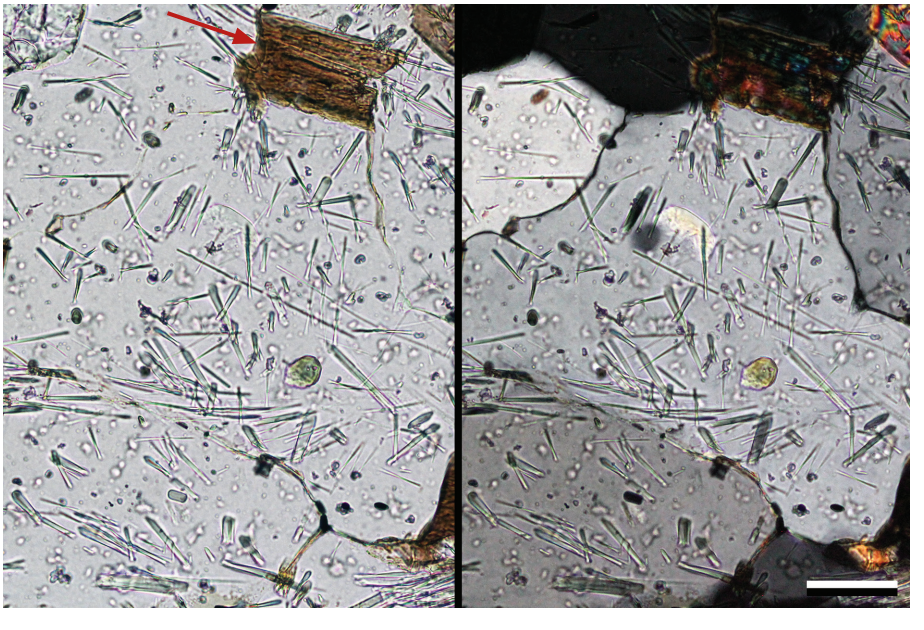
Multiple quartz crystals in a schist that have abundant needle-like mineral inclusions. These inclusions are probably sillimanite or tourmaline on the basis of their moderate relief and birefringence. When sillimanite occurs in fibrous masses as in this sample, it is called fibrolite.



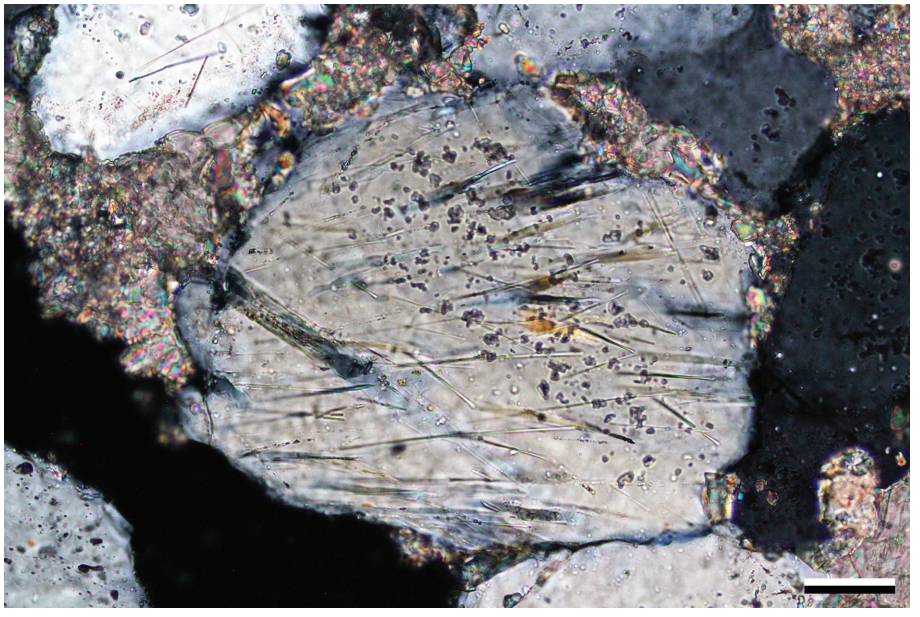
XPL, Scale bar = 0.05 mm

Lo. Paleozoic andalucite schist, Carroll Co., New Hampshire

Quartz crystals with abundant mineral inclusions. The largest inclusions are biotite crystals (e.g., the brown crystal indicated by the red arrow). The smaller needle-fiber inclusions are probably tourmaline on the basis of their greenish crystal color, shape and birefringence.



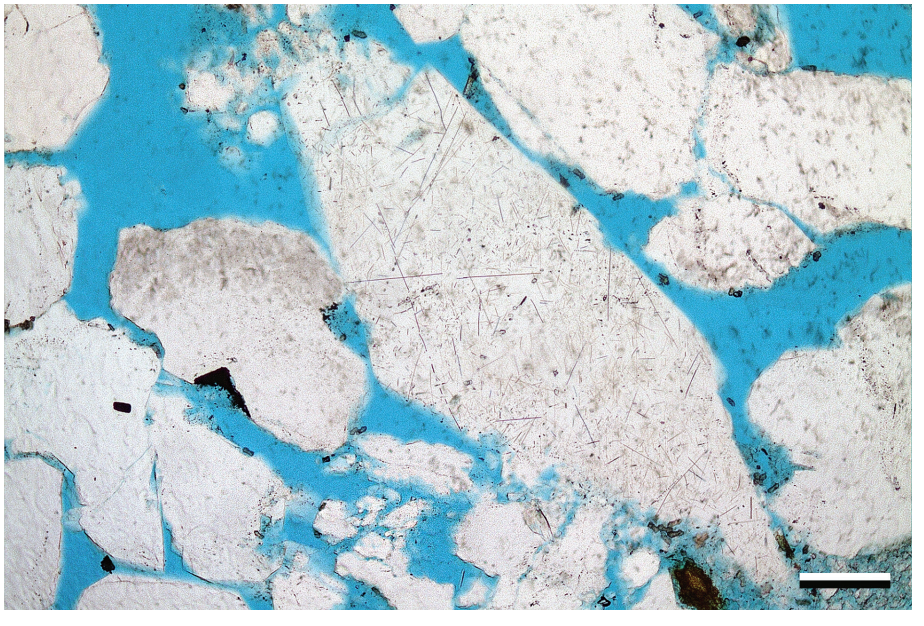
PPL | XPL, Scale bar = 0.05 mm



Mid. Permian (Guadalupian) Brushy Canyon Fm., Culberson Co., Texas

A quartz grain with numerous mineral inclusions. The needle-shaped mineral inclusions probably are rutile and/or tourmaline, but there also are fluid inclusions which make the grain appear speckled or dusty. These quartz grains are surrounded by carbonate cement.

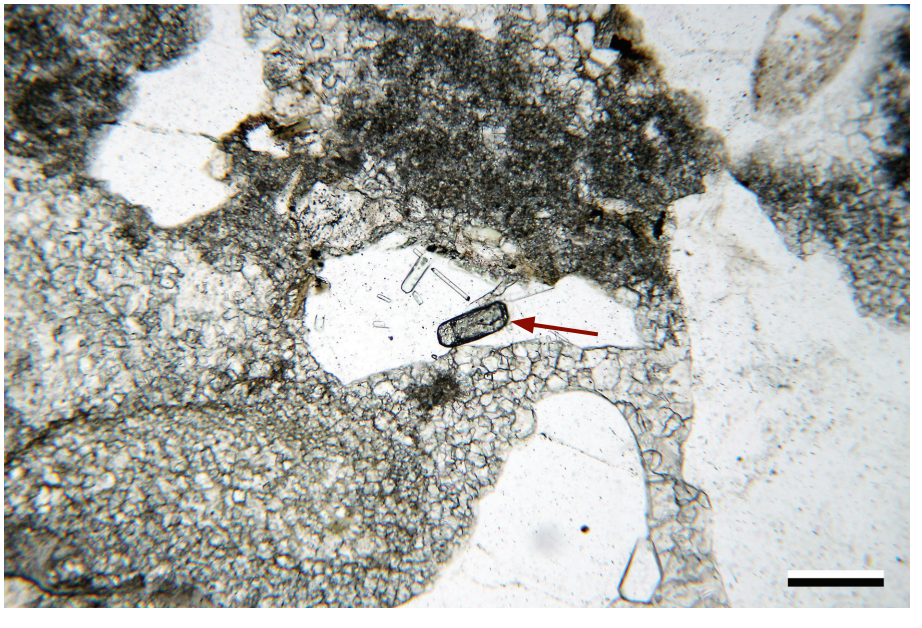
XPL, Scale bar = 0.05 mm



Mid. Jurassic Ness Fm., Norwegian sector, North Sea †

Acicular mineral inclusions within a quartz grain. The crystals are likely to be rutile but are too fine crystalline to determine their optical properties. The crystals show no preferred orientation.

