Quartz crystals (field diamonds) in Tennessee

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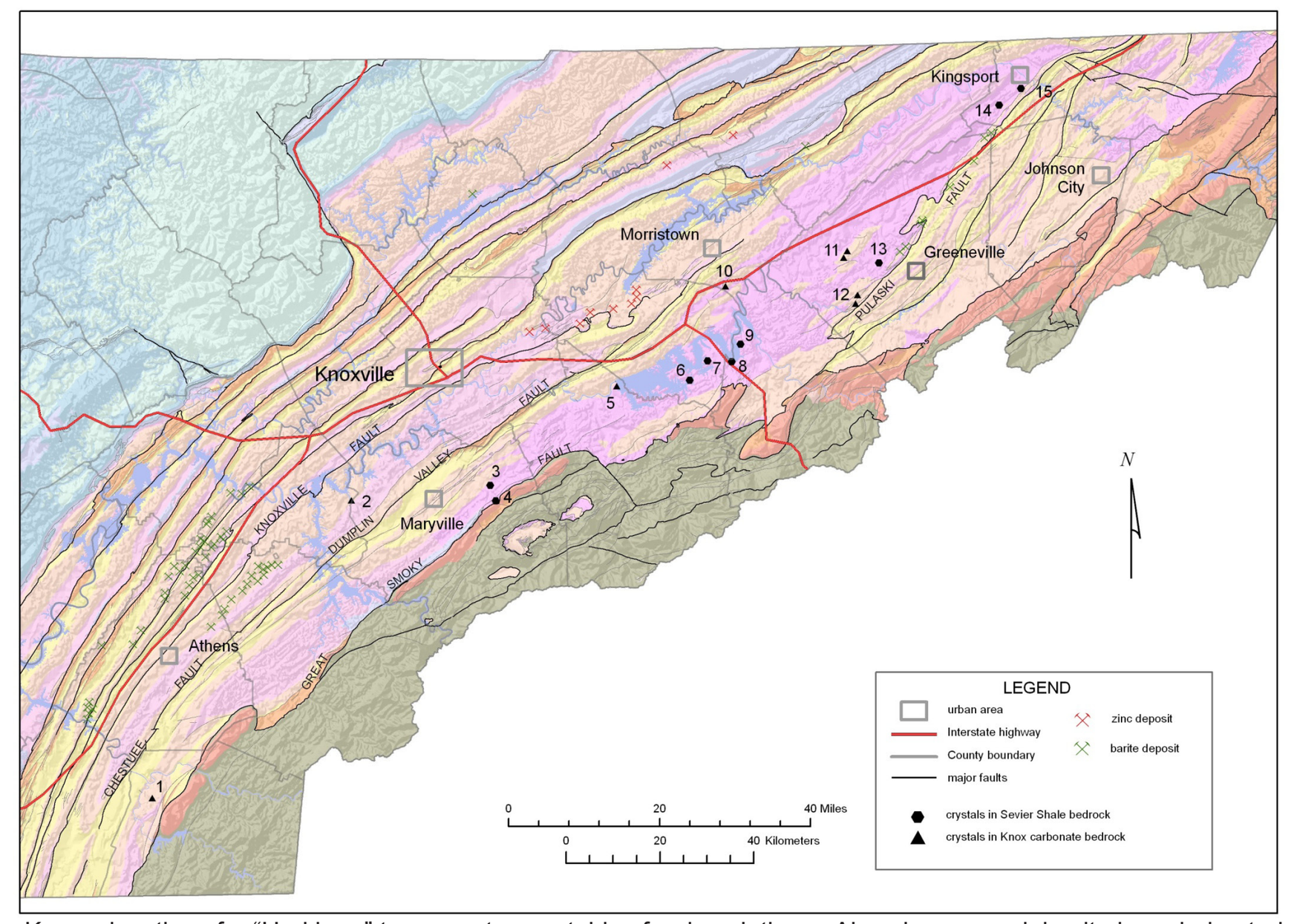
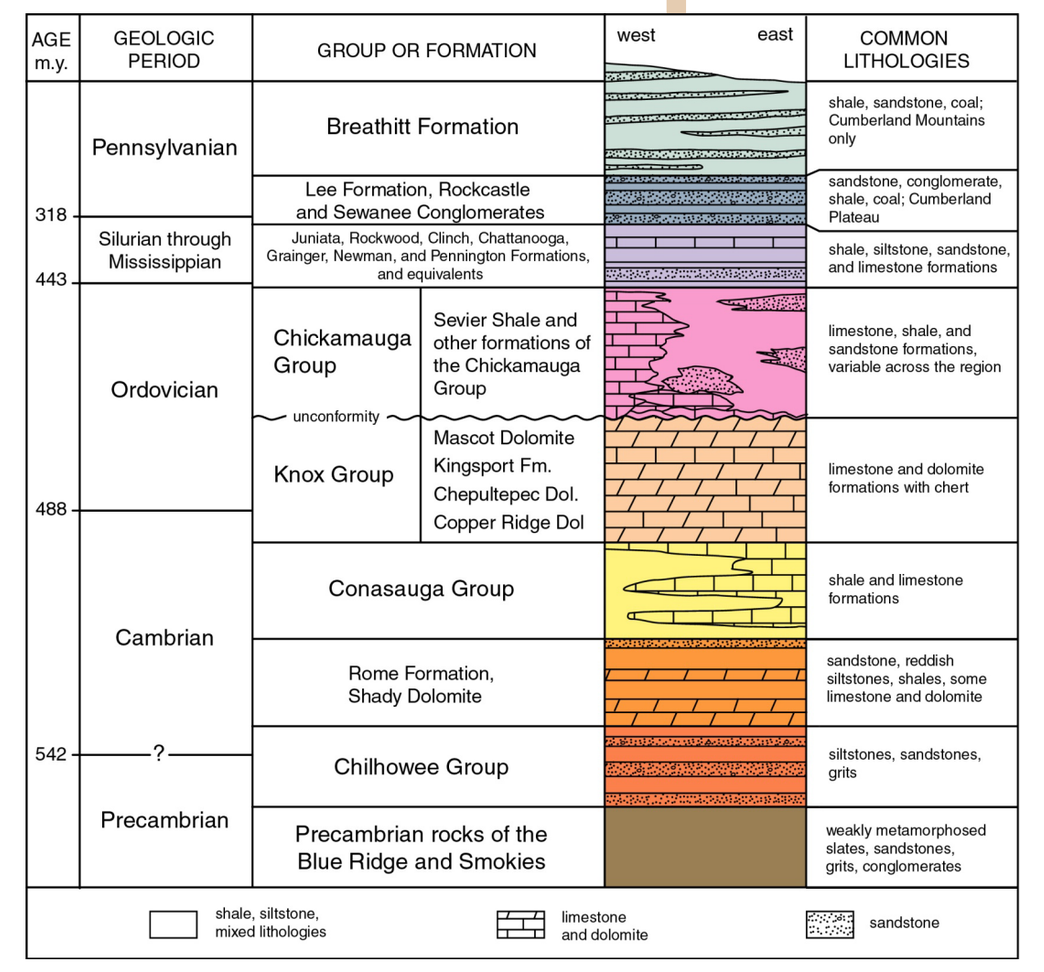
Abstract

"Field diamond" or "Herkimer" type quartz crystals are found in many places throughout the world. In Tennessee they occur in two geologic environments and their overlying residual soils: firstly, scattered locations associated with breccias in the Lower Ordovician Knox Group dolomites, and secondly, within zones of folding and faulting in the Lower Middle Ordovician Sevier Shales. Evidence for the presence of hydrocarbons can be found in both environments. Their distribution may reflect geochemical zoning that also controls the distribution of zinc and barite deposits.

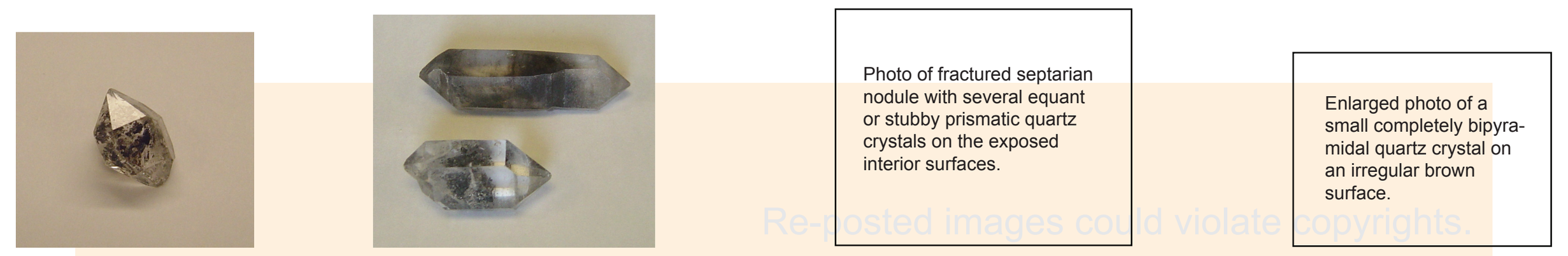
The greatest variety of crystal habits is found in the Knox breccia environment, where crystals often display morphology suggesting multiple stages of deposition under changing conditions. Breakage and regrowth observed in some specimens suggests tectonic activity. There is a consistent morphologic change from earlier more prismatic crystals to later bipyramidal overgrowths in the Knox crystals that points to a change in environmental conditions, perhaps an increase in temperature. Sevier Shale crystals tend to be simpler, usually bipyramidal in form. Crystals from both sources may also show evidence of later modification by processes of transport and erosion, and possibly by the action of moving groundwater. These crystals could eventually provide insight into the conditions surrounding the Alleghanian Orogeny, as well as factors that control open-space quartz deposition – whether silica takes the form of drusy quartz, agate, or field diamond type crystals.



