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WELL-DEVELOPED GROWTH ZONING IN A STRUVITE BLADDER STONE

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ABSTRACT

An ellipsoidal bladder stone composed of struvite shows exceptionally distinct single-crystal growth zoning which records rhythmic changes related to physiology and suggests the opportunity for the therapeutic use of growth inhibitors. The specimen also presents the geological mineralogist with the unusual chance of studying crystal zoning in a compositionally open system where temperature and pressure are known and constant.

INTRODUCTION

The Redpath Museum recently received a calculus 3.5 cm in length and weighing 13.4 g which was removed surgically from the bladder of a nine-year-old male shepherd dog. Since the dog had experienced symptoms of stones for approximately one year, it is thought that the calculus was formed over a one-year period. Several smaller stones were removed at the same time. The animal is alive and in good health four years after surgery. The calculus is cream-coloured and ellipsoidal, and appears to have formed its final shape from the coalescence of several orthorhombic pyramids (Fig. 1).

The stone was examined by x-ray diffraction using the Nonius-Guinier camera and CuK_{α} radiation, and was found to be composed of struvite

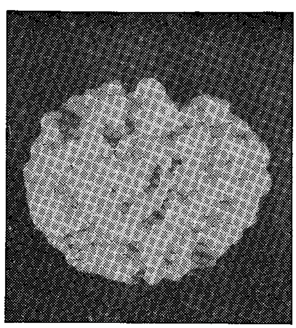

FIG. 1. Struvite bladder stone, Redpath Museum No. NS4835A, x 1.

(Larsen & Berman 1934). Optically the stone material gave the following constants : orthorhombic positive ; $\alpha = 1.495$, $\gamma = 1.502$; $Z = b$, $X = a$. The specific gravity of the stone material is 1.7 and the hardness is 2.5.

Struvite is frequently found in animal and human calculi and is usually formed in alkaline infected urine (Milton & Axelrod 1951 ; Prien & Frondel 1947). Perhaps the most famous struvite calculus is the bladder stone "the size of a large date" removed from Napoleon III in 1873 (Lonsdale 1968a). Stones very similar to ours in appearance, although much smaller, were photographed by Lonsdale (1968b) ; these were formed entirely of struvite and were a few of about 100 stones formed in a pouch of a human bladder. However, human stones usually consist of more than one mineral ; in such stones a struvite layer may record a period when the patient who normally had acid urine had, for a time, an alkaline infected urine (Lucas *et al.* 1950), whereas an all-struvite stone implies continuously alkaline urine.

We were unusually fortunate in getting an excellent thin section of the complete stone directly through the centre. This enabled us to trace the growth of the stone from the struvite anhedra at the centre (Fig. 2) through the intermediate portion of the stone composed largely of subhedra (Fig. 3) to the outer rim of large euhedra (Fig. 4). Many of the smaller crystals and all the larger ones show distinct growth zoning. This

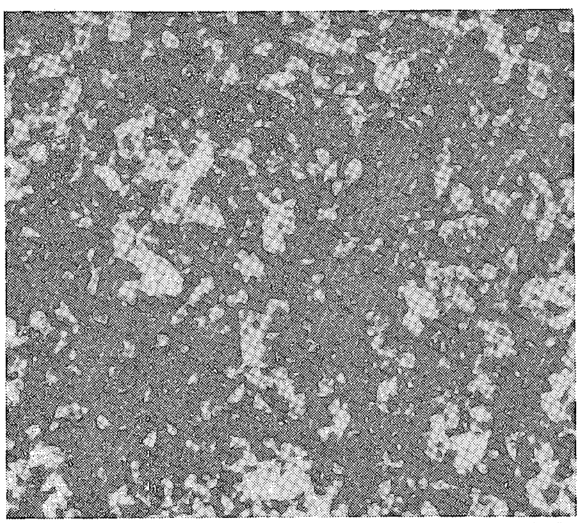

FIG. 2. Centre of bladder stone with closely-packed struvite anhedra ; a few crystals show pyramidal faces (photomicrograph 3 mm across).

section also presents the geological mineralogist with the unusual chance of studying growth zoning in a compositionally open system in a specimen where temperature and pressure are known and are constant within quite narrow limits.

The stone appears to have been relatively free to grow in space, and to have built up with a series of concentric layers crossed by radial growth corresponding to the pyramidal faces in the struvite (Fig. 4). As Lonsdale (1968b) has emphasized, such a high degree of preferred orientation is a sure sign of epitaxial growth.

As seen in thin section, the struvite crystals evidently grew by a layering process, but somewhat slower than the rate below which the intersection of growth surfaces could be perfected. Hence they grew as cellular layerites under conditions of considerable supersaturation (Smith 1963).

There is no separate organic material forming a nucleus. However traces of organic material are present throughout the stone, and it is

FIG. 3. Intermediate portion of stone; subhedral struvite crystal in centre of photograph shows growth zoning (photomicrograph 3 mm top to bottom).

