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Relating X-Ray Attenuation Measurements to Water Content and Distribution in SB-15D Core

B.P. Bonner, J.J. Roberts and D.J. Schneberk

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Lawrence Livermore National Laboratory

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B.P. Bonner, J.J. Roberts and D. J. Schneberk
Lawrence Livermore National Laboratory
L-201 Livermore CA, 94550

Introduction

Making improved estimates of the water content of The Geysers reservoir is fundamental to efficient and economic long term production of steam power from the resource. A series of coordinated physical properties measurements for core recovered from SB-15D, reported in this volume in a series of papers by Bonner, Roberts and co-authors, have been made to better understand water storage and to relate water content and distribution to observable geophysical properties such as electrical conductivity and seismic velocities. A principal objective here is to report new interpretations of x-ray scans made within 72 hours of core recovery from SB-15D, which suggest, taking advantage of preliminary measurements of capillary suction for metagraywacke, that water content was low (<20%) in much of the preserved core.

Experimental Methods and Procedure

High energy x-ray scanning and three dimensional image reconstructions (x-ray Computed Tomographs) were made as soon as possible after recovery from depth while samples were still in the aluminum coring tubes. The expectation was that disturbance of the fluid distribution would be minimized by prompt scanning. Subsequent measurements, involving drying and resaturation of whole core, have demonstrated that carefully preserved core was critical for reliable measurements. The third generation scanning procedure used here differs from more familiar medical imaging technology in that higher energy is used to improve penetration, and true three dimensional images can be reconstructed from a sequence of radiographs collected as the sample is rotated in the x-ray beam. Spatial resolution for the images analyzed here is approximately ten times better than for typical medical scanners (140 micrometers) and contrast resolution is ~0.2%. Details of the sampling procedure, core preservation method, and scanner hardware and capabilities are given in the papers by Bonner and colleagues included in this volume.

Results

All of the data reported here are images or plots showing x-ray attenuation, relative to air in arbitrary units. Radial reconstructions though cores at a range of depths are reproduced here for convenience (Bonner et al 1995, Figure 3). Beginning from the upper left and proceeding clockwise, scan depths are 875, 918, 1420 and 1530 ft. All were recorded within 72 hours of drilling. The corresponding profiles span approximately a core diameter, which equals ~ 3.4 in. All of these profiles have, to some degree, characteristic higher x-ray attenuation near the core edges, although the details are clearly sample dependent. The 1530 ft profile also shows high attenuation near the center, a region crossed by a partially filled vein. This porous region clearly appears in the three dimensional reconstruction shown by Bonner et al., 1995 as Figure 4, and probably connects to the core surface. High attenuation near the core edges is consistent with fluid intrusion during drilling. The possible effect of hardening of the x-ray beam, which can produce a 'cupping' of attenuation profiles, has been eliminated by calibration procedures. The characteristic profile shape seen in prompt scans (Figure 2a) is lost when core is dried slowly for a period of several weeks, as demonstrated in a scan taken of a slightly different section of the 918 ft core. A scan of the core dried to ambient humidity (~ 30%) is shown as Figure 2b. The left side of the profile is typical for the dry case, showing constant or decreasing attenuation near the core edge. The right side does not show a profile characteristic of fluid infiltration, but instead shows a step change associated with a fracture and change in lithology. The last profile, Figure 2c, was taken close by after the sample was backfilled with water following vacuum evacuation. Saturation in this case was probably greater than 90%. This profile is characteristic of the backfilled sample. The attenuation has become higher on average (Roberts et al., 1996), but more importantly, shows a decrease near the edges of the core. Although the core was transferred from the water vessel to the aluminum core tube within seconds and the tube was immediately sealed with excess water to saturate the air in the tube with water vapor before the scan, the sample edges dried as the sample reached equilibrium with the small volume of vapor in the tube. It is significant to note that core preservation methods employed in the field prevented dryout, and made it possible to observe profiles indicative of mud intrusion.

Conclusions

Preliminary measurements and indirect indications of permeability to fluid for SB-15D metashale and metagrawacke (Persoff, Boitnott, Roberts, work in progress and this volume) indicate that Darcy flow cannot account for mud infiltration during the limited time core is exposed to pressurized mud at depth. The most likely explanation is that capillary suction causes the observed fluid transport. Independent evidence supports this hypothesis. Mercury porosimetry shows that the Geysers rocks have significant porosity in the 10 micrometer range. Since capillary suction varies inversely with pore size, large capillary suctions are expected. Measurements of capillary pressure by Persoff for SB-15D graywacke shows that suction is large for low water saturation. Capillary suction is in general a strong nonlinear function of water saturation for low porosity rocks, rapidly diminishing for saturations greater than 20-30%. Since this appears to be true for typical samples from SB-15D, then the observed early time x-ray attenuation profiles from SB-15D can only be explained by mud infiltration into matrix rocks with low water saturations.