Known locations for "Herkimer" type quartz crystals, see tables for descriptions. Also shown are dolomite breccia-hosted barite and zinc deposits, and major faults with shaded relief overlay. Base map and faults from the Geologic Map of Tennessee, 1:250,000.



Stratigraphic units of the Valley and Ridge Province of East Tennessee. Quartz crystals occur in open space within collapse breccia bodies in dolomites of the Knox Group, and in vugs and cavities in the Sevier Shale created by deformation associated with the Alleghanian Orogeny.



"Pakistan"

"Tibet"

Photo of fractured septarian nodule with several equant or stubby prismatic quartz crystals on the exposed interior surfaces.

Jurassic limestones, French Alps

Enlarged photo of a small completely bipyramidal quartz crystal on an irregular brown surface.

Devonian Huron Shale, Ohio

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Similar crystals are found throughout the world

Double terminated crystals are found world wide in a variety of geologic environments including cracks in septarian nodules from the French Alps (http://www.quartzpage.de/dia_text.html), and septarian nodules along the Huron River in northern Ohio (late Devonian age Huron Shale) (http://www.vasichkominerals.com/Lamereaux1.html). Black carbonaceous material is commonly present as inclusions or otherwise associated with these occurrences. Crystals from many world locations including "Tibet", Argentina", "Pakistan" are widely sold without context information. Most famous are the "Herkimer diamonds" from irregular vugs and cavities within undeformed Cambrian dolomites in upstate New York. Many images can be found online, for example http://www.quartzpage.de/her_text.html. The "scepter" morphology is common to a number of these occurrences, as it is in the Tennessee Valley and Ridge.

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Several quartz crystals in a small cavity growing on a drusy quartz lining in dolostone matrix.

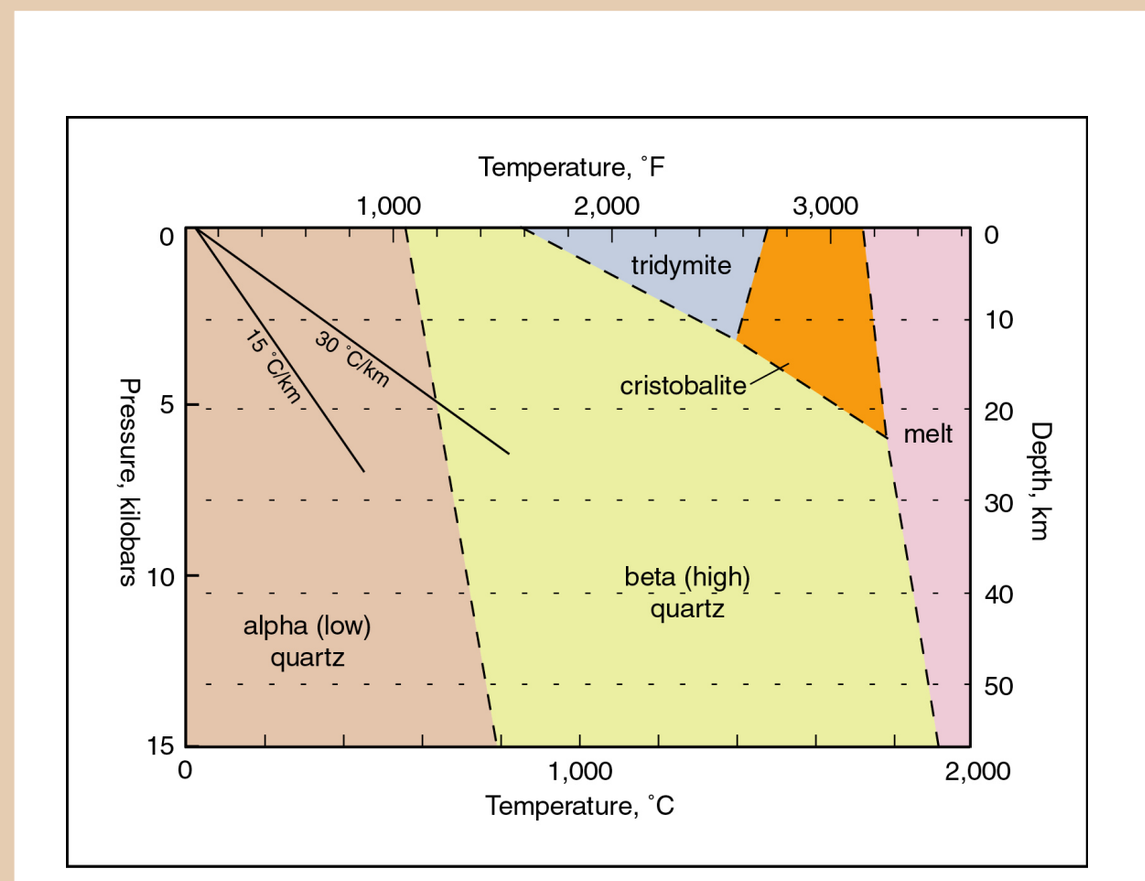
Photo of a stubby prismatic quartz crystal with smaller and druzy crystals, and dull dolomite crystals on grayish yellow dolostone matrix.

A large newly exposed in-situ vug in gray cracked dolostone, with a number of large dusty crystals loose on the bottom.

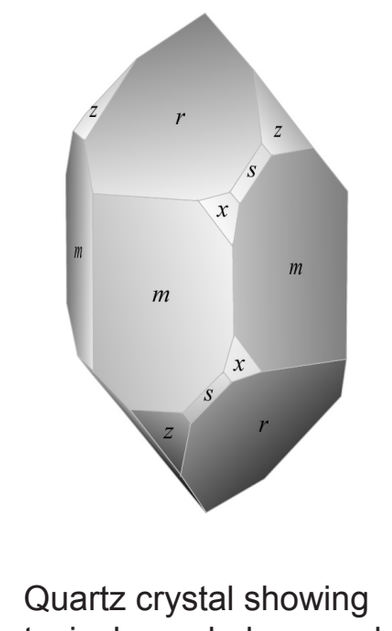
Photograph of a display of large gemmy "Herkimer Diamond" crystals, many of which are clusters, and labeling featuring anthraxolite inclusions.

Four examples of the well-known "Herkimer" quartz crystals from vugs and cavities in the Cambrian dolomites of New York.

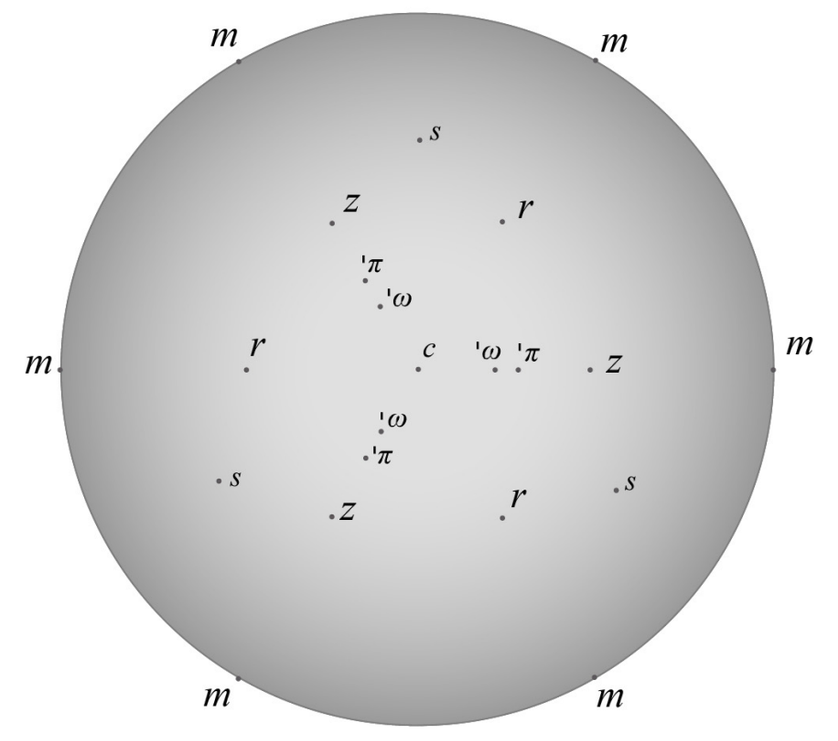
Silica phase diagram and α-quartz crystallography



Phase diagram for anhydrous silica modified from Boyd and England, (1960), with typical geothermal gradient ranges, pressure is shown increasing in the downward direction. High Pressure phases coesite and stishovite are not shown



Quartz crystal showing typical morphology, and stereo plot. "S" and "x" faces allow one to determine the handedness of the crystal. s faces were seen in a few specimens from one locality, and x faces have not yet been observed in these crystals