PPL, BDI, Scale bar = 0.12 mm



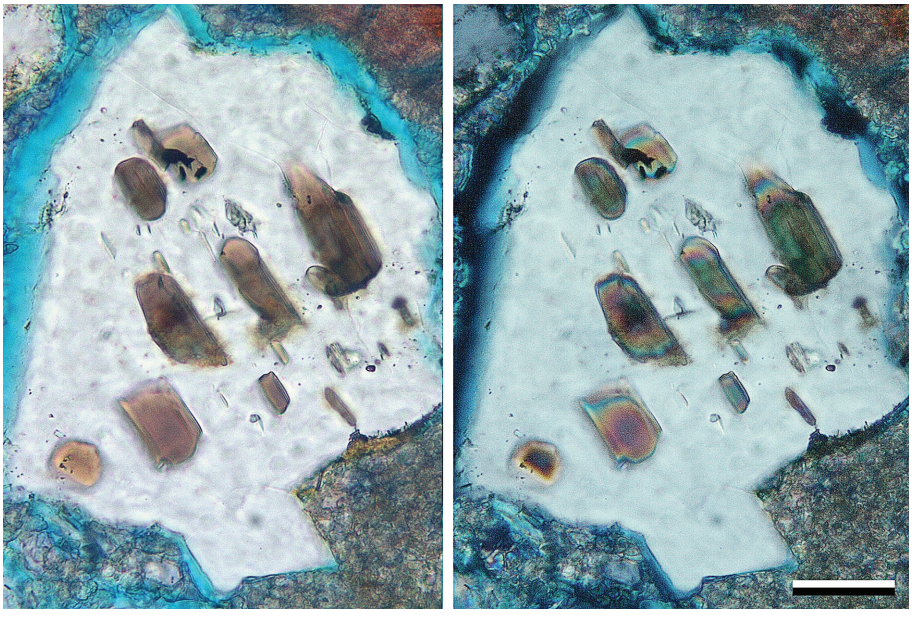
Pennsylvanian Alamitos Fm., San Miguel Co., New Mexico

A quartz grain containing both zircon and apatite inclusions. The zircon inclusion (indicated by red arrow) is the large greenish crystal with very high relief. The apatite inclusions are the colorless, moderate relief crystals (they have more relief than the surrounding quartz grain). This grain may be from a pegmatite or hydrothermal vein deposit. To see examples of zircon's very high and apatite's very low birefringence under crossed polarizers, see Chapter 4.

PPL, Scale bar = 0.16 mm

Up. Miocene (Tortonian), Tagus Basin, Setúbal Peninsula, Portugal †

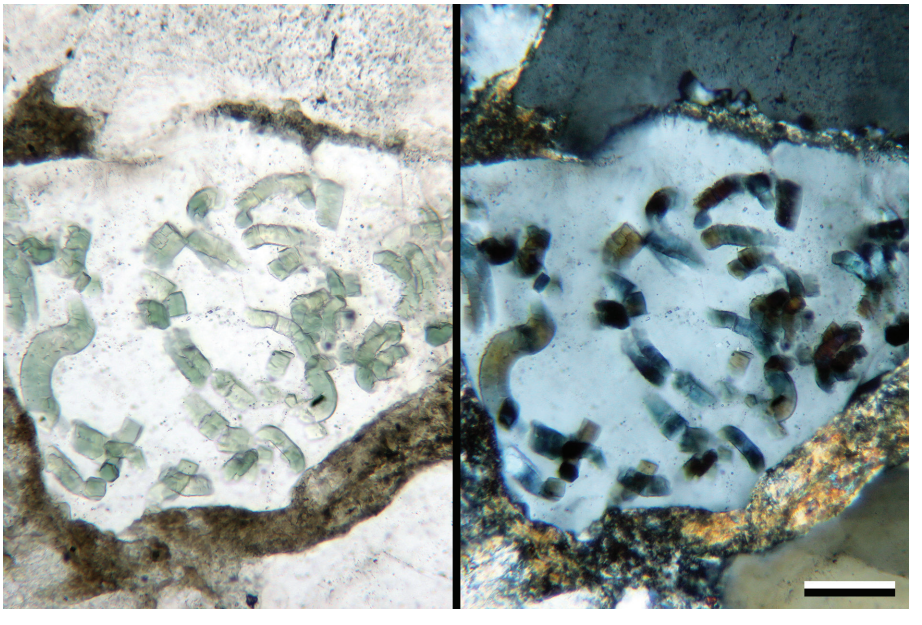
A quartz grain displaying mineral inclusions of biotite. The host grain is nonundulatory and inclusion free, suggesting a possible igneous origin. The biotite crystals are in optical alignment with each other. They show a single, well-defined cleavage, which distinguishes them from tourmaline.



PPL | XPL, BDI, Scale bar = 0.04 mm

Silurian Tuscarora Sandstone, Lebanon Co., Pennsylvania

Vermicular chlorite inclusions in a detrital quartz grain. The chlorite booklets are pale green, have anomalous "ultrablue" colors under polarized light and appear to be worm-like masses. These inclusions are typical of hydrothermal quartz.



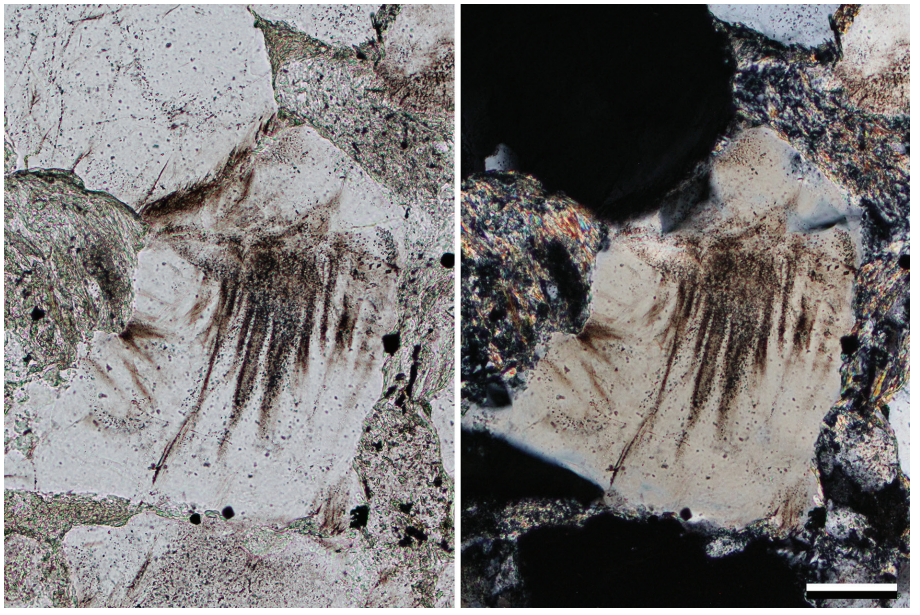
PPL | XPL, Scale bar = 0.14 mm

Silurian Tuscarora Sandstone, Lebanon Co., Pennsylvania

Vermicular chlorite inclusions in a detrital quartz grain. Vermicular chlorites can form during hydrothermal alteration or within pegmatites, but they also can form during metamorphism. These photomicrographs were taken with the substage condenser raised, thereby highlighting the individual chlorite plates that make up the vermicules.



