ANOMALOUS DEVELOPMENT OF PLANAR DEFORMATION FEATURES IN SHOCKED QUARTZ OF POROUS LITHOLOGIES.

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Planar deformation features in tectosilicates, particularly in quartz, have been recognized as unique evidence of shock deformation since early petrographic studies of terrestrial impact breccias. Carter (1) and Engelhardt and Bertsch (2) established that such features in quartz are the traces of glide dislocations containing dense SiO_2 glass or high-pressure quartz polymorphs. Robertson et al (3) demonstrated that the planar features developed parallel to a relatively few rational crystallographic planes, and that a succession of shock levels could be defined from the appearance, disappearance or relative abundance of particular orientations. Laboratory experiments (4,5) confirmed that such features were the product of shock and that they developed between approximately 10 and 20 GPA. Although there still exists some uncertainty in the absolute correlation of particular levels of planar feature development with pressure values, largely due to the change of scale between laboratory experiments, nuclear explosion craters, and large hypervelocity impact structures, with the accumulation of new or refined data the early descriptions and interpretations have remained valid with one or two annoying exceptions. The number of exceptions, however, has now reached the point where some reassessment is required.

Our scheme (3) of the progression of planar feature orientations was based on samples of crystalline rocks of minor porosity, generally "granitic" gneisses, and was corroborated by the Ries crystalline material (2). The progression has since been supported in every case where measurements are on crystalline rocks. Our earlier caution that "... the sequence outlined for gneissic rocks of low porosity will differ in detail from sequences of shock features formed in more porous materials ..." (3) has been borne out by the exceptions which occur in sedimentary rocks of some porosity.

The anomalies fall into two groups: (i) sites where planar features are completely lacking, or almost so, in quartz shocked to normally suitable pressures, (ii) sites where the normally predominant $\underline{\omega}$ orientation is lacking or severely reduced, whereas orientations supposedly characteristic of relatively high deformation levels appear in rocks which have obviously not experienced the required shock pressures.

In the first category Barringer provides the most striking example. Coconino Sandstone spans a range from unshocked to entirely glass, with up to 32% coesite (6). However, in no instance do planar features occur in more than 5% of the grains whereas in crystalline rocks 100% of the quartz would display planar features at equivalent shock levels. At Gosses Bluff, planar features are considerably less abundant in porous sandstone than in adjacent heavily silicified units (7). Athabaska sandstone at Carswell appears unshocked although quartz of the immediately underlying garnet gneiss shows planar features indicative of > 15 GPa (8). The extensive literature on the Ries, where the crystalline rocks furnish a virtually complete spectrum of shock effects, contains practically no reference to shock features in the sedimentary rocks except to note that such effects in a Bunte breccia sample are almost exclusively confined to the 1% of crystalline rock fragments (9).

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The circular structure near Uvalde, Texas has been proposed as an impact crater (10) although there was no distinctive evidence of shock metamorphism reported from the abundant breccia of largely ferruginuous sandstone clasts. However, from examination of numerous breccia samples, containing several sandstone clasts each, one single quartz grain was found to contain two sets of definite planar features parallel to ω. This seems slight evidence to confirm an origin by meteorite impact but in light of the findings described above it can be considered characteristic of the effects of low to moderate shock pressures on such lithologies. Uvalde may now be classified among the terrestrial impact structures which contain evidence of shock metamorphism.

At a number of sites, almost all in sedimentary rocks, there is a deviation from the normal sequence of planar feature orientations. At the B.P. and Oasis structures in Libya (11), respectively, only 10% and 5% of the planar features have ω orientations with the vast majority of orientations inclined at $\geq$ 40° to the basal plane. It has been noted (12) that ω orientations are deficient in sandstones at Decaturville. In the Dogger sandstone of the Steinheim, 30% of the quartz features are $(10\bar{1}1)$ with no indication of any ω orientations (13). At the Slate Islands structure shock distribution in the central uplift has been established from the typical progression of planar feature development in the crystalline rocks (14). In certain quartz veins, however, ω orientations are severely reduced whereas the occurrence of π and other orientations would normally assign a much higher deformation level to these rocks than their structural position allows. A similar situation appears to exist at Vredefort. Here, most quartzite samples display only c features in keeping with their distance from the presumed shock center. However, although ω features are rare to absent in these as well as in another population of samples, the occurrence of high-angle features in the latter would assign to them a much higher level of shock deformation than acceptable, using the normal progression of planar feature development (15).

The sequence of deformation in the porous Coconino sandstone (4) culminating in the enhanced production of coesite, stishovite and glass provides an insight into the suppressed planar feature development. Below approximately 5.5 GPa work is done to reduce porosity by physical closing of the voids by compression. Above the HEL, in the regime where plastic deformation is normally manifested by glide dislocations producing planar features, plastic deformation occurs as marginal flow and recrystallization to further reduce porosity by forming an interlocking network. At still higher pressures, again where planar features would normally develop, the energy deposited in the voids creates a pressure-temperature regime which is more conducive to the production of high pressure structural polymorphs at an average shock pressure lower than required in crystalline rocks. Comparable behavior has been demonstrated in the laboratory where the onset of diaplectic glass and shock melting is lowered in porous (particulate) material *vs.* crystalline (16).

Explanation of the anomalous sequence and lack of ω features is more speculative. The laboratory production of quartz planar features (4,5) differed from that in crystalline rocks (3) in that ω orientations were produced *first* in the laboratory, with c features recorded at higher pressures. The laboratory results may be applicable to porous lithologies and the sequence in sandstones, for example, may be ω followed by c. If such is the case, and if at pressures where ω should develop strain was taken up in closing voids and plastic deformation and recrystallization, the ω pressure regime may be surpassed without their significant formation. Above this regime, where other forms of plastic deformation have been completed, the normal production of c features proceeded, followed by the remainder of the normal sequence. Although this explanation may have some plausibility in the porous sedimentary rocks it is difficult to apply such reasoning to the Vredefort quartzites and Slate Islands quartz veins.

It is apparent that a total comprehension of quartz planar feature development has not been achieved and that attention should be focussed on shock deformation of porous lithologies.

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