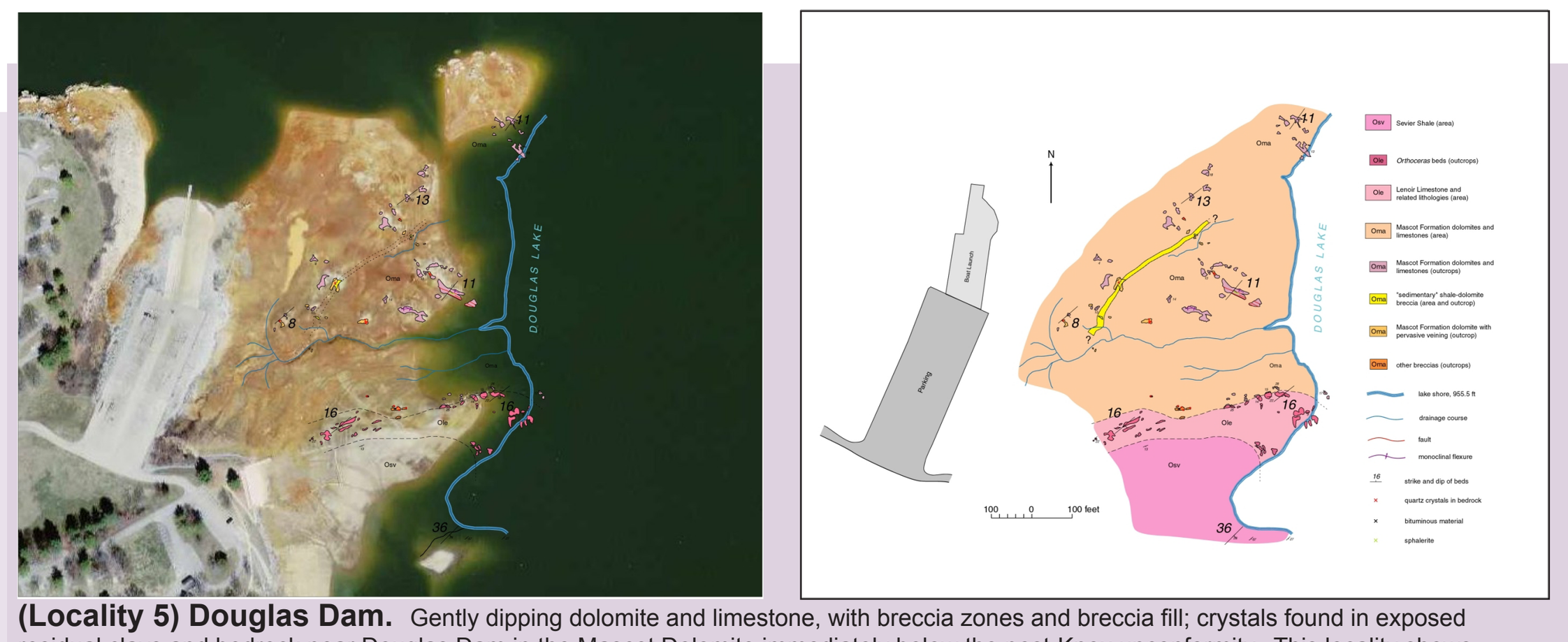


Stereogram. More commonly developed faces are shown with larger font. Also shown are the uncommon 'π and 'ω faces seen on some crystals from the Walland occurrence, here plotted from angle data tabulated by Frondel (1962).

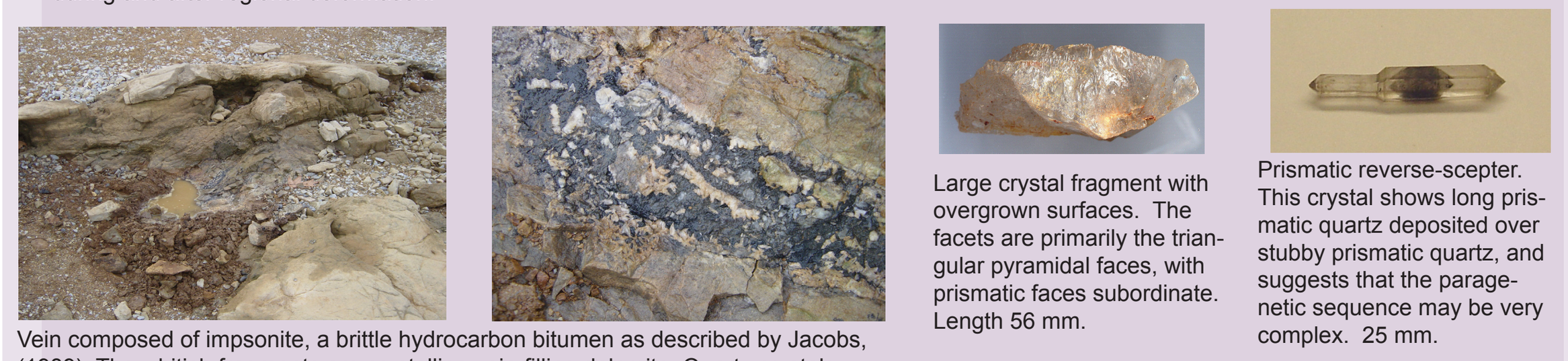
Knox breccia hosted field diamonds

Quartz crystals occurring in and over Knox Group dolomites are the most varied in form. When encountered in situ, they are most commonly seen in fissures and cavities related to the post-Knox unconformity paleokarst system. Here, open spaces existed from that time, through the Alleghanian deformation, and into the present day. Locality numbers in table below keyed to map, left.

Locality	Description	Mapped formation	Source/ Reference
1	Bipyramidal crystal in small vug in rock with 35° dip near Benton, TN.	Upper and Middle Knox Group	Field mapping; Lemiszki and Kohl, 2007.
2	A few crystals in small vugs in gently dipping dolomites exposed in lake shore, Cloyd Creek arm of Ft. Loudon Lake.	Kingsport Formation	Field mapping, 2012
5	Gently dipping dolomite and limestone, with breccia zones and breccia fill; exposed residual clays and bedrock near Douglas Dam.	Mascot Dolomite	Widely known locality discussed in this project
10	Gently dipping dolomite with breccia zones, above mapped fault, excavated area near road.	Longview Formation	Lemiszki, personal. comm. / Oder and Milici, (1965)
11	Two areas in residual clays, northwest limb of Mosheim anticline; breccia zones present nearby.	Chepultepec Formation	Mike Streeter; Web posting / Brokaw et al, (1966)
12	Gently northeast-dipping dolomites, and nearby residuum; breccia present.	upper part of Kingsport Formation	Lemiszki, 2003, mapping



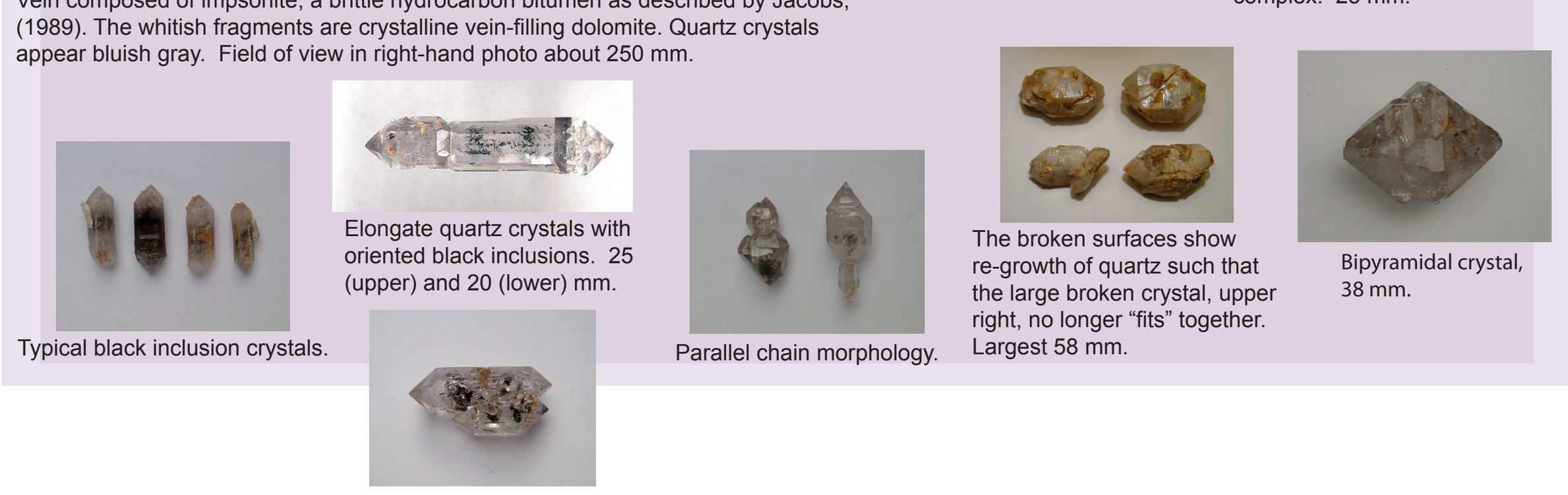
(Locality 5) Douglas Dam. Gently dipping dolomite and limestone, with breccia zones and breccia fill; crystals found in exposed residual clays and bedrock near Douglas Dam in the Mascot Dolomite immediately below the post-Knox unconformity. This locality shows evidence of crystal regrowth after breakage, suggesting that quartz was present before or during the orogenic event, and growth continued during and after regional deformation.