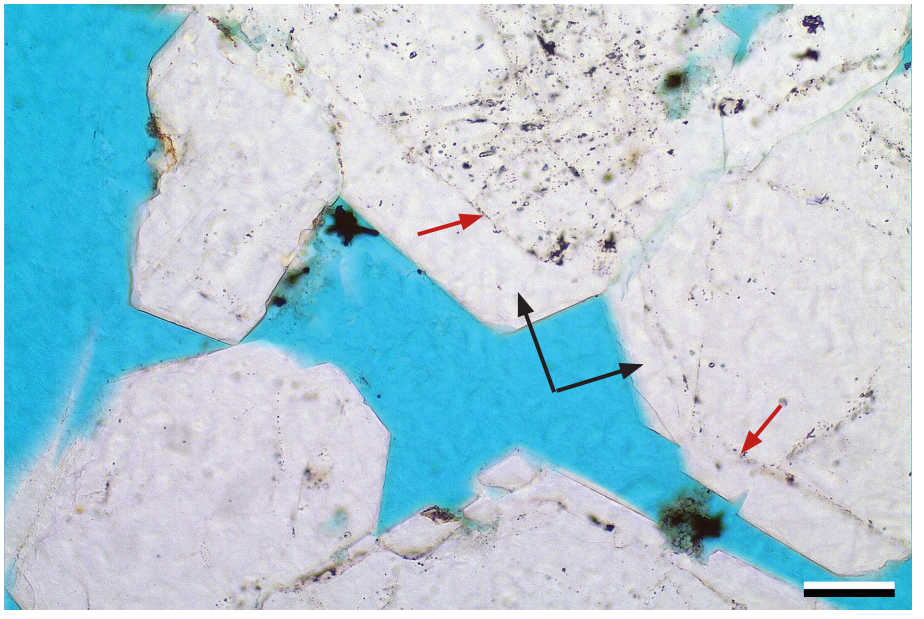
PPL | XPL, Scale bar = 0.05 mm



Silurian Tuscarora Sandstone, Lebanon Co., Pennsylvania

A detrital quartz grain with subparallel lines of submicron- to micron-sized bubbles (vacuoles). These features, a product of intense strain deformation, are termed Boehm lamellae. When identifying these structures in thin section, it is important to distinguish between reworked detrital strained grains and those that were strained *in situ*. Also, one must be careful not to confuse them with twinned feldspars.

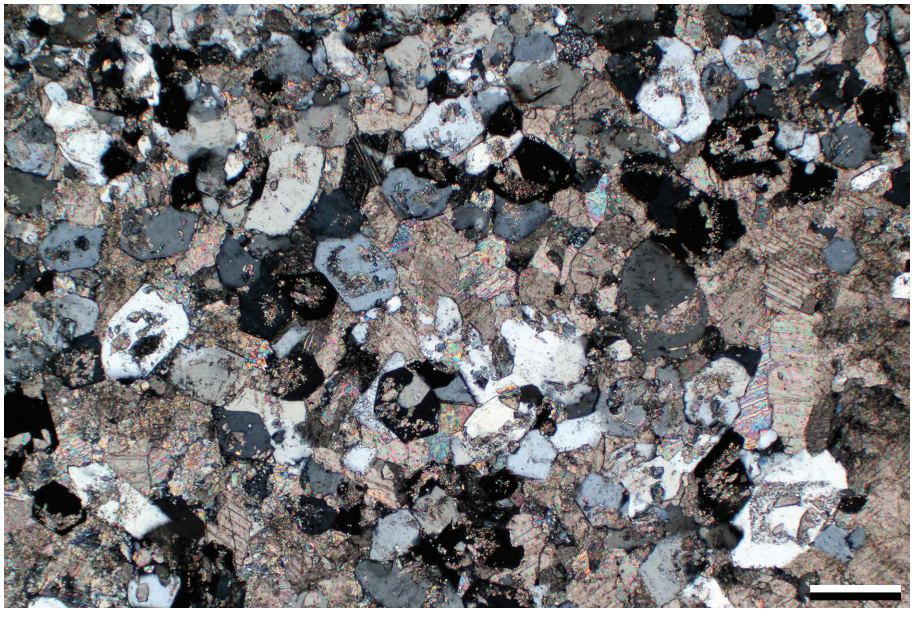
PPL | XPL, Scale bar = 0.10 mm



Jurassic Fulmar Fm., United Kingdom sector, North Sea †

Quartz grains that display well-formed, syntaxial quartz overgrowths extending into pore space (examples shown by black arrows). Some of the grains display a marked grain boundary, whilst others do not. The distinction between the grain and the overgrowth relies on the presence of thin clay or iron oxide coatings or a line of inclusions along the grain-overgrowth contact, such as in this case (red arrows).

PPL, BDI, Scale bar = 0.07 mm



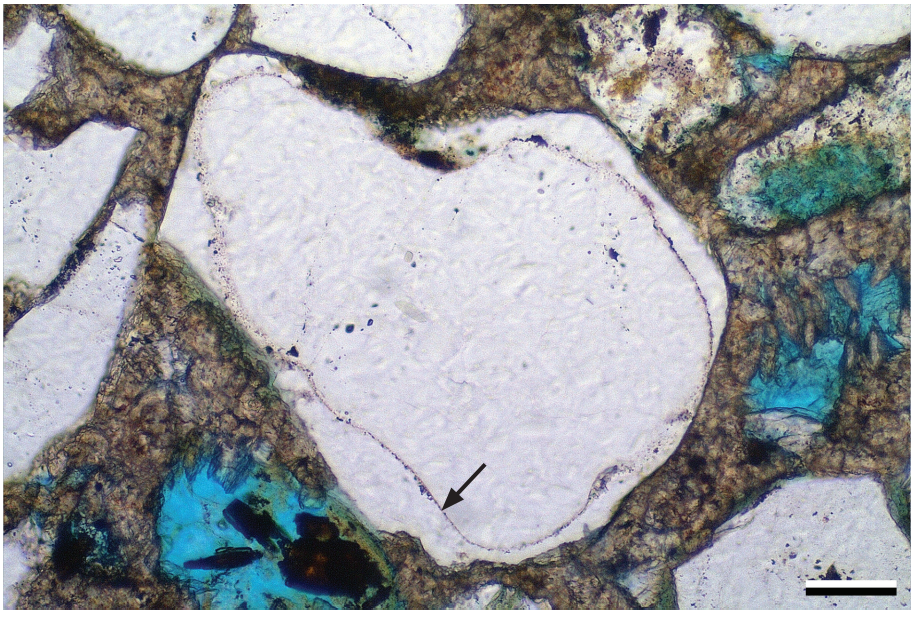
Up. Devonian Cairn Fm., Jasper area, Alberta, Canada

Euhedral quartz overgrowths on very fine sand grains in a dolomitized reefal limestone. Such replacement crystals can be a major source of quartz grains with reworked (second-cycle or inherited) overgrowths after they are released from their carbonate host rock during weathering. Transport and abrasion during reworking yields rounded overgrowths that are the main diagnostic feature of second-cycle quartz (quartz grains from a sedimentary source).

XPL, Scale bar = 0.26 mm

Jurassic Tilje Fm., Norwegian sector, North Sea †

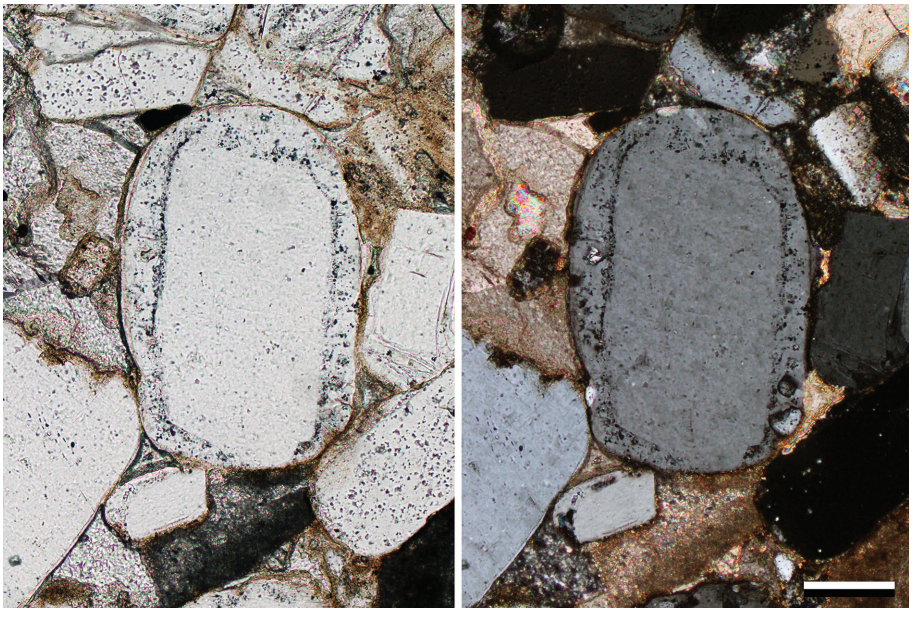
A quartz grain with an inherited quartz overgrowth. The overgrowth is distinguished from the grain by a line of vacuoles (indicated by black arrow). The irregular (abraded?) margin of the overgrowth is an indicator of reworking but is not conclusive. The lack of overgrowths on the vast majority of the other detrital quartz grains in this sample, however, supports the conclusion that these overgrowths were formed in a precursor deposit. The main cement in this sample is early-formed siderite.



