DISTRIBUTION AND CHARACTERISTICS OF MULTI-SOURCED SHOCK-METAMORPHOSED QUARTZ GRAINS, LATE DEVONIAN ALAMO IMPACT, NEVADA.

J. R. Morrow[1] and C. A. Sandberg[2], [1]Dept. of Earth Sciences, Univ. of Northern Colorado, Greeley, CO 80639 (jrmorro@bentley.unco.edu), [2]Geologist Emeritus, U.S. Geological Survey, Box 25046, MS 939, Federal Center, Denver, CO 80225 (sandberg@usgs.gov)

Introduction: Documentation of the Late Devonian oceanic Alamo Impact Event is contained in polymict megabreccias, tsunamites, and shock-altered subjacent units exposed in nearly 20 mountain ranges of southern and central Nevada. Although post-event geologic processes have obscured the crater, several converging lines of evidence, including abundant shock-metamorphosed quartz [1-3], verify an impact origin. The subcritical Alamo impactor penetrated a thick sedimentary target composed primarily of carbonate strata with minor interbedded quartz sandstone and quartzite. Based on a minimum crater-excavation depth of ~1.5 km below the Late Devonian seafloor [4], two important subsurface quartz sources were the Lower-Middle Devonian Oxyoke Canyon Sandstone and Middle Ordovician Eureka Quartzite.

Distribution: Allochthonous, shock-altered quartz sand, recovered from conodont microfossil sample residues, is now known from 18 peritidal to oceanic Alamo Breccia sites (Fig. 1). In addition, quartz containing planar fractures (PFs) and prominent hematite inclusions was recovered from Alamo Event age-equivalent beds in the N. Antelope Range (NAR), ~150 km north of the inferred impact site. Stratigraphically, shock-altered quartz is present: (1) in fallout/tsunamite beds at the top of the Breccia [3]; (2) in the matrix of the polymict megabreccias [1-3]; (3) in allochthonous and semi-autochthonous clastic injection dike and sill fillings beneath the Breccia at Tempiute Mountain [3] and Upper Empire Canyon (TMS and UEC, Fig. 1); and (4) among autochthonous grains of the Oxyoke at TMS [3]. At TMS, clastic dikes and sills, which extend at least 300 m below the Breccia [3], contain predominantly monocrystalline quartz similar in composition to *in situ* grains within both the Oxyoke and Eureka. Also, weak planar deformation features (PDFs), displaying one or rarely two sets of lamellae with $c(0001)$, $\omega\{10\bar{1}3\}$, or $\pi\{10\bar{1}2\}$ orientations, were identified in autochthonous Eureka Quartzite grains at TMS. At Sand Spring (SS, Fig. 1), an isolated spire of highly silicified breccia with vertically oriented clasts, which may be genetically linked to the Alamo Event, has a fabric of shattered groundmass containing allochthonous, micro-injected clastic quartz grains.

Allochthonous Shock-Metamorphosed Quartz: Shock-metamorphic features occur within both single-crystal quartz and polycrystalline quartz/quartzite. Polycrystalline quartz (Fig. 2) is more abundant in platform-margin and ramp localities, where it composes up to 50% of the total quartz population (e.g. MKR, SKR, TMS, and UEC, Fig. 1). Both types of quartz contain abundant shock-metamorphic features, including single and multiple sets of decorated PDFs, PFs, curvilinear percussion fractures, hematite and other high-relief inclusions, mosaic extinction, and reduced refractive indices and birefringence.

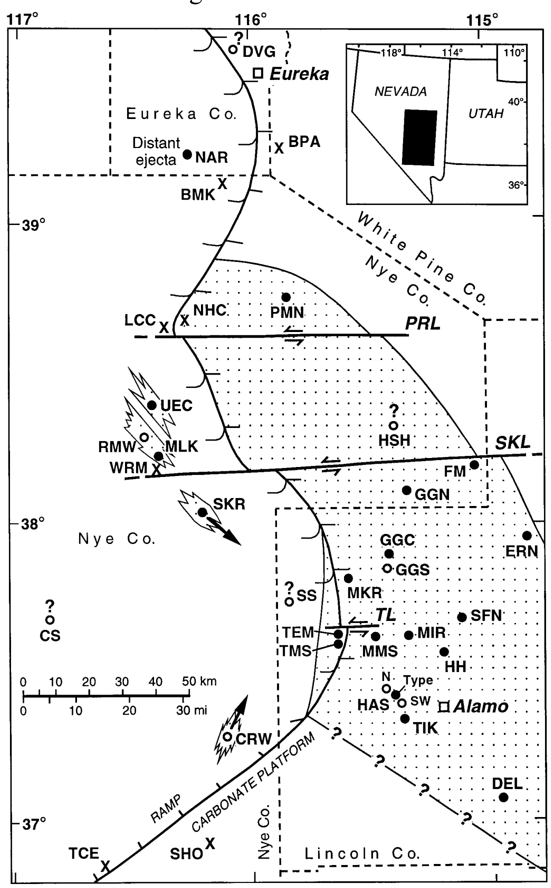

Figure 1 - Partly restored paleogeographic map of shocked quartz localities and distribution of Alamo Breccia (patterned). Late Devonian carbonate-platform margin is shown by stylized, hachured line. Tertiary strike-slip lineaments affecting Breccia distribution: *PRL*, Pancake Range; *SKL*, Silver King; *TL*, Tempiute. Reconstruction of other post-event faulting is not attempted. Solid circles, Alamo Event localities with shock-altered quartz; open circles, Event localities either without shock-altered quartz or without studied residues; 'x' symbols, other non-Breccia localities used to constrain map. Arrows show suggested Breccia channel directions. Modified from [5].