Vein composed of impsonite, a brittle hydrocarbon bitumen as described by Jacobs, (1989). The whitish fragments are crystalline vein-filling dolomite. Quartz crystals appear bluish gray. Field of view in right-hand photo about 250 mm.

Large crystal fragment with overgrown surfaces. The facets are primarily the triangular pyramidal faces, with prismatic faces subordinate. Length 56 mm.

Prismatic reverse-scepter. This crystal shows long prismatic quartz deposited over stubby prismatic quartz, and suggests that the paragenetic sequence may be very complex. 25 mm.



Typical black inclusion crystals.

Elongate quartz crystals with oriented black inclusions. 25 (upper) and 20 (lower) mm.

Parallel chain morphology.

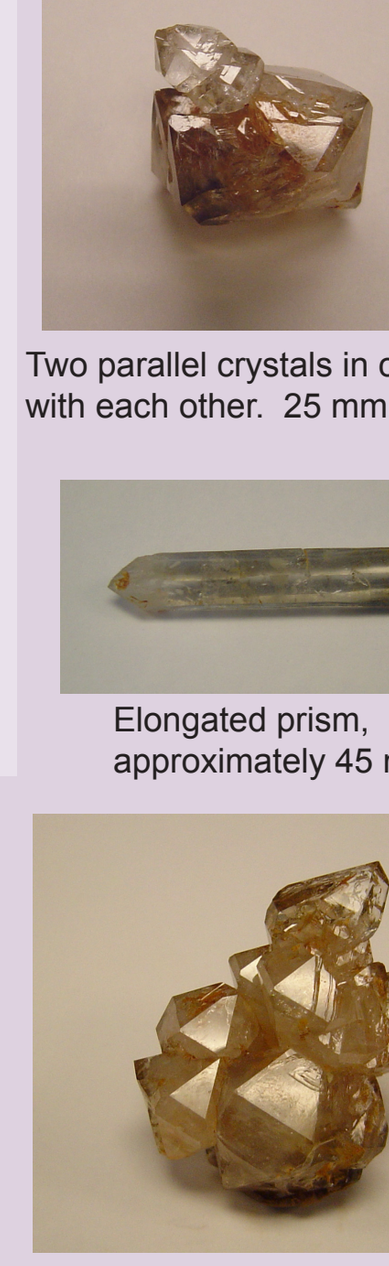
The broken surfaces show re-growth of quartz such that the large crystal, upper right, no longer "fits" together. Largest 58 mm.

Bipyramidal crystal, 38 mm.

Calcite-filled vugs or other growth media may explain some of the features we see in these crystals. These are exposed in the same beds as those near Douglas Dam, a few miles northeast along strike. Field of view 400 mm.

Thin almost needle-like quartz crystals and two larger ones in breccia vugs in fine-grained Knox dolomites. Field of view about 150 mm across.

(Locality 10), near I-81 Exit 8. Breccia zones and residuum in gently dipping dolomite; Knox Group Kingsport and Longview Formations above mapped fault, in excavated residuum and bedrock, Jefferson County.



Two parallel crystals in contact with each other. 25 mm.

Elongated prism, approximately 45 mm.

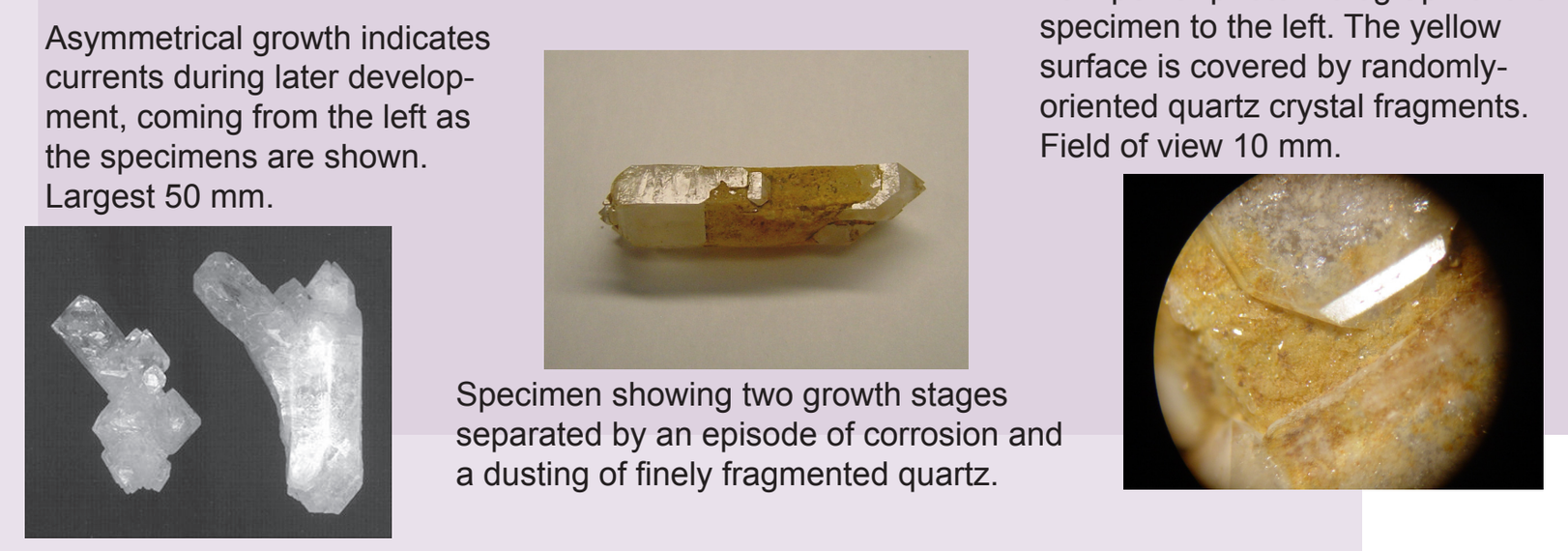
Complex multiple bipyramidal specimen. The separate sections were only weakly connected when found. 50 mm.

Examples of the variety of forms from this area.

Scepter growth, where prismatic quartz is followed by bipyramidal quartz. 30 mm.

Chain-crystal growth.

(Locality 12) Near the top of the Kingsport Formation (middle part of the Knox) in Greene County shows a great variety of morphologies. Most crystals are found in residuum but outcrops of dolomite bedrock are present. The locality has become picked-over since being listed on the Internet as a geocache site.

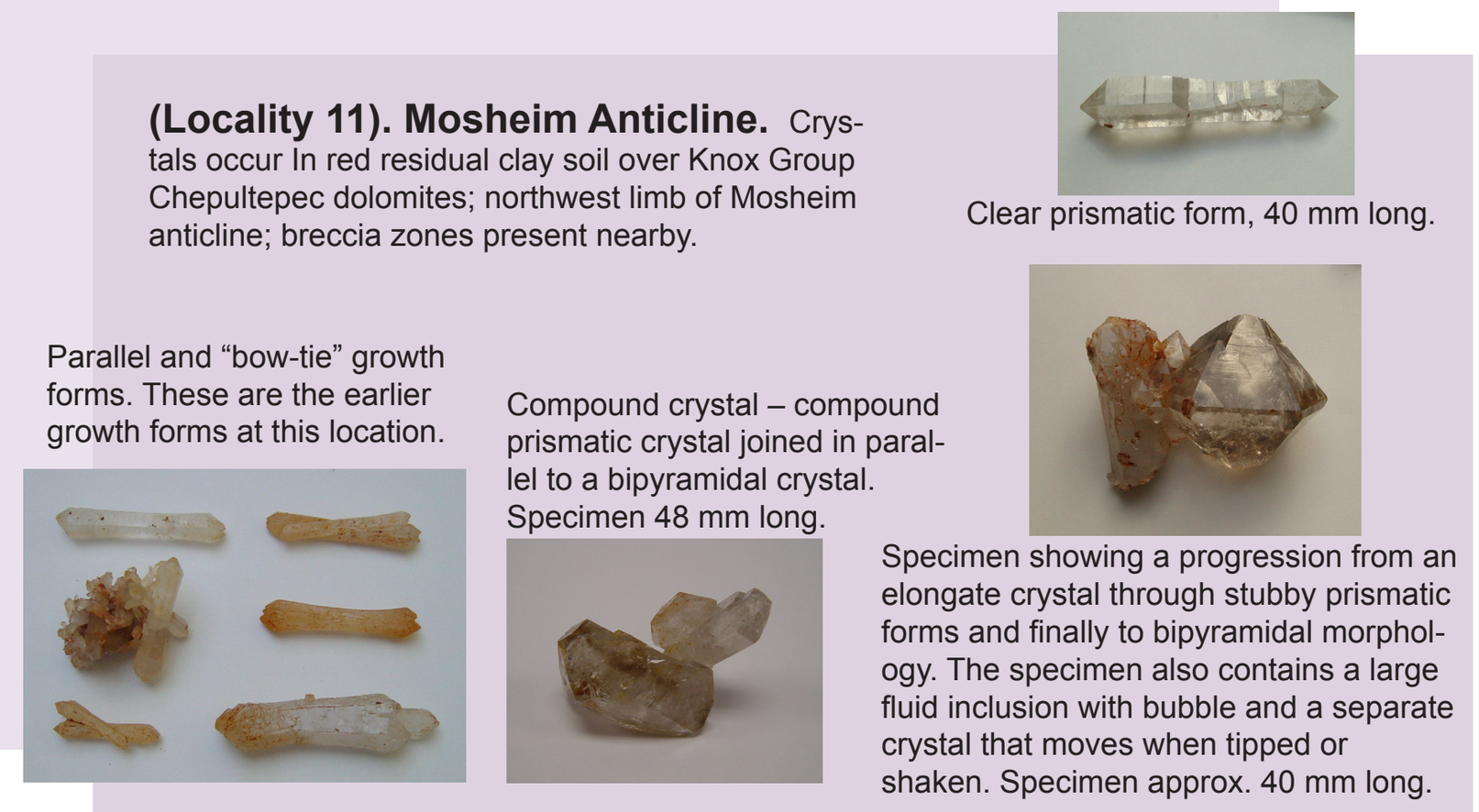


Asymmetrical growth indicates currents during later development, coming from the left as the specimens are shown. Largest 50 mm.