PPL, KFS, BDI, Scale bar = 0.07 mm

Paleogene Vieja Gp., Presidio Co., Texas

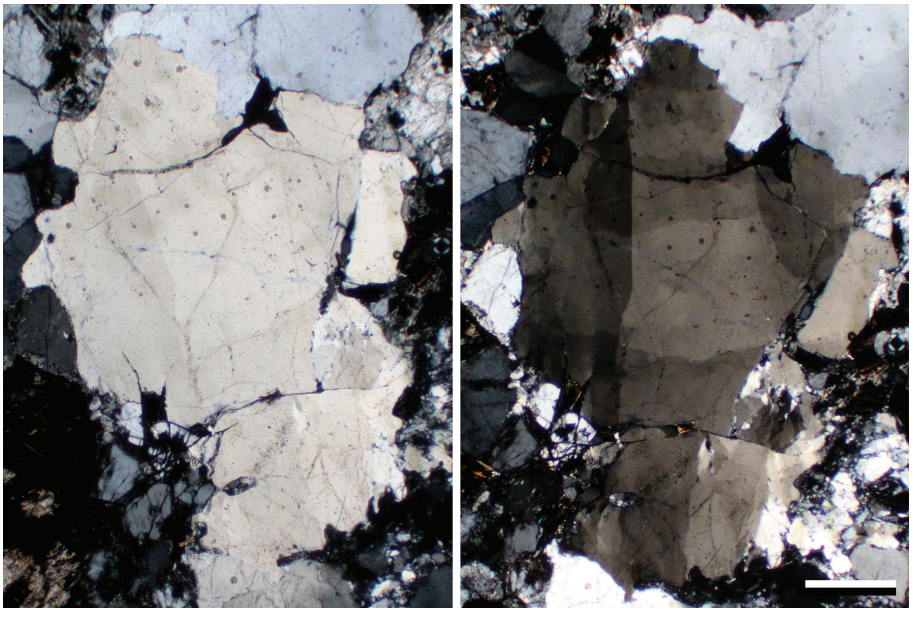
A detrital grain with authigenic quartz overgrowths that have been rounded during a second cycle of erosion followed by deposition. Recycled or second-cycle quartz grains can be difficult to recognize if quartz overgrowths are not present. The original grain is largely inclusion free whereas the surrounding, rounded overgrowth is rich in inclusions (carbonate, clays and iron oxides).



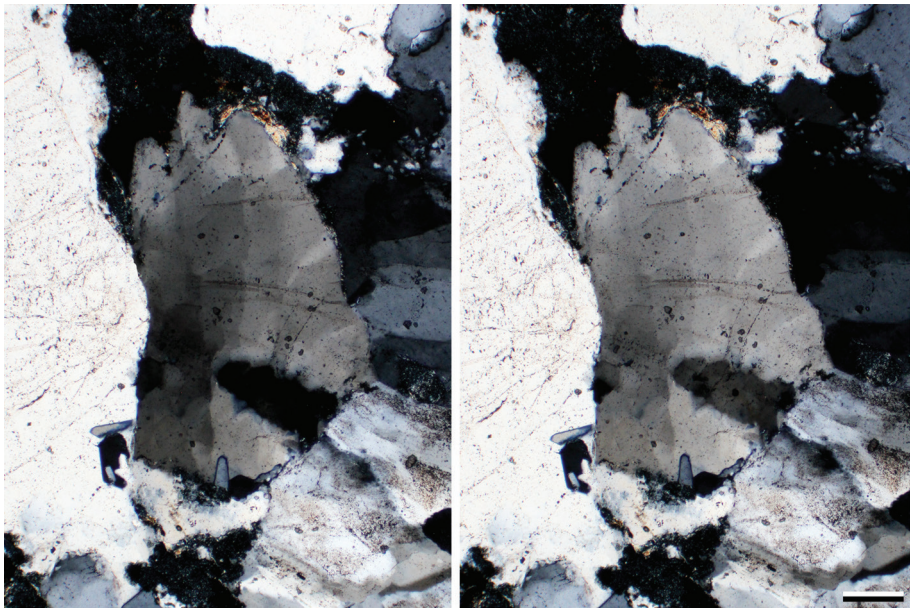
PPL | XPL, Scale bar = 0.05 mm

Up. Triassic – Lo. Jurassic New Haven Arkose, New Haven Co., Connecticut

This semicomposite quartz grain exhibits undulatory extinction. Grains like this are composed of numerous quartz crystals that have closely aligned optic c-axes. Such quartz grains are common in metamorphic, plutonic and hydrothermal environments.



XPL | XPL, Scale bar = 0.64 mm

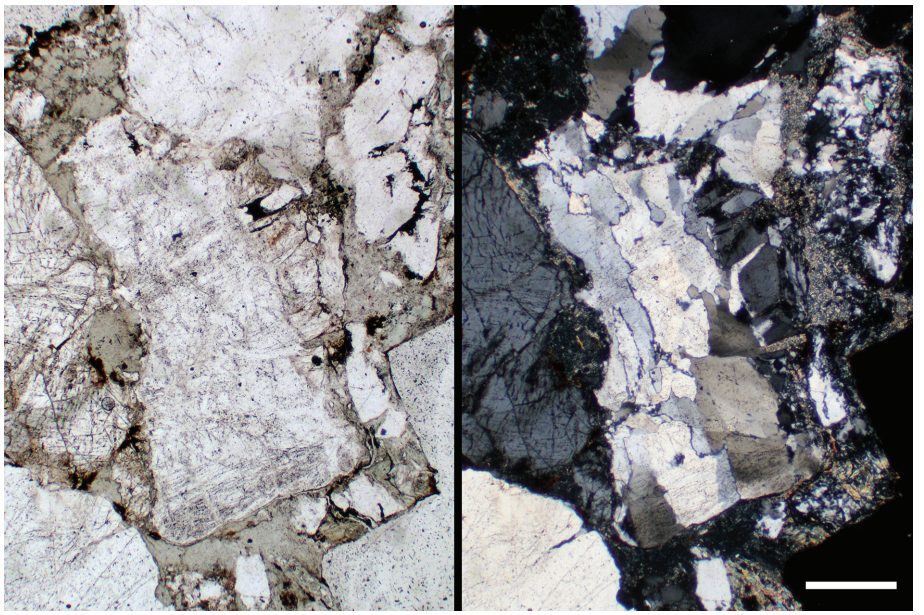


Up. Triassic – Lo. Jurassic New Haven Arkose, New Haven Co., Connecticut

A semicomposite quartz grain, with slightly undulatory extinction, in a lithic arenite. Note the changes between the two images that show sweeping extinction with less than five degrees of stage rotation.

XPL | XPL, Scale bar = 0.17 mm

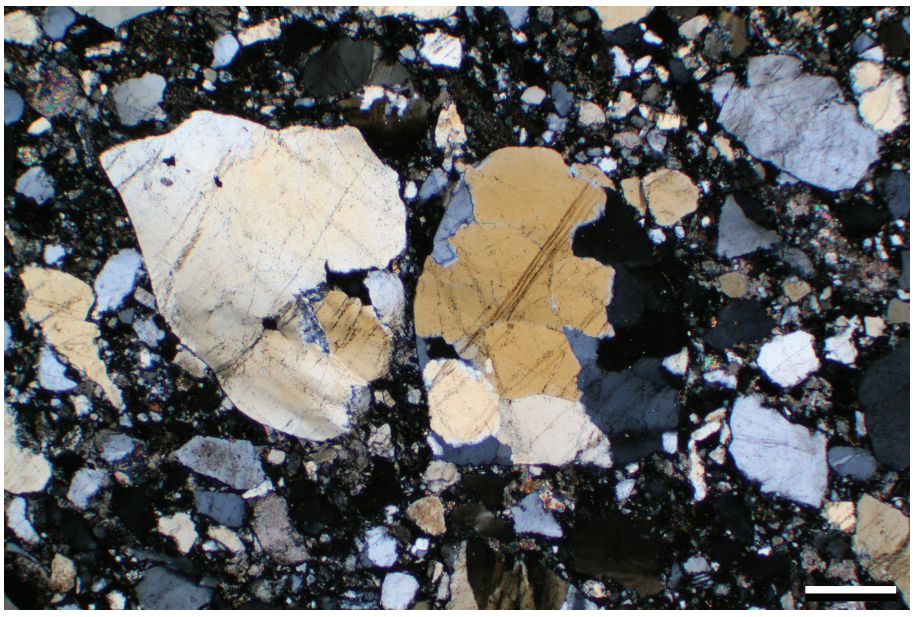
POLYCRYSTALLINE



Up. Triassic – Lo. Jurassic New Haven Arkose, New Haven Co., Connecticut

A polycrystalline quartz grain with strong elongation or stretching of the quartz crystals. This may indicate that the origin of this grain is from a metamorphic source terrane. This rock would be classified as a lithic sandstone on the basis of the abundance of rock fragments (lithic clasts). Polycrystalline quartz grains, however, are grouped differently in various classifications—some assign them to lithic fragments and others to quartz grains. Such differences reflect, in part, whether one is more interested in accurate description of composition or the determination of provenance.

