Topographic Measurement of Disking Fractures from KTB Pilot Hole, Depth 3606 m

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We have recently obtained detailed digital images of both faces of a disking fracture from the KTB Vorbohrung. The fracture is in core number 882G4au at the 3605.87-m level. The images were obtained using a digitizing profiling device (a "profilometer") specially designed to provide accurate and correctly registered images of the facing walls of joints in rock specimens [*Durham and Bonner*, 1993]. Because the images returned by the profilometer are indexed with respect to one another, one has the ability to numerically reconstruct images of the joint space itself, along with having an accurate image of the walls of the joint.

Images of both faces of the disking fracture, and of the numerical difference between the two faces, i.e., of the joint space itself, are shown below.

Techniques

The profilometer is described in *Durham and Bonner* [1993]. It holds a rough surface horizontally on an x-y traversing table and measures vertical elevation in the z direction by direct mechanical contact of a mechanical stylus that is slowly lowered until it contacts the surface. Points on the surface are digitized on a rectilinear grid, and the action of the machine is x-y translation, lowering of the stylus and measurement, retraction of the stylus, x-y translation, etc. Thus there is no dragging of the stylus along the surface, and because it has a low mass (25 g) and slow descent velocity (1 mm/s), damage to the rock surface is usually confined to a scale finer than the observation scale. The stylus has a flat tip about 10 μm across, which flattens to 25 - 30 μm over the course of several 10,000s of measurements. The measurement cycle (translation, lowering, retraction) takes about 6 s, so profiling can take considerable time. The distinguishing feature of the profilometer is not the z elevation measurement but the accuracy and precision of the x-y positioning. Because we built the instrument to study joints rather than individual surfaces, the x and y position sensors are linear optical encoders with an accuracy of ± 5 μm over the entire range of travel. Thus, provided two surfaces can be correctly aligned in the apparatus, the relative positions of points on facing surfaces can be known to within ± 10 μm. Correct sample alignment is therefore critical, so we expend considerable effort on sample preparation prior to profiling. Samples containing joints are usually outfitted with several precise reference flats and markings before the joint surface is ever exposed. The combined effects of positional measurement uncertainty, alignment error, and stylus flattening give the profilometer a resolution limit in the horizontal plane of a few tens of μm.

The interval of core, 882G4au, measured in this study is roughly 8 cm long and terminated at either end by disking fractures. Three to four more incipient disking fractures were evident, so we handled the core as gently as possible during sample preparation. We carried out a number of

