CO_2-RICH FLUID INCLUSIONS IN THE POLYMETAMORPHIC BASEMENT ROCKS OF THE VREDEFORT STRUCTURE, SOUTH AFRICA, AND THEIR POSSIBLE BEARING ON ITS ORIGIN

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The ring-like Vredefort Structure consists of a collar of steeply dipping overturned Witwatersrand metasediments and a 50 km diameter core of Archean basement in a similar tectonic position. The border between the Archean and the collar is marked by a sedimentary unconformity. Thus the whole structure represents a section through most the continental crust (Slawson 1976).

Within the collar metamorphism increases inward changing the nearly unaffected peripheral slates into hornfelses with andalusite, cordierite etc. On the basis of the mineral assemblages reported by Bisschoff (1969) maximum temperatures of about 500°-600°C may be estimated for this static metamorphism. Petrologic studies of the Archean basement rocks reveal, however, that this type of metamorphism continues and increases further towards the center of the structure, where it is superimposed on the previous dynamic metamorphism of the Archean and where it may affect possibly unmetamorphosed granites and other intrusives. Metamorphic conditions could be deduced for two polymetamorphic sediments:

1. A former regional metamorphic granulite located about midway between collar and center exhibits breakdown of its former garnet in the presence of quartz into a symplectite of cordierite, hypersthene, and a different garnet. Microprobe analyses yield the following M-values (Mg/(Mg+Fe)) of the new minerals:
   cordierite: 0.60; hypersthene: 0.41; garnet: 0.19.

   Based on the experimental results of Hensen and Green (1973) who studied this multivariant breakdown reaction some 750° and 5 kb can be estimated.

2. In an iron formation occurring at the center of the ring ferropigeonite ($En_{70}Fs_{17}Wo_{13}$) had formed which requires minimum temperatures of some 800°-850°C (Simmons et al. 1974). Upon cooling this pyroxene did not invert but exsolved into <u>clino</u>eulite and ferroaugite (Schreyer et al. 1977).

Many quartz crystals occurring in polymetamorphic basement rocks from various localities within the ring contain two-phase fluid inclusions which, on the basis of their freezing temperature near -56°C, consist of virtually pure CO_2. In some

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rocks near the unconformity three-phase inclusions with some additional H_2O were found. Although CO_2-rich inclusions are well known from deep-seated granulites elsewhere (Touret 1971), the ones observed here are of particular genetic significance: In rocks of the outer portion of the core they form decorations of quartz lamellae which are regarded by some investigators as indications for meteorite impact (e.g. Carter 1968).

Kink bands in biotites and the appearance of pseudotachylites and shatter cones both in the outer core as well as in the collar are further testimonies of a high-strain-rate deformation which has been attributed to shock metamorphism. Since this deformation is clearly younger than the static metamorphism, the impact hypothesis meets with the difficulty in explaining why a meteorite should have hit the very spot in Southern Africa where this localized static metamorphism had occurred.

Comparison of quartz lamellae and other deformational features of Vredefort with the shock features observed in basement rocks of the Ries crater indicate that similarities only exist with the very lowest grades of shock metamorphism of the Ries. Contrary to the Ries the quartz lamellae of Vredefort exhibit all stages of a recrystallization which increases in intensity from the outer core to the center of the structure. Thus, whereas in rocks close to the unconformity SEM investigations show parallel open fractures, these are healed by finely recrystallized quartz closer to the center. In the central portion of the structure the quartz grains form excellent polygonal annealing textures with 120° triple points. Nevertheless, in many cases the CO_2 inclusions can be found to follow parallel planes that are continuous beyond the grain boundaries of the annealing fabric. Since the arrangement of these planes is directly comparable to that of the decorated quartz lamellae of the outer core, this observation must be considered as evidence that high-strain-rate deformation has also produced quartz lamellae in the center of the structure prior to annealing. In the course of the complete recrystallization of quartz the CO_2 inclusions have partly coalesced into larger but fewer inclusions which are notably rarer in zones close to the new grain boundaries of quartz.

Heating-stage measurements of CO_2 inclusions in six rocks of various portions of the core revealed a remarkably consistent behavior: In all cases the inclusions homogenized to form liquid at temperatures ranging from 22°-28°C which indicates specific densities of 0.7-0.8 gr/cm^3. Using the extrapolated PVT data for CO_2 of Kennedy (1954) in conjunction with the metamorphic temperatures derived mineralogically the following ranges of partial pressures of CO_2 can be estimated: At 750°C 2.9-3.9 kb, at 850° 3.3-4.4 kb.

The spatial arrangement of CO_2-rich inclusions along the lamellae in quartz suggests that the gas was incorporated either concomitantly with or subsequently to a rock deformation characterized by very high strain rates. Similar fluid inclusions decorating quartz lamellae in rocks of the Charlevoix structure, Quebec, were found by Pagel and Poty (1975) to consist of H_2O. The lack of CO_2 is used by those authors as a strong argument for meteorite origin of that structure. Following their reasoning and keeping in mind that no higher-grade features of shock metamorphism were found at Vredefort, a meteorite impact is unlikely to have caused the Vredefort structure but an endogenous origin must be sought: The time of CO_2 incorporation is, like that of the high-strain-rate deformation, subsequent to the first period of static metamorphism, but it precedes a second period of static metamorphism (annealing) which is confined to the central area of the core. Thus all these events must be seen as episodes in a long history of thermal and structural development of the Vredefort dome. As already suspected by Nicolaysen (1972) for other cryptoexplosion structures high fluid pressures and their explosive release seem to be the dominant reason for the high-strain-rate deformation at Vredefort. The source of both the CO_2 and the enormous heat flow causing static metamorphism with a vertical extent of more than 25 km over a limited area can best be seen in a mantle-derived magma diapir that cooled near the base of the continental crust.

References

Bisschoff, A.A.: D.Sc.Thesis, Univ. of Pretoria, 234 pp., 1969

Carter, N.L.: In: Shock Metamorphism of Natural Materials, Mono Book Corp., Baltimore, 453-475, 1968

Hensen, B.J. and Green, D.H.: Contr.Mineral.Petrol. 38, 151-166, 1973

Kennedy, G.C.: Am.Journ.Sci. 252, 225-241, 1954

Nicolaysen, L.O.: Geol.Soc.Am.Mem. 132, 605-120, 1972

Pagel, M. and Poty, B.: Fortschr.Miner. 52, 479-489, 1975

Schreyer, W., Stepto, D., Abraham, K. and Müller, W.F.: Manuscr.for Contr.Mineral.Petrol., 1977

Simmons, E.C., Lindsley, D.H. and Papike, J.J.: Journ.Petrol. 15, 539-565, 1974

Slawson, W.F.: Geochim.Cosmoch.Acta 40, 117-121, 1976

Touret, J.: Lithos 4, 423-436, 1971