PPL | XPL, Scale bar = 0.64 mm



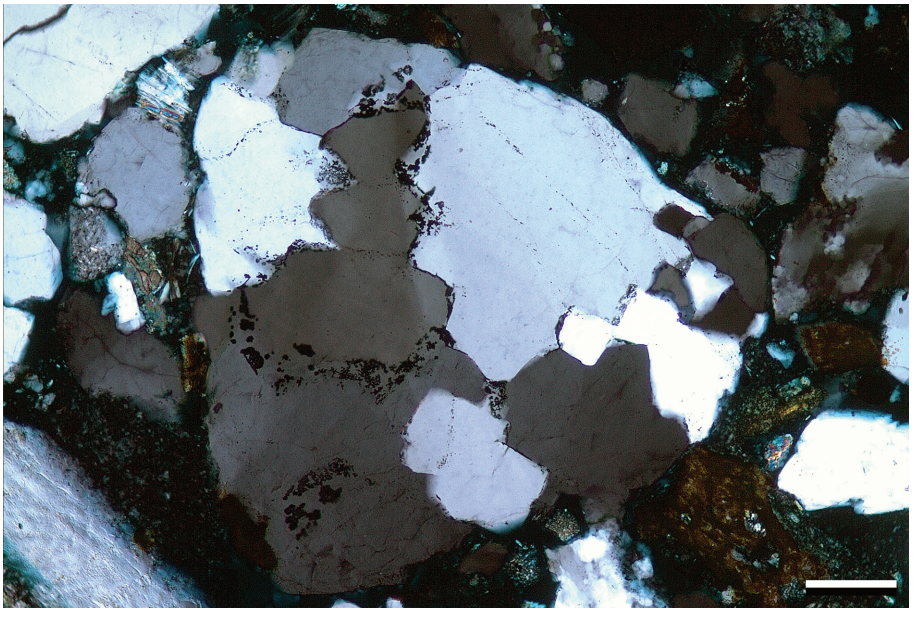
Mid.–Up. Ordovician Martinsburg Fm., Berks Co., Pennsylvania

Polycrystalline (also known as composite) quartz grains in a poorly sorted sandstone. The large size of the individual crystals in the grains may indicate that the origin of the grains is from an igneous or high-grade metamorphic source terrane.

XPL, Scale bar = 0.51 mm

Paleocene Tang Fm., Møre Basin, Norwegian Sea †

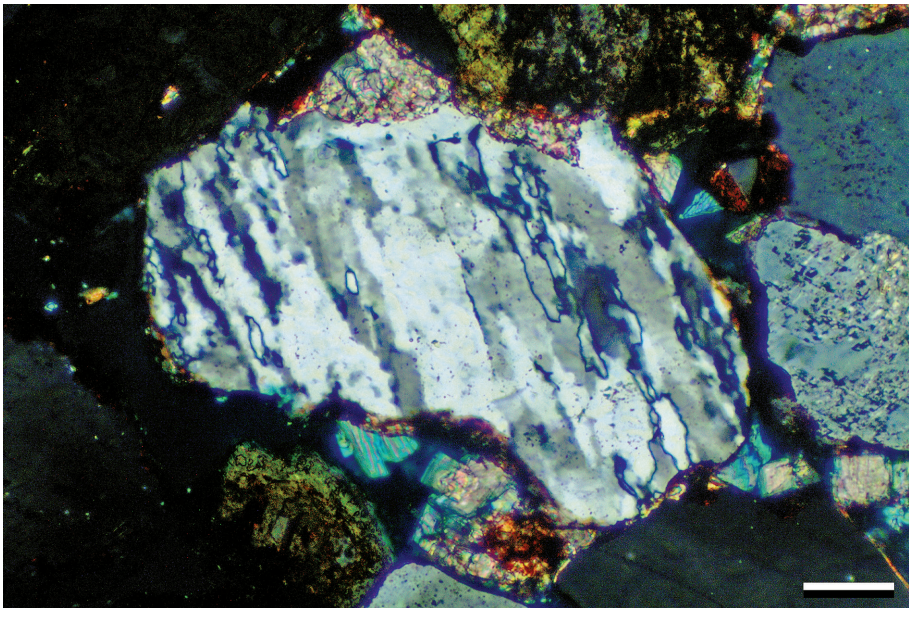
A polycrystalline quartz grain that neither displays sutured internal crystal/boundaries nor truly polygonal boundaries. This would support an origin from weakly metamorphosed sandstone or quartzite.



XPL, BDI, Scale bar = 0.12 mm

Triassic Sherwood Sandstone Gp., Co. Antrim, Northern Ireland, U.K. †

A polycrystalline quartz grain of metamorphic origin. The grain has sutured internal boundaries between composite crystals and a preferential alignment of the constituent crystals. In addition, crystal boundaries are diffuse.



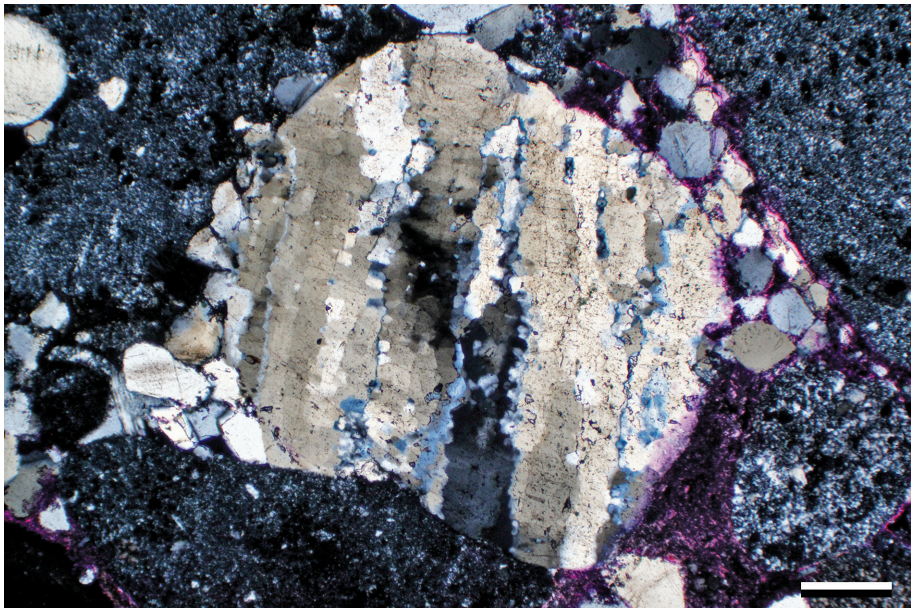
XPL, AFeS, KFS, BDI, Scale bar = 0.07 mm

Miocene Topanga Fm., Ventura Co., California

A rounded polycrystalline quartz grain in a lithic arenite. The elongation of the quartz crystals in the grain indicates that this grain probably formed in a metamorphic terrane. High-density lattice dislocations in quartz produce polycrystallinity and are indicative of metamorphic environments (Basu, 1985).