Specimen showing two growth stages separated by an episode of corrosion and a dusting of finely fragmented quartz.

Low-power photomicrograph of the specimen to the left. The yellow surface is covered by randomly-oriented quartz crystal fragments. Field of view 10 mm.

(Locality 11). Mosheim Anticline. Crystals occur In red residual clay soil over Knox Group Chepultepec dolomites; northwest limb of Mosheim anticline; breccia zones present nearby.



Clear prismatic form, 40 mm long.

Parallel and "bow-tie" growth forms. These are the earlier growth forms at this location.

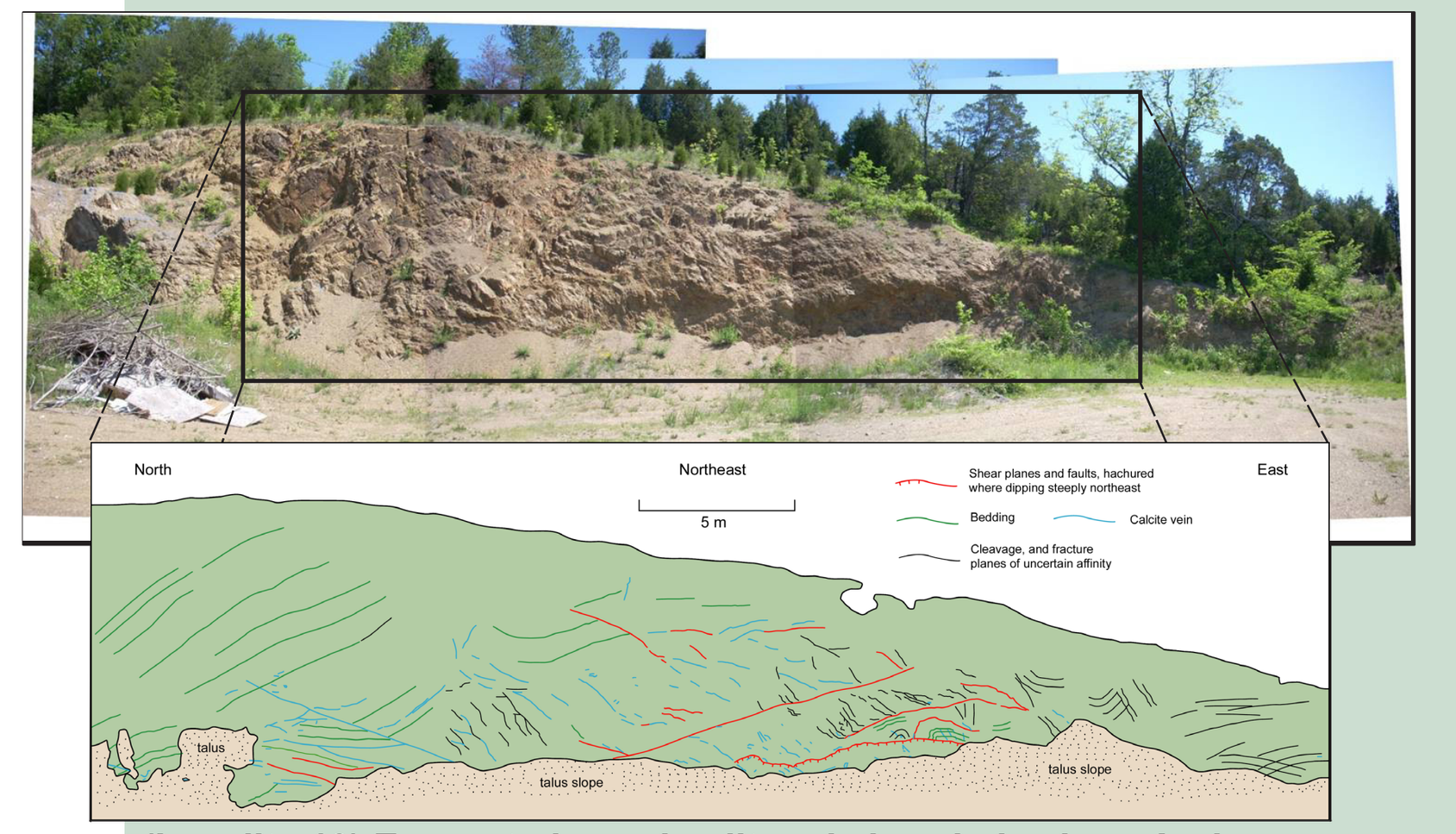
Compound crystal – compound prismatic crystal joined in parallel to a bipyramidal crystal. Specimen 48 mm long.

Specimen showing a progression from an elongate crystal through stubby prismatic forms and finally to bipyramidal morphology. The specimen also contains a large fluid inclusion with bubble and a separate crystal that moves when tipped or shaken. Specimen approx. 40 mm long.

Sevier Shale hosted field diamonds

Quartz crystals from the Sevier Shale reflect later quartz deposition that took place during or after the Alleghanian Orogeny. Sevier Shale crystals tend to be simpler, with less evidence for multi-stage of growth, but parallel-oriented crystals grown together are fairly common. The Sevier Shale was deposited after the post-Knox unconformity, and open space is the result of later Alleghanian deformation. Localities in table below keyed to map, upper left.

Locality	Description	Mapped formation	Source/ Reference
3	Crystal found in spoil, construction site.	Sevier Shale	Leigh Yates, pers. communication, 2005
4	Small fractures perpendicular to thin contorted limestone beds less than 100 m below the Great Smoky Fault. Crystals attached to surfaces.	Blockhouse (Lower Sevier) Shale	Don Byerly, Web posting
6	Exposed regolith over silty shales and siltstones. Crystals found loose on surface over considerable area of Muddy Creek arm of Douglas Lake.	Sevier Shale	Jack Wheat, personal communication 1998
7	Exposed regolith over silty shales, siltstones, thick-bedded sandy limestones.	Sevier Shale	Tonya & Kristofer Kenley, pers. comm. 2012
8	Veinlets and brecciated zones exposed in lakeshore near Newport, TN	Sevier Shale	Found, 2002
9	Gravels and sediments deposited by creek, over and draining shale and siltstone bedrock. (Diamond Creek)	Sevier Shale	Robert Fulweiler, personal comm. 1990
13	Excavated area in silt and clay shale along Andrew Jackson Highway. Vugs associated with shear planes present. Crystals observed loose within vugs, attached to vug walls, and enclosed in calcite vein material.	Upper Sevier Shale	Peter Lemiszki, personal communication, 2003
14	Residual material over clay shale bedrock, Lone Star area.	Lower Sevier Shale	Field mapping, 2002
15	Calcite veinlets within large exposure of folded Sevier Shale, commonly with pencil cleavage.	Upper part of lower Sevier Shale	Found, 2008

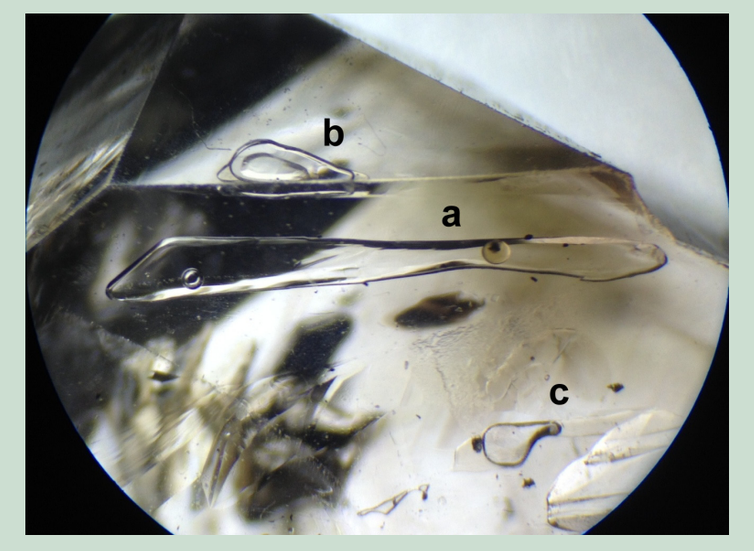


(Locality 13) Excavated area in silt and clay shale along Andrew Jackson Highway. Crystals occur in vugs in sheared and deformed shale bedrock. Crystals were observed loose within vugs, attached to vug walls, and enclosed in calcite vein material. The geology is complex and sheared, a common occurrence in the Sevier Shale.