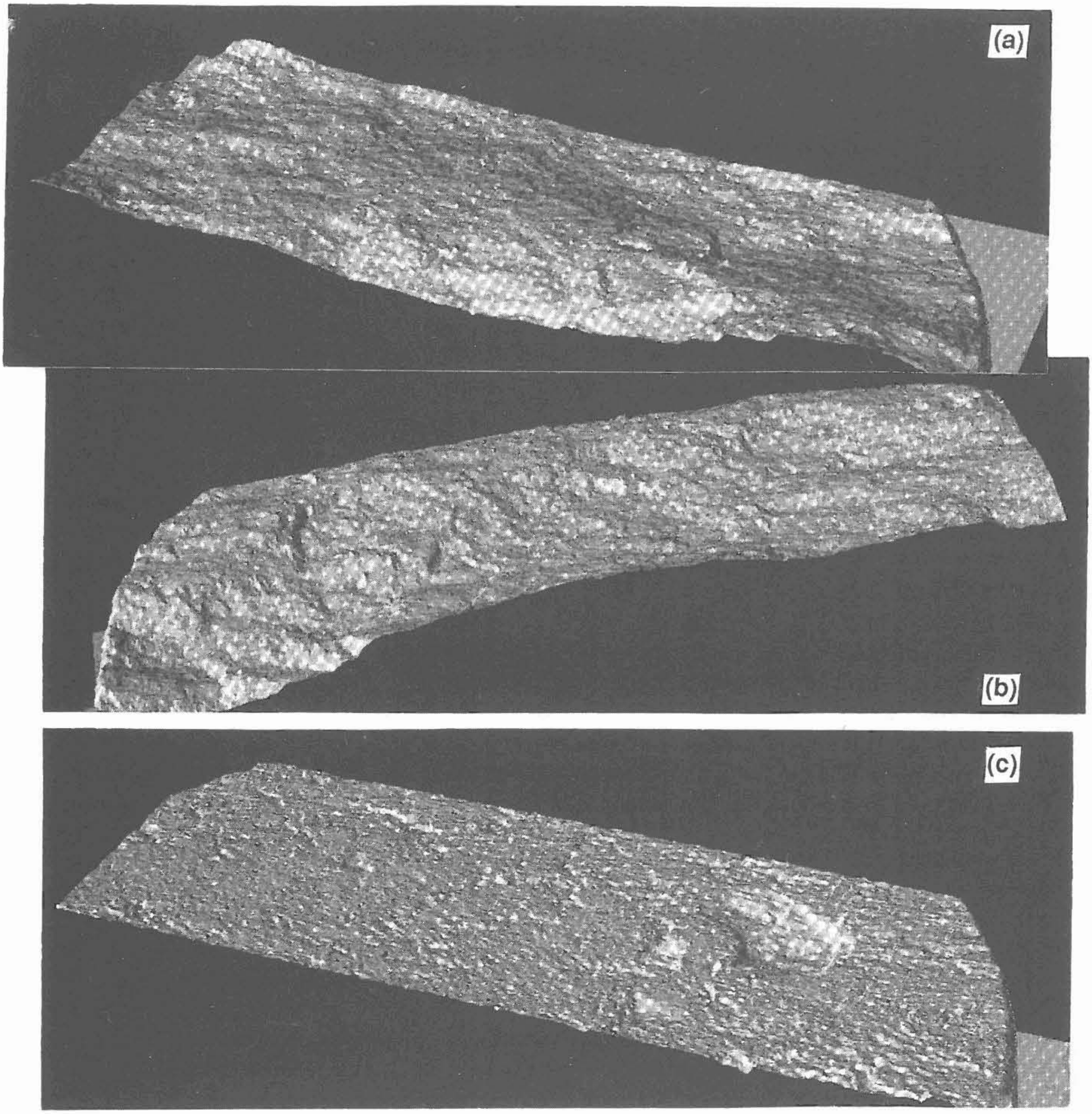

Figure 1. Digital topographic images of the bottom (a) and top (b) surfaces of a disking fracture from 3606 m depth. The digital image in (c) is the difference image of the surfaces in (a) and (b), i.e., surface elevations in (c) are the pixel-by-pixel differences of the elevations in (a) and (b). Lighting of all images comes from the left foreground. Surface area measures about 88 x 28 mm and there is no vertical exaggeration. The surface in (b) is fit to (a) by rotating (b) counterclockwise about an axis sticking out of the page (the rounded cylindrical edge of the core, at the right side of (a), aligns with that on the left side of (b)). The images in (a) and (b) compare well to the visual image one gets in viewing the rock surfaces. The "scarps" that form as apparent breaks between planes of failure are easily seen, for example. The image in (c) reveals missing material, which is more or less random except for one large pit, and another small one nearby, where material has apparently broken off between adjacent scarps.

preparation steps in order to bring the sample halves, once broken apart, into correct registration: We made one V-shaped notch in the axial direction, parallel and immediately adjacent to the solid reference line at lab orientation 0° (field orientation approximately N185°). We then ground a reference flat approximately 4 cm wide on the opposite side of the core, i.e. approximately 180° from the notch. Finally we ground a second reference flat 90° from the first flat. The grinding was precise: the surfaces deviated from flatness by less than 4 μm (the limit of our ability to measure) and the deviation from 90° of the angle between the flats was also exceedingly small (in the interests of time we have not yet characterized this error). The preparatory sequence thus completed, we then broke open the most frail of the unbroken fractures by holding one end firmly in a machine chuck and tapping lightly with a hammer on the side of the core. The fracture opened gently, with no shearing. Some debris fell from the fracture as it opened, and a bit more loose material was brushed from the surface prior to profiling. All debris was gathered and weighed. Three chips had masses of 3.4, 0.3, and 0.2 g, and the remaining debris had a mass of 0.4 g.

We mounted the two pieces of rock side-by-side in the profilometer with fracture surfaces facing upward. We oriented the surfaces so the V-notches faced each other, and dropped a dowel pin between the two pieces in order to get positive alignment. The assembly was then clamped to the x-y traversing bed of the profilometer, and the ground reference flats, now at the right and left sides of the assembly, contacted the flat platens of the clamping vise. The final positioning adjustment was a slight shifting front-to-back in order to put the 90° reference surfaces, now facing frontwards, exactly in the same plane. This accomplished, we then digitized the topography of the two surfaces on a grid of points spaced 0.2 mm apart in both the x and y directions.

Observations and Interpretation

Figures 1a and 1b show matched portions of the disking fracture surfaces. The images were formed on a Silicon Graphics workstation using the Explorer imaging processing software. The images measure 440 x 141 pixels each, or 88 x 28.2 mm, roughly one-fourth of the total surface. The is no vertical exaggeration. The images stretch from the reference flat opposite the V-notch (left-hand side of Fig. 1a, right-hand side of Fig. 1b) to the curving outer surface of the core. The surfaces are viewed obliquely, but from different angles, as if one held one surface (Fig. 1a) in the left hand, the other in the right, with hands held comfortably at elbow height in front of the body. Figure 1a is the lower surface, and the direction of the N185° azimuth is parallel to the front of the image, pointing towards the right. Likewise, on the upper surface (Fig. 1b) the N185° azimuth is towards the left.

The surfaces show features at higher magnification than one gets by viewing a hand specimen and, except for the removal of color, gives a similar view. For example, there are many large and small scarps running approximately front-to-back (field direction E-W) that are also apparent visually. The digital topographic information allows us to state that from a statistical standpoint these fracture surfaces are fractal (roughness scales with length), and they are therefore ordinary fracture surfaces. Specifically, treating the topographic information as a random process of two variables and performing a spectral analysis shows a linear relationship between the logarithm of power spectral density and the log of spatial frequency: the signature of a fractal geometry

The images of the individual surfaces are useful for comparison to the actual surfaces, but the real power of the technique is the image of the joint space (Fig. 1c), the difference surface formed by the pixel-by-pixel subtraction of the elevations of the single surfaces. This "surface" is distinctly non-fractal: it is quite flat at long wavelengths, since the two surfaces of the fracture are rather well mated. The roughness of the surface at finest scale may be noise; this has yet to be evaluated. The main feature of the difference surface is a large depression towards the right side that is probably one of the 0.2 or 0.3-g chips removed as debris during the opening up of the fracture. It corresponds to the largest visible scarp on the upper (Fig. 1b) surface. One can conclude that the surface is mechanically layered, either as a result of coring and removal from depth, or as a result of intrinsic structure. The scarps formed as the surfaces were pulled apart (in tension) and cross fractures formed because the macroscopic fracture was not exactly parallel to the mechanical layering.

References

Durham, W. B. and B. P. Bonner, PEAK: A new kind of surface microscope, *Int. J. Rock Mech. Min. Sci.*, accepted, 1993.

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