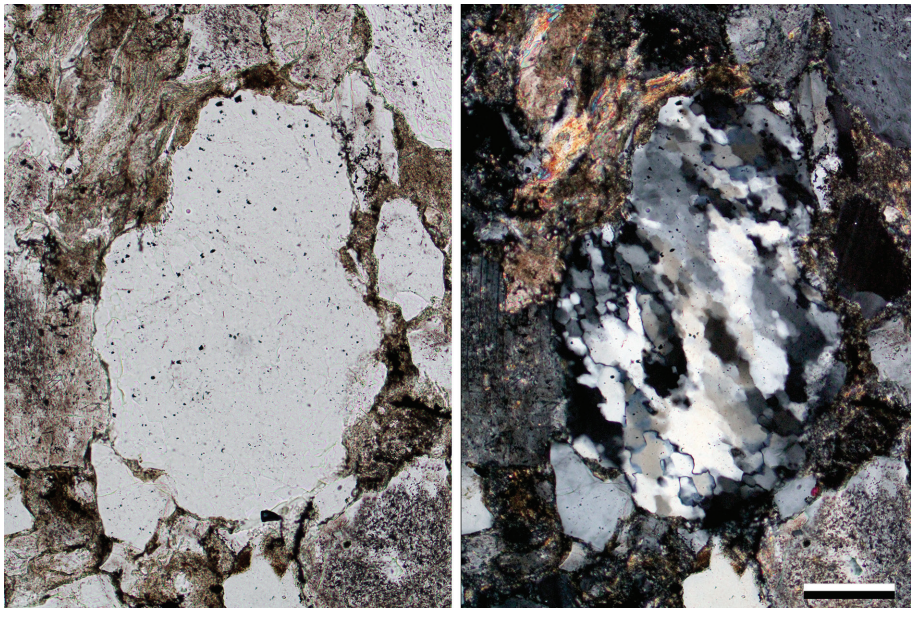
XPL, Scale bar = 0.26 mm



Jurassic Morrison Fm., Moffat Co., Colorado

A polycrystalline quartz grain (center) surrounded by chert clasts. Based on the strong elongation of the quartz crystals, this was most likely sourced from a metamorphic terrane. Surrounding the stretched polycrystalline quartz grains are several large chert clasts that have a dark gray birefringence and speckled appearance related to the microcrystalline character of chert. These indicate that sedimentary rocks were also present in the source area. Numerous silt-sized monocrystalline quartz grains also are present in the interstices between the larger grains.

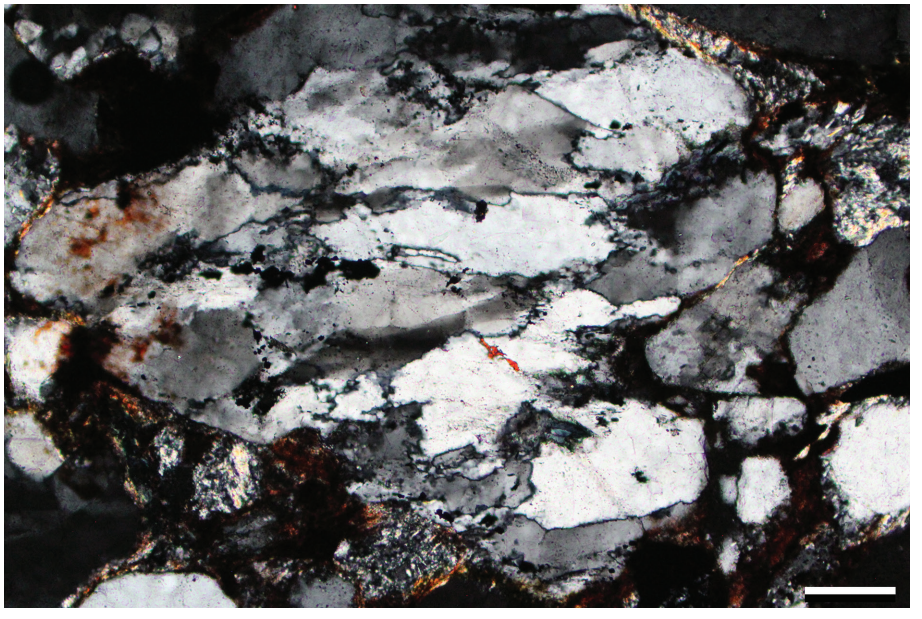
XPL, RDI, Scale bar = 0.26 mm



Miocene Topanga Fm., Ventura Co., California

A polycrystalline quartz grain in a feldspathic sandstone. As in the previous photomicrograph, there is strong elongation to the quartz crystals in the grain suggesting a high-grade metamorphic origin for the grain. This sample also shows, especially in plane-polarized light, how feldspar can be sometimes be distinguished from quartz simply based on its tendency to be more “dusty”.

PPL | XPL, Scale bar = 0.12 mm



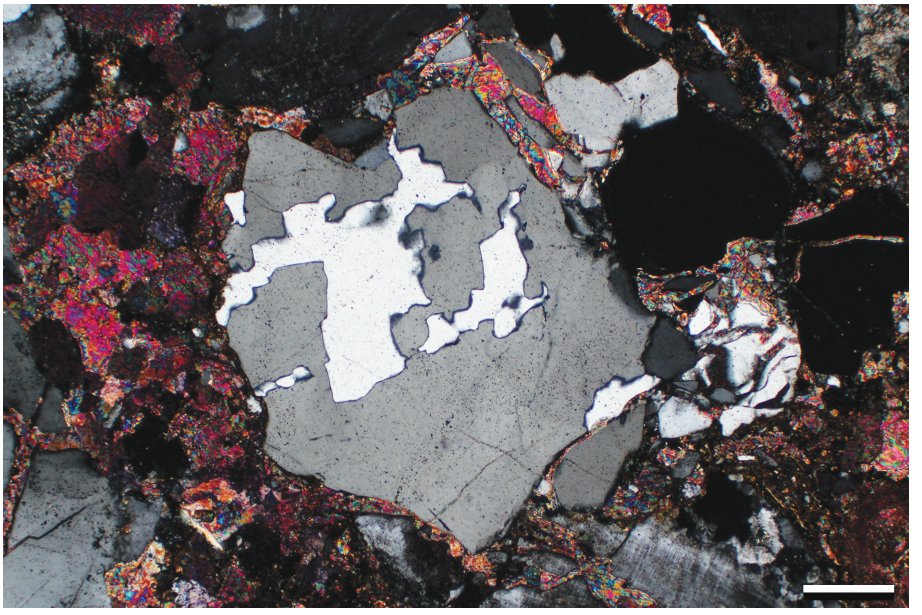
Up. Silurian Bloomsburg Fm., Warren Co., New Jersey

A polycrystalline quartz grain with strong elongation and sutured crystal boundaries. The probable origin of this grain is in a high-grade metamorphic terrane.

XPL, Scale bar = 0.10 mm

Mid. Permian Wegener Halvø Fm., Karstryggen area, East Greenland

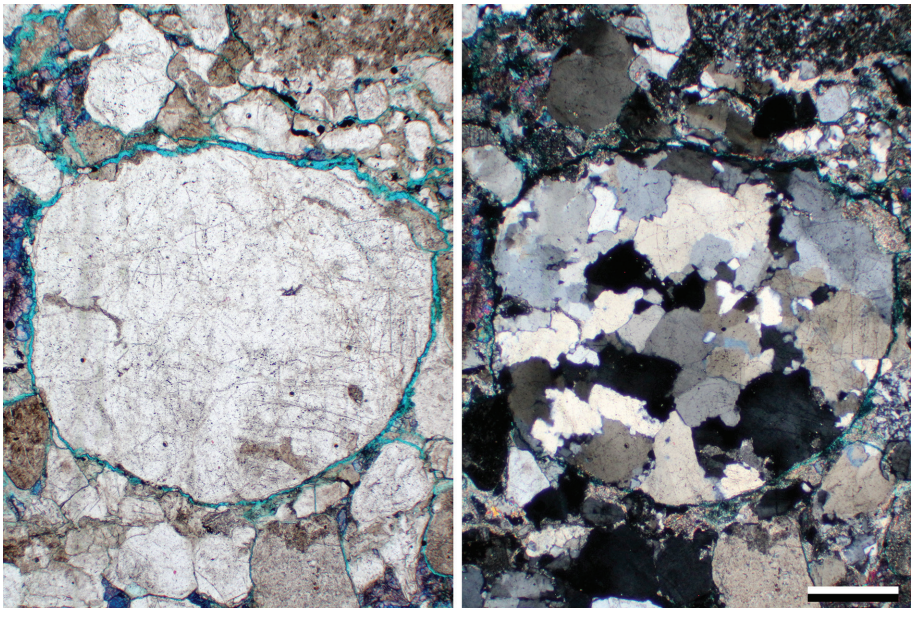
Polycrystalline or composite quartz in a feldspathic arenite. The origin of this grain is problematic; it may be metamorphic, but plutonic or hydrothermal sources are equally likely. The inability to assign a unambiguous source terrane is common if one only has quartz indicators. The calcite cements in this sample are stained and therefore appear to be red even in cross-polarized light.