Crystals typical of Locality 13. "S" crystal faces are fairly common here.

Stubby prismatic crystal typical of Locality 13, 25 mm.

Calcite-lined vug with quartz crystal. Doubly terminated bipyramidal crystals were found completely loose in some vugs. This crystal was not "loose" only because it had impinged on the cavity walls.

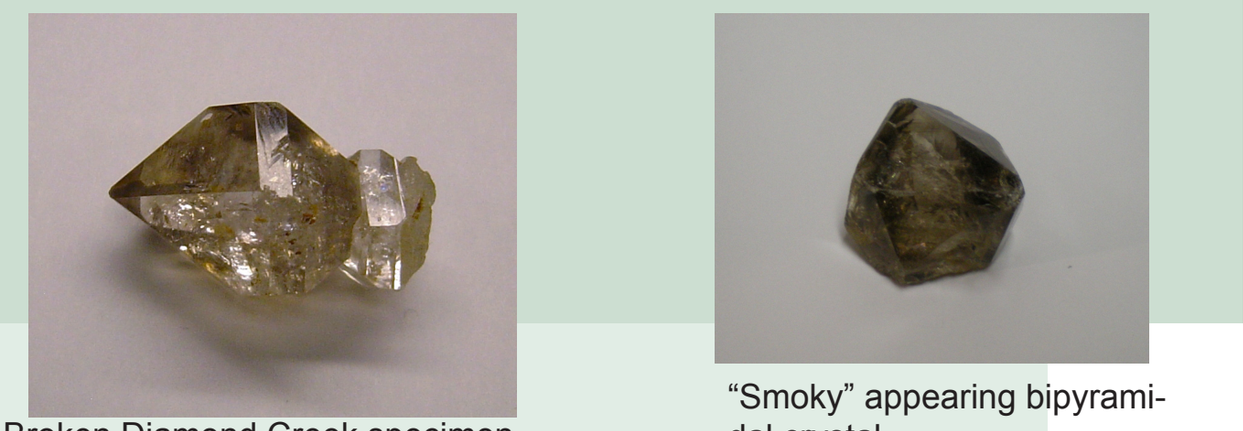


Multi phase fluid inclusions in a crystal from locality 7. In this example, the large inclusion **a,** contains a gas phase, an aqueous phase, and a waxy and strongly fluorescent hydrocarbon droplet. The inclusions at **b** and **c** both contain a gas phase surrounded by weakly fluorescent hydrocarbons. Field of view approximately 9 mm across.

Large complex bipyramidal crystal, 40 mm.

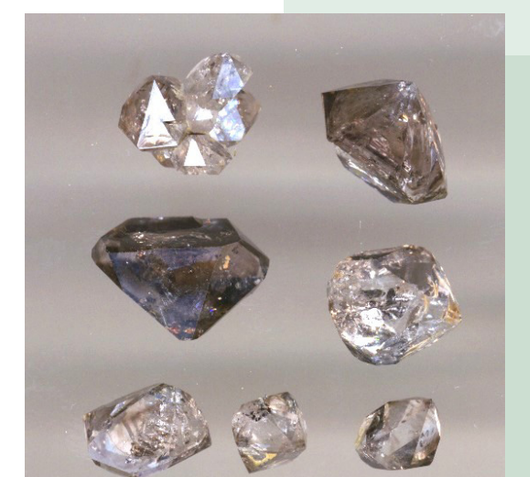
These distorted crystals are all oriented with the "c" axis vertical.

(Locality 9) Diamond Creek. At Diamond Creek, crystals occur alluvial gravels exposed in the drawdown area of Douglas Lake, restricted to the area near the creek. All crystals show some evidence of transport. This is reflected in the presence of at least some chips on the points and edges. The locality is also unusual in the number of distorted-appearing crystal shapes elongated in the direction of the rhombohedral r or z faces.



Broken Diamond Creek specimen, unusually complex for Sevier Shale hosted crystals, 25 mm.

"Smoky" appearing bipyramidal crystal.



Some of the typical crystals from Muddy Creek. Many have face-parallel brownish veils giving them the appearance of smoky quartz. Crystals 10 to 15 mm in size.

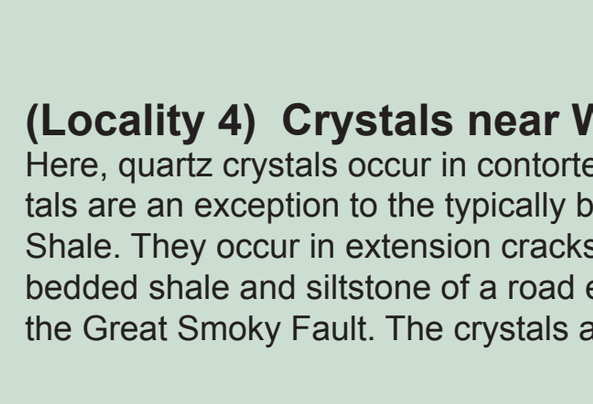
(Locality 6) Muddy Creek arm, Douglas Lake. Many fresh crystals of local origin plus a few slightly water-worn crystals occur on the surface. Almost all are bipyramids. There are few hexagonal prisms, and none of the "scepter" forms where bipyramidal quartz is deposited over earlier prismatic quartz. Distorted crystals are common..

Clay inclusion crystal. The clay-filled inclusions are deep embayments defined by partially overgrown septa. Their margins are growth surfaces, not broken surfaces. Crystal is approximately 25 mm across.

Folds in bedded shale and siltstone. This locality is often visited by geology field trips for its good examples of folding.

Tectonic extension crack within silty limestone, calcite lined, with sparse quartz crystals

Block of siltstone with extension cracks (boudinage) resulting from the ductility contrast between the ductile clay-rich layers and the more rigid silty layers.

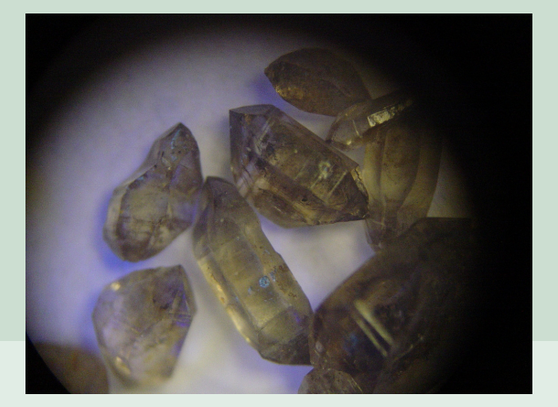


Quartz crystals in a calcite-lined vug formed in an extension crack. Vug was approximately 80 mm long

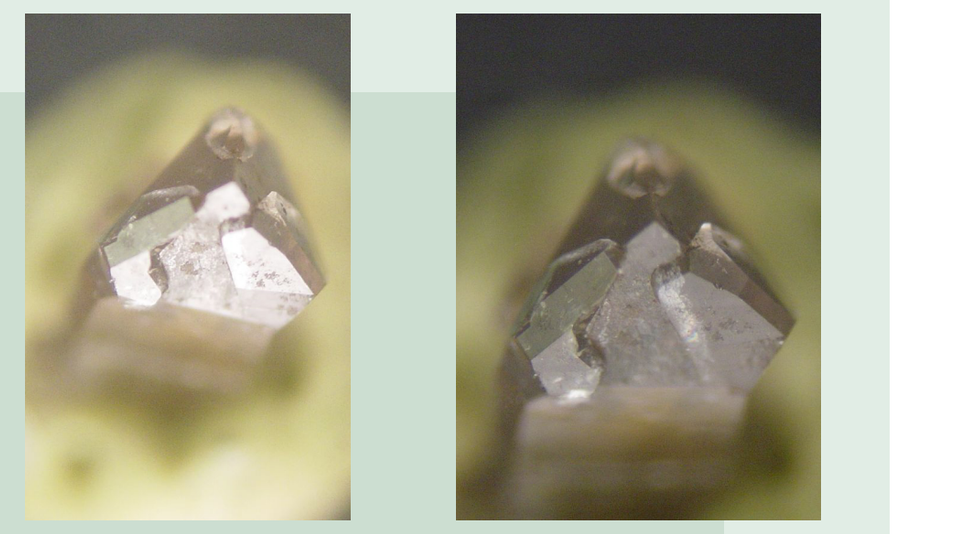
(Locality 4) Crystals near Walland

Here, quartz crystals occur in contorted and sheared Sevier Shale. These crystals are an exception to the typically bipyramidal crystals found in the Sevier Shale. They occur in extension cracks (boudinage) in folded and sheared interbedded shale and siltstone of a road embankment a few tens of meters below the Great Smoky Fault. The crystals are small, but some are very unusual.