Previous TEM analysis of Alamo quartz grains documented the presence and character of planar shock lamellae, and noted their preferred orientation parallel to the $\{10\bar{1}3\}$, $\{10\bar{1}2\}$, $\{10\bar{1}1\}$, and $\{11\bar{2}1\}$ indices [1]. In our study, U-stage indexing of PDFs in quartz has confirmed these orientations and identified several additional common indices (Fig. 3). We recognize two types of PDF development within the Alamo grains. The first, composing <5% of the shocked quartz, consists of very conspicuous, highly decorated single PDF sets usually oriented at $c(0001)$, $\omega\{10\bar{1}3\}$, or $\pi\{10\bar{1}2\}$ (Fig. 4A). The second, dominant type contains two to six decorated PDF sets that include low, intermediate, and high indices (Fig. 4B). Hematite inclusions, which are a common and diagnostic feature of shock-altered Alamo quartz grains [1-3], display rare micro-injection fabric into the enclosing grain and are commonly associated closely with PDFs, PFs, and percussion fractures. The mean refractive indices of altered Alamo grains have values of 1.544 to 1.547, with birefringence values of 0.005 to 0.008.

Discussion: Abundant intermediate- and high-index PDFs, as documented in the Alamo grains (Fig. 3), are a characteristic feature of sedimentary-target impacts and result from the heterogeneous dispersion of shock energy through the target [6]. Because of this, shock barometry calculations based on the shock-recovery of solid, crystalline rocks cannot be directly applied to sedimentary impacts [6]. However, shock lamellae in the crystalline Eureka Quartzite may be significant if this unit, which was buried to a pre-event depth of ~1 km, had reached low-grade metamorphic levels prior to the Alamo Impact. If this unit behaved as a crystalline solid, the presence of low-index PDFs would suggest that shock pressures reached a threshold value of 10-16 GPa [7] at this depth.

An unanswered question concerns the source of the common polycrystalline shocked quartz grains recovered from Breccia samples, which are unlike the largely monocrystalline quartz grains in source units such as the Oxyoke and Eureka. The finely polycrystalline texture of the grains could be a relict of impact shock, or the grains may have been ejected from an as yet unidentified, possibly deeper, metasedimentary source unit. We are now examining additional siliciclastic units, including the Proterozoic to Lower Cambrian Prospect Mountain Quartzite, in search of possible polycrystalline quartz sources to further constrain the impact excavation depth and crater size.

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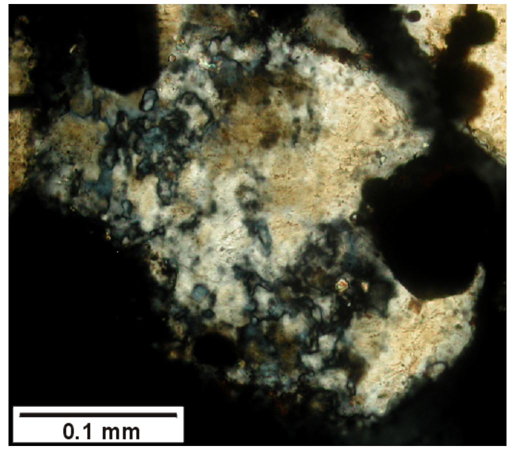

Figure 2 - Photomicrograph (crossed polars) of polycrystalline quartz grain with weak, decorated, multiple PDFs and prominent hematite inclusions, locality MKR.

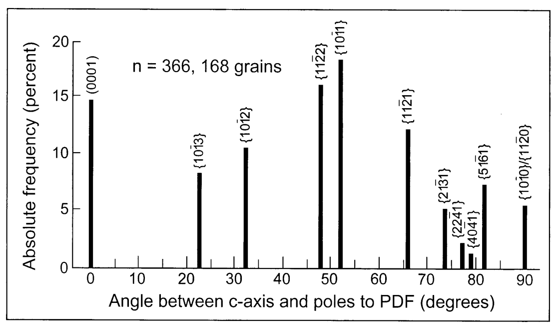

Figure 3 - Indexed PDFs in shocked quartz, based on combined data from ERN, FM, HH, MKR, SKR, and TMS Alamo Breccia localities. Indexing method after [6].

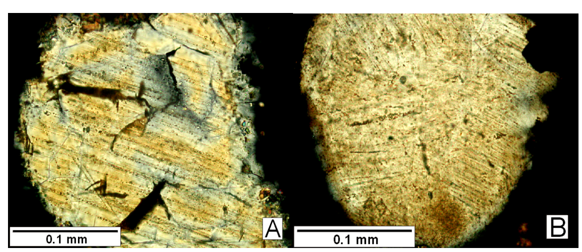

Figure 4 - Photomicrographs (crossed polars) of shocked quartz grains: 4A) strong PFs and highly decorated, single conspicuous PDF set, locality SKR; and 4B) PFs and decorated, multiple PDFs, locality HH.