XPL, AFeS, Scale bar = 0.26 mm

Up. Permian Schuchert Dal Fm., Jameson Land, East Greenland

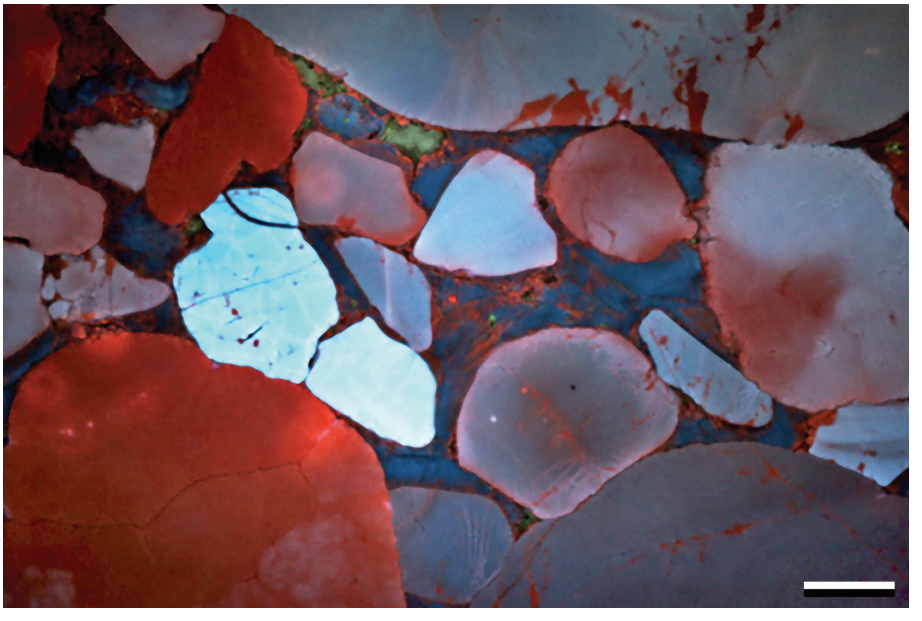
A well-rounded polycrystalline quartz granule. The blue-dyed fracture porosity surrounding the grain may have been produced by pressure release during uplift and unloading of overburden.



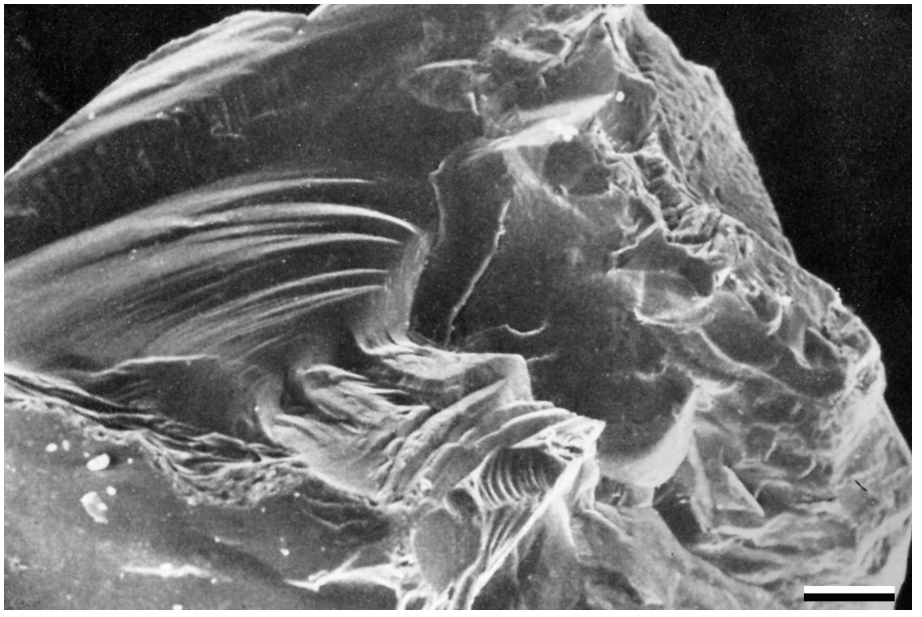
PPL | XPL, AFeS, BDI, Scale bar = 0.51 mm

Precambrian Neihart Quartzite, Little Belt Mountains, Cascade Co., Montana

A live-color cathodoluminescent SEM photomicrograph of a quartz arenite. Blue grains have the highest formation temperatures, suggesting derivation from plutonic or high-grade metamorphic sources (e.g., Augustsson and Reker, 2012). Reddish grains are likely from lower-grade metamorphic source rocks (greenschist). Reddish blotches and healed fractures in the grains may reflect lower temperature, hydrothermal overprint. Low-temperature quartz cements (deep blue) have a late (hotter) overprint (reddish) along grain boundaries and residual pore spaces in overgrowths.



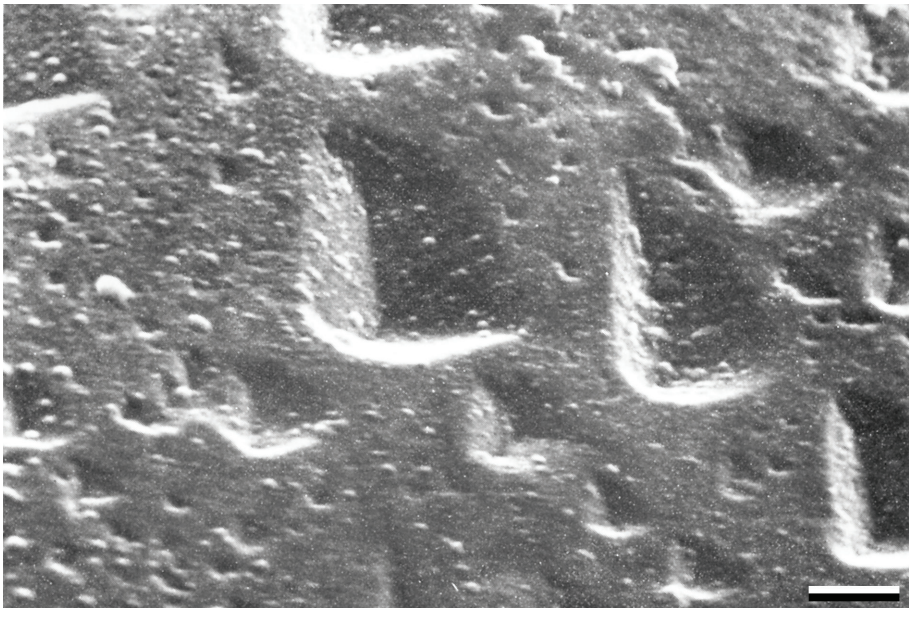
CCL, Scale bar = 100 μm



Holocene grus on Mesozoic granite, California

Quartz grains are commonly studied using scanning electron microscopy, either to obtain more three-dimensional images of grain shape or to examine surface features. Quartz grains are normally recognizable in the scanning electron microscope on the basis of their conchoidal fracture and lack of cleavage. Photo by David E. Hoyt.

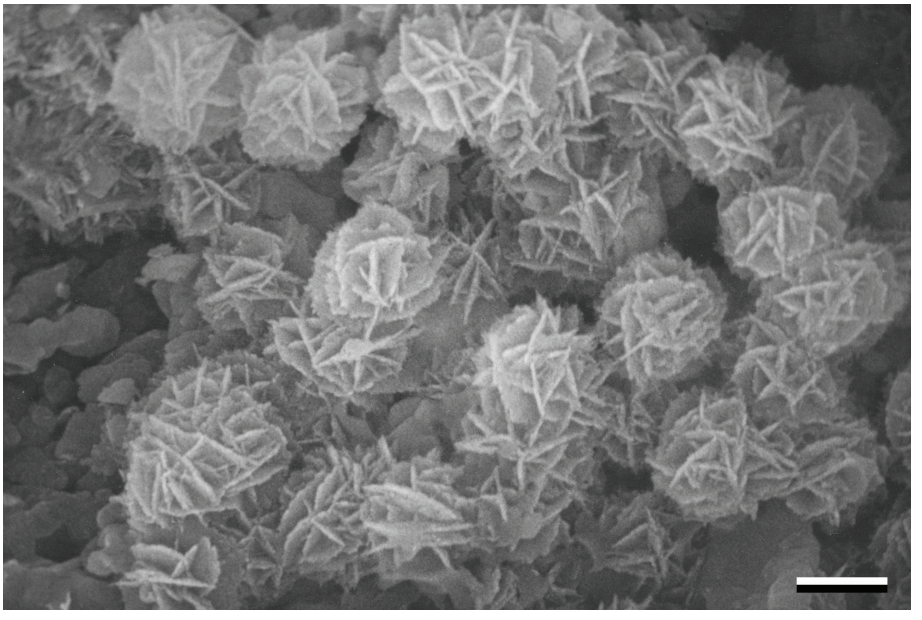
SEM, Scale bar = 50 μm



Quaternary grus on Precambrian Packsaddle Schist, Texas

Quartz grains have a wide variety of surface textures when examined in SEM. V-shaped indentations are seen in this example and are probably formed by chemical dissolution. Various structures have been interpreted as being indicative of particular source rocks, transport processes, depositional environments or diagenetic settings (see Krinsley and Doornkamp, 2011). Photo by David E. Hoyt.