Low-power photomicrograph with ultraviolet illumination. Blue or yellow fluorescence indicates the presence of hydrocarbons.



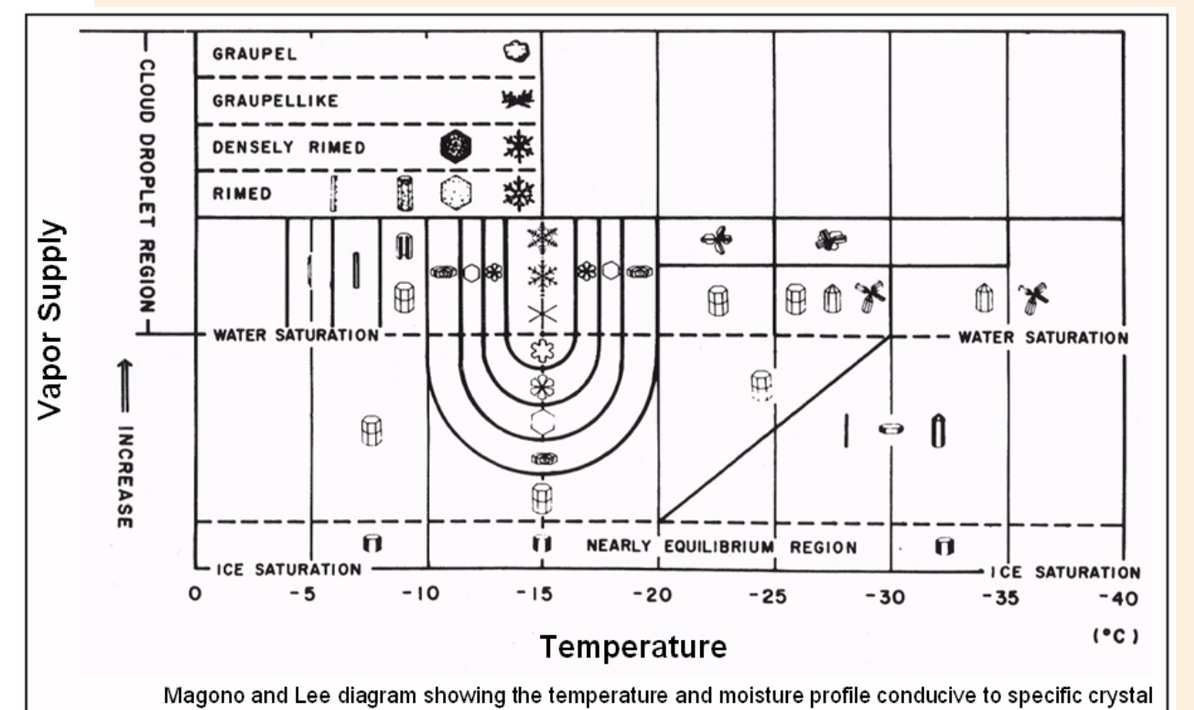
Phantoms defined by the dark inclusions indicate the crystals were originally separate, and grew together later. Approximately 6 mm long.



These late-stage overgrowths display the 'pi and 'omega faces -- obtuse rhombohedral terminations that are generally rare in quartz. Approx. 2 mm across.

Another crystal with 'pi and 'omega termination faces, approx. 4 mm across.

Discussion



Magono and Lee diagram showing the temperature and moisture profile conducive to specific crystal type. Note the "sweet spot" for crystal formation in the temperature range between -10°C and -20°C.

Magono, C., and C. W. Lee. "Meteorological Classification of Natural Snow Crystals". Journal of the Faculty of Science, Hokkaido University, Ser. VII (Geophysics), II, No 4 (November 1966), 321-35.

This diagram by Magono and Lee is modified from the work of Nakaya (1954), whose widely reproduced diagram presented experimental results from the first experiments to grow snow crystals. Magono and Lee's diagram is applied to natural snow, with morphology plotted against temperature and degree of water supersaturation. It shows a "sweet spot" of conditions where dendritic "classical" type snow crystals form. The question of whether there could be analogous relations for quartz was one of the things that spurred this investigation.

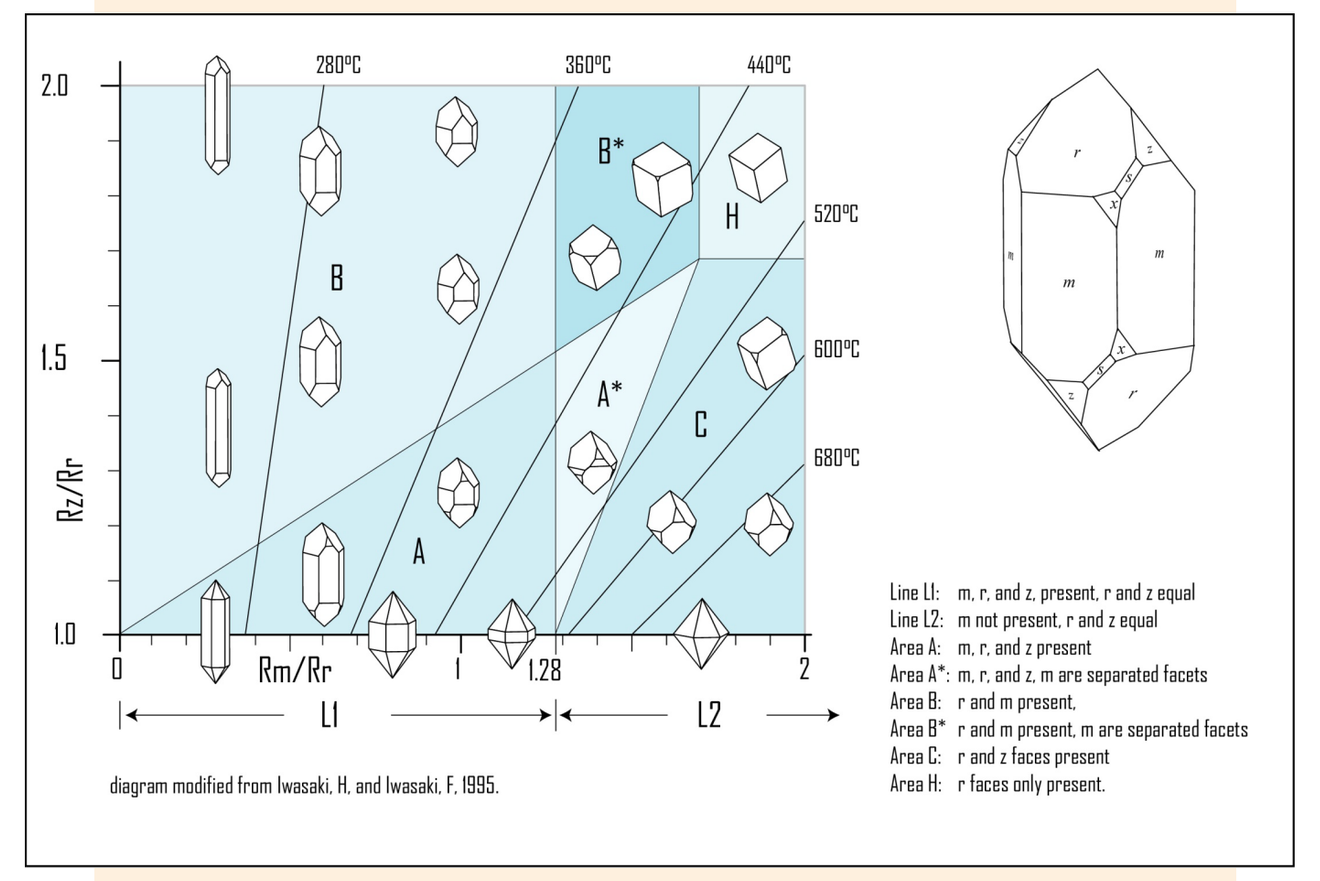


diagram modified from Iwasaki, H. and Iwasaki, F. 1995.