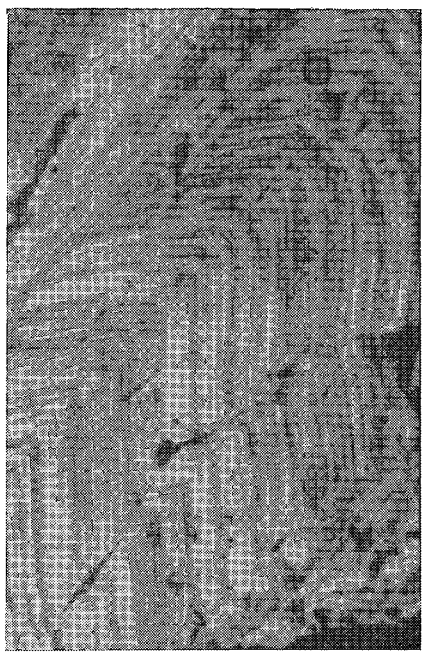

FIG. 4. Rim of bladder stone; dark lines mark growth zones (photomicrograph 3 mm top to bottom).

probable that organic material was caught up in the crystallization process and may well have contributed to the initial formation of the nucleus as well as the promotion of further crystallization.

The darker bands result from a greater concentration of fluid inclusions arranged parallel to growth planes. Although a few of the smallest inclusions are spheroidal, most inclusions are irregularly oval. The smallest inclusions are 1 micron in diameter, the largest approximately 10 microns long and 4 microns wide. These fluid inclusions were trapped on growth layers with each surrounded on all sides by the continuous crystal structure of the host. Generally, in going from the inside to the outside of the calculus, the bands within a zone gradually become darker and reach a stripe of high concentration followed rather abruptly by the beginning of the lighter phase of the next zone. This would suggest that some physiological change such as the sudden intake of fluids had put a stop temporarily to the rapid development of the crystal. In addition to the fluid inclusions, opaque indefinite shapes 10 to 15 microns in maximum dimension are seen, frequently aligned along the growth planes. These are thought to be part of the organic matrix which occurs throughout the stone. A dark stain also occurs along many zone edges and is considered organic in origin.

Single-crystal growth zoning has seldom been reported in urinary calculi, although fine-grained "tree ring" growth, similar to that seen in geological concretions, is common. Baker & Grubb (1966) have not observed growth zoning in the many calculus thin sections with which they have worked. It is not surprising that such zoning would not be developed in the fine-grained anhedra comprising most calculi. Single-crystal growth zoning has been noted previously only in whewellite and cystine stones where large single crystals were found (Prien & Frondel 1947; Lucas *et al.* 1950).

Viewed in geological terms, zoning generally might suggest low temperature, rapid growth and impure solutions, with possible fluctuations in temperature and pressure during crystal formation (Ramdohr 1969). The temperature of animals is geologically low, and in the body, urine temperature fluctuations are unlikely to be more than 1°C. Likewise, the constant atmospheric pressure required by the body precludes any significant effect of pressure on the crystallization process. However urinary calculi contain organic matrix of approximately $2\frac{1}{2}$ per cent of their dry weight, which would certainly indicate formation from an impure solution. Furthermore, the very short time, geologically speaking, that this stone has taken to reach its large size indicates a relatively rapid growth process.

The concentration of the precipitating solution, with associated organic impurities, would be the most variable feature and seems to be the most important factor in the formation of the zoning in these struvite crystals. Optical zonation can indeed result from exceedingly minute chemical differences. Such zoning records here the work of a diffusion mechanism by which the concentration of impurity in a thin layer of solution adjacent to the crystals built up to a critical value at the crystal-solution interface and was then incorporated. This would deplete the solution and the process would be periodically repeated. The animal's body must have been producing a good supply of the struvite-forming materials and the urine would have been saturated or supersaturated with such substances during the 24-hour cycle, but the dilution of the solution following intake of liquids would have served to arrest the crystal formation temporarily. If, after such periods of cessation, further crystal growth could have been inhibited or stopped, the stone would not have grown to dangerous proportions.

For many years efforts have been made to find substances which inhibit crystal growth. Buckely (1951) found that very small amounts of dye could modify crystal shape. Van't Riel *et al.* (1964), working with both pure crystals of magnesium ammonium phosphate hexahydrate and also struvite bladder stones from laboratory rats, observed significant inhibition and dissolution of urinary calculi through the use of dyes. They noted that in the therapeutic use of such inhibitors, the compound formed at the surface should cause a misfit in the lattice structure of the calculus crystal. Sutor (1969, 1970) and Sutor & Wooley (1970), in a series of growth studies of calculus constituents in the presence of various ions and compounds, appraised a number of materials which act as inhibitors in crystal formation. Therapeutic applications are being made in the successful treatment of illness involving calculus formation.

The particularly good demonstration of the manner of growth shown in this specimen illustrates the way in which calculus formation may accelerate when there is a supply of material which will quickly fit the crystal structure being developed. It also shows that the process is not a continuous one, and that there are natural periods when there are pauses in growth. Such a series of cessations of growth should give an opportunity for growth inhibitors to do effective therapeutic work.

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