SEM, Scale bar = 0.07 μm



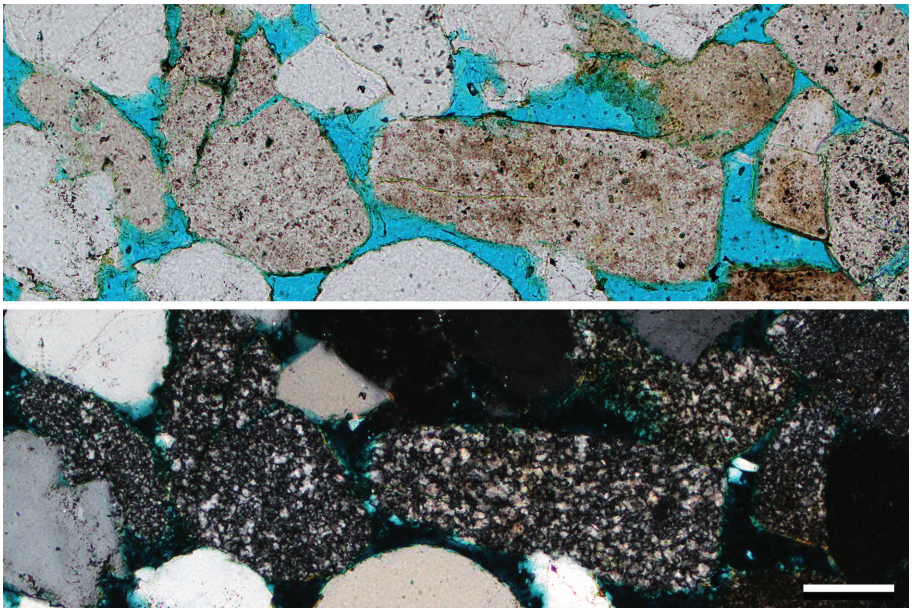
Up. Cretaceous Craie Grise, Limburg, The Netherlands

One of the polymorphs of quartz is cristobalite (opal-CT). In this photomicrograph, the cristobalite occurs as spherulites that are commonly termed lepispheres. The alteration of biogenic opal to quartz generally goes through the intermediate stage of cristobalite. The transitions between these three phases are largely temperature controlled, although time and associated lithologies also play a large role. In general, the presence of clay minerals retards the transformation; $CaCO_3$ accelerates it (e.g., Isaacs, 1982). The opal-CT pictured here forms part of larger replacive nodules in a sandy limestone.

SEM, Scale bar = 2.4 μm

Lo. Permian Park City Fm., middle Franson Mbr., Daggett Co., Utah

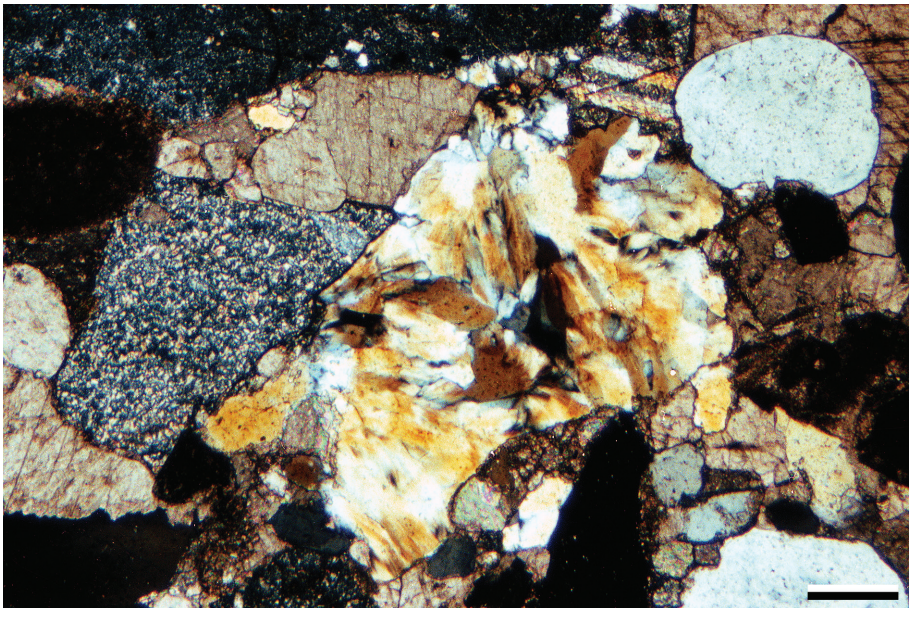
Detrital chert clasts in a quartz arenite. Chert is microcrystalline quartz, and it typically contains abundant inclusions. These are mostly water-filled, but inclusions also can be organics, iron oxides, iron sulfides, carbonates and other insolubles that make the grains look cloudy and brownish in plane light. In cross-polarized light, chert appears to be finely speckled due to its microcrystallinity.



PPL / XPL, BDI, Scale bar = 0.10 mm

Mid. Jurassic Curtis Fm., Utah

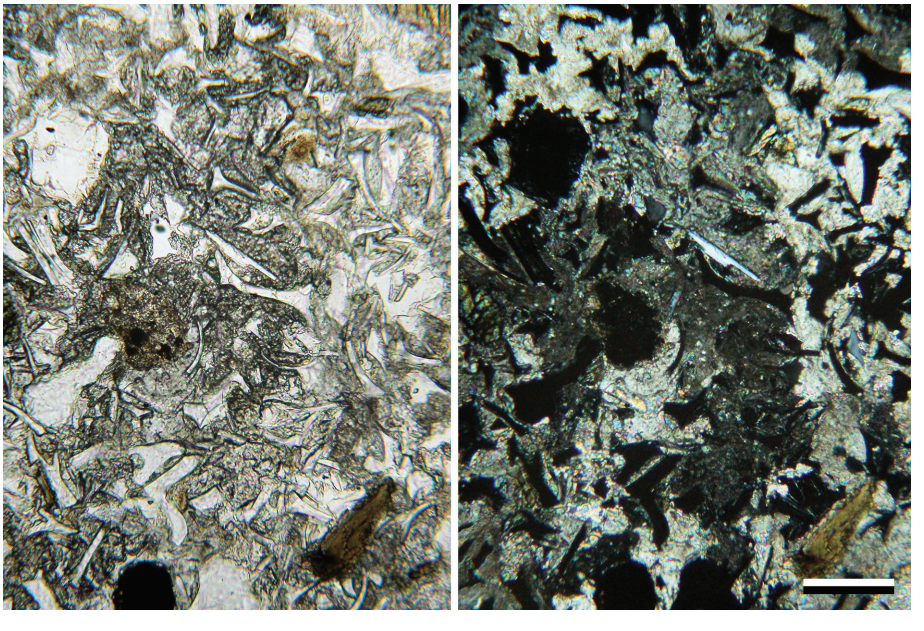
Fragments of detrital chert (left) and detrital chalcedony (right). Chalcedony is a microscopically fibrous form of quartz that is common as void fillings or replacement fabrics in sedimentary rocks. Here, the chalcedony is surrounded by carbonate (dolomite) cement crystals. As with cherts, a wide variety of chalcedonic textures exist and chalcedony occurs in length-fast and length-slow forms (those can be distinguished using a gypsum or other sensitive tint plate).



XPL, Scale bar = 0.03 mm

Oligocene – Miocene Horse Spring Fm., Clark Co., Nevada

Shards of volcanic glass in a calcite-cemented tuffaceous sandstone. The glass shards (volcanic glass) are isotropic (black under cross-polarized light). They are commonly dissolved or are replaced by quartz or other minerals during diagenesis, in part because, as hydrophilic particles, they are especially susceptible to alteration. Because shards are isotropic, it can be difficult to distinguish dissolved shards (shard-shaped pores) from intact ones.



PPL | XPL, Scale bar = 0.15 mm

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Facing Page: Top – Thin section view of Carlsbad-twinned orthoclase feldspar, Mid. Ordovician Newtown Gneiss, New Haven Co., Connecticut (XPL). Bottom – Twinned orthoclase feldspar crystal, Otero Co., New Mexico. Photo from Mineral Museum, New Mexico Bureau of Geology and Mineral Resources.