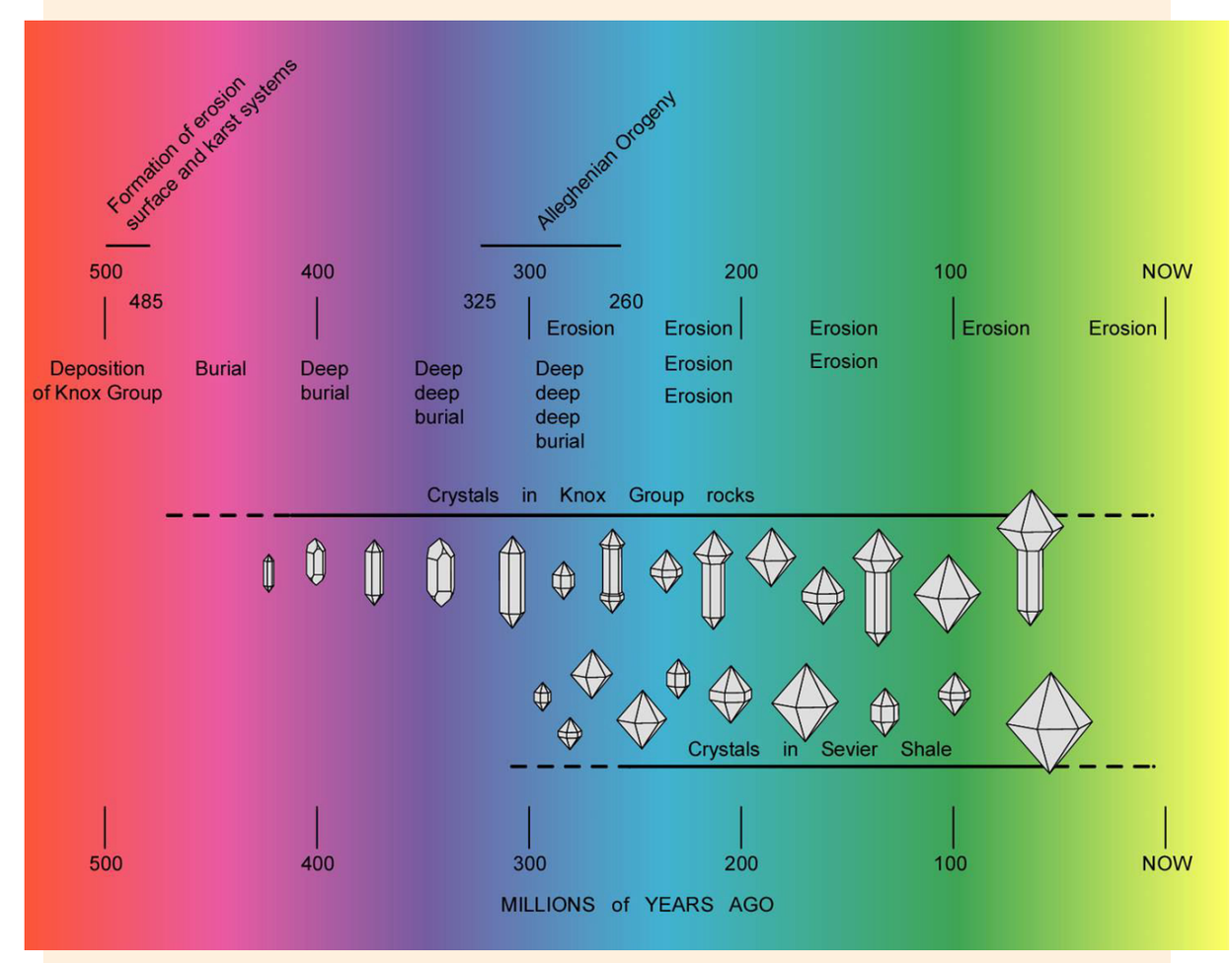
This is a plot of morphology, referred to as a "morphodrom" modified from Iwasaki and Iwasaki (1995). Here, quartz deposition on the prismatic faces increases to the right, and the relative development of the two sets of pyramidal (rhombohedral) faces changes in the y direction. Fields are defined by the presence of specific faces and their relations.

Isotherm lines are also included. The authors do not specify how they arrived at them, but if they are correct, then we can infer the earlier stages where we find the longer prismatic crystals were generally cooler, and the later stages of quartz deposition and overgrowths--the scepter quartz and the bipyramidal crystals from the Sevier Shale, took place at higher temperatures. A "path" showing change in morphology over time can be defined.

Unfortunately, the values he places on the isotherms are not supported by available data for this region. Fluid inclusion analyses for sphalerite in East Tennessee reported by Edwin Roedder (1971) showed homogenization temperatures all below 180 and most below 150 °C. Further, conodont alteration indices of 3 to 4 (Harris and Milici, 1977) (300 °C maximum) for these rocks do not suggest anything nearly as hot as his isotherm values suggest. Additionally, the bipyramidal crystals reported by Joseph Vasichko in concretions from northern Ohio are in areas shown by Rupert and Ryder (2014) as having a conodont alteration index of only 1, (http://pubs.usgs.gov/pp/1708/f1/pdf/pp1708_f1-figure8.pdf), which suggest heating only to 50-80 °C in that area.

The low temperatures in Northern Ohio are considered to be characteristic of immature sediments from the standpoint of oil and gas, while those in East Tennessee are mature. As hydrocarbons are found associated with quartz in East Tennessee, and many other occurrences of doubly terminated quartz crystals, a possible role for petroleum within these systems has been suggested. Research by Bennett and Siegal (1987) observed evidence for the increased solubility of silica in water in the presence of hydrocarbons, and Chamberlain, (1988) concluded that the Herkimer crystals could be the result of organic complexes holding significant quantities of silica in solution.

Although one of the objects of a study such as this would be to allow an estimation of hydrothermal conditions by looking at crystal morphology, consistent estimates cannot be made from information available at this time.



Time line, with crystal morphologies, showing possible paragenesis. The truth is probably more complex, as the crystals at Douglas Dam show evidence of a stage of "reverse scepter" or long prismatic over stubby prismatic growth. Also, crystal formation is likely concentrated nearer the period just before, during, and after the Allegheny Orogeny than shown.

Post-crystallization History

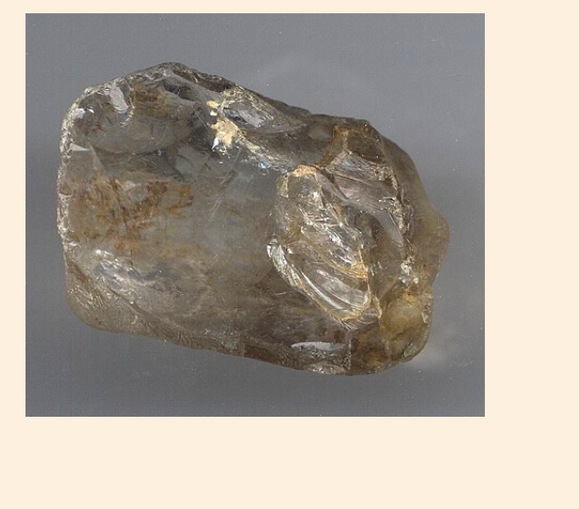
Exposure by weathering of bedrock

While all crystals formed within bedrock, most, particularly within the Knox Group dolomites and limestones, are seen in the residual clay soils or on the surface.

Transport and mechanical weathering

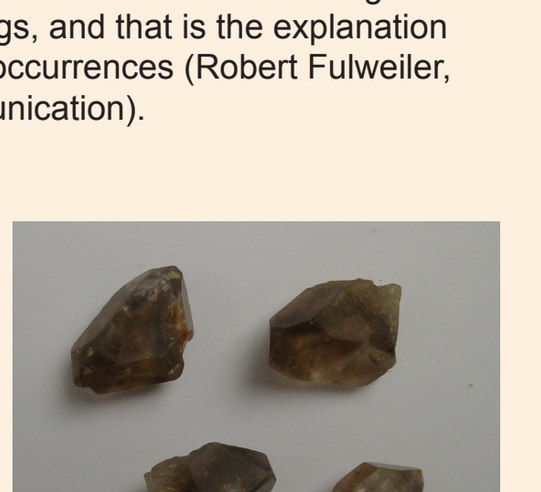
In most places, most crystals are completely unworn which suggests that they come from the nearby bedrock, and have not been transported by water. In many places both worn and unworn crystals occur in the same area, however warn and eroded crystals are seldom or ever encountered in areas where untransported crystals are not also found, suggesting they have been abraded without having been moved significant distances.

The exception is the Diamond Creek tributary of Douglas Lake and the French Broad River (Locality 9), where all crystals show some degree of erosion and tumbling. Here they occur in stream gravels in and adjacent to the creek where its course is exposed in the lake bed. The creek's watershed is entirely in the Sevier Shale. The large crystal fragment shown above is from Diamond Creek.



At Douglas Dam (Locality 5), small concentrations of rounded and abraded crystals occur in the residual clay. The crystals are similar to local unworn specimens, including characteristic black inclusions. An explanation might involve the in-place milling action caused by channeled groundwater flow within restricted cavities. In the zinc mines of the Mascot-Jefferson City District, they have found rounded and eroded fragments of zinc ore in vugs, and that is the explanation given for those occurrences (Robert Fulweiler, personal communication).

Some crystals found at Muddy Creek(Locality 6) and elsewhere show abraded faces, but without the chipping on edges and points as the Diamond Creek or the above specimens. These may have been in the regolith for some time, exposed to creep, solifluction, and the activities of animals and plants.



Conclusions

These crystals are similar in many ways to individually occurring doubly terminated quartz crystals from localities throughout the world.

Hydrocarbon bearing inclusions occur in these crystals in multiple instances, and one example is known where quartz crystals are found embedded in a matrix of solid hydrocarbons.

Crystals from the Sevier Shale typically display bipyramidal or stubby prismatic habit. Those from the Knox Group dolomite formations are extremely diverse. They range from bipyramidal to elongate prismatic. Prismatic quartz is commonly followed by later bipyramidal overgrowth, sometimes after a period of corrosion or fracturing, and these changes may reflect the changing environments under which they grew.

Finally, some crystals have been worn or abraded by various mechanisms in the more recent geologic past.

Further research

Studies using fluid inclusion could shed light on the environmental conditions present when these crystals grew, and what parameters influence crystal morphology and habit. Other forms of open space quartz such as drusy quartz, agate, and quartzine could also be included, perhaps allowing one to place constraints on their conditions of formation using macroscopic specimen morphology alone.

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