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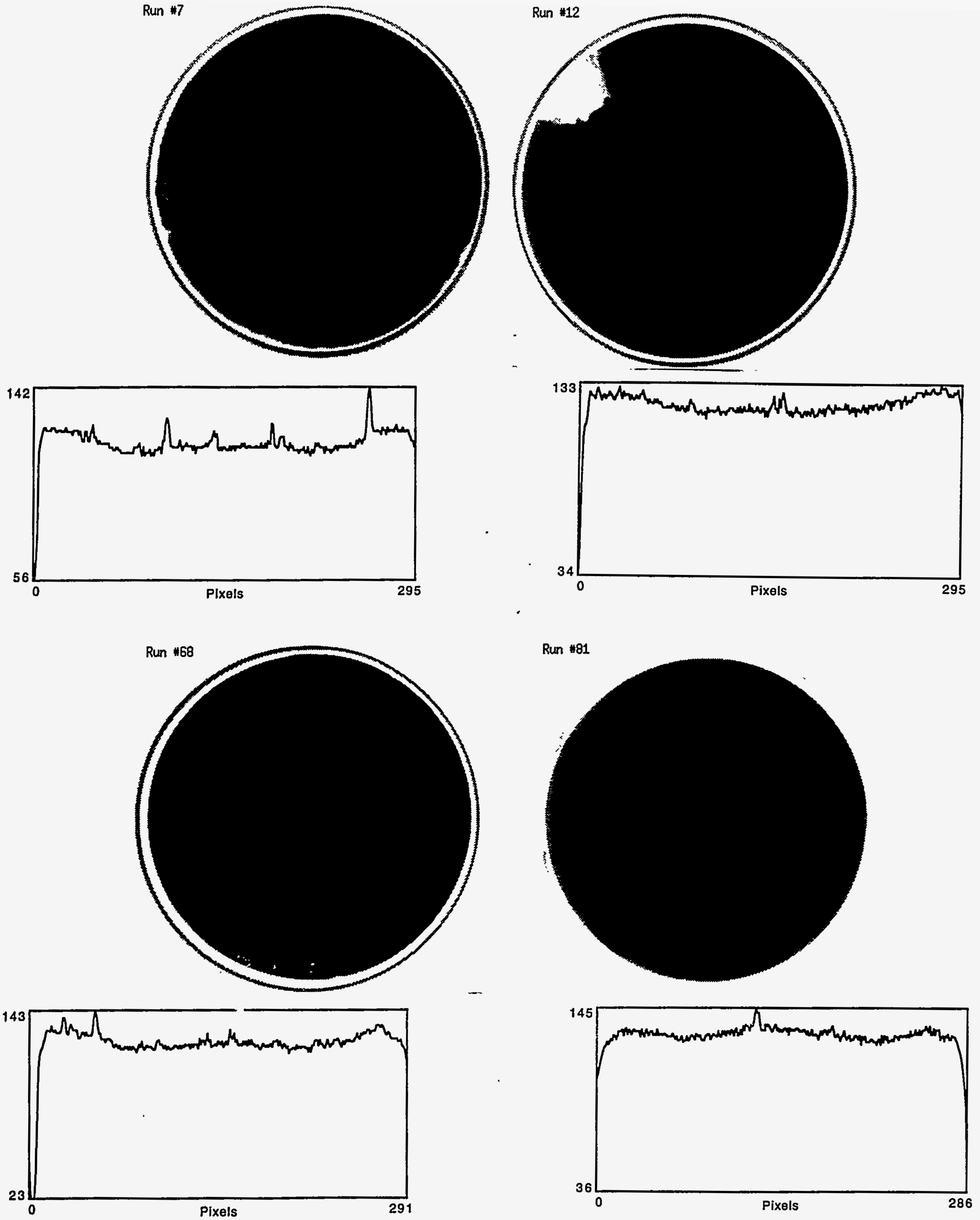

Figure 1 a-d. Radial scans reconstructed for preserved core within 72 hours of drilling; negative images are presented here for improved reproduction, darker areas indicate high attenuation. Beginning from the upper left and proceeding clockwise, scan depths are 875, 918, 1420 and 1530 ft. Profiles of relative attenuation in arbitrary units are shown for a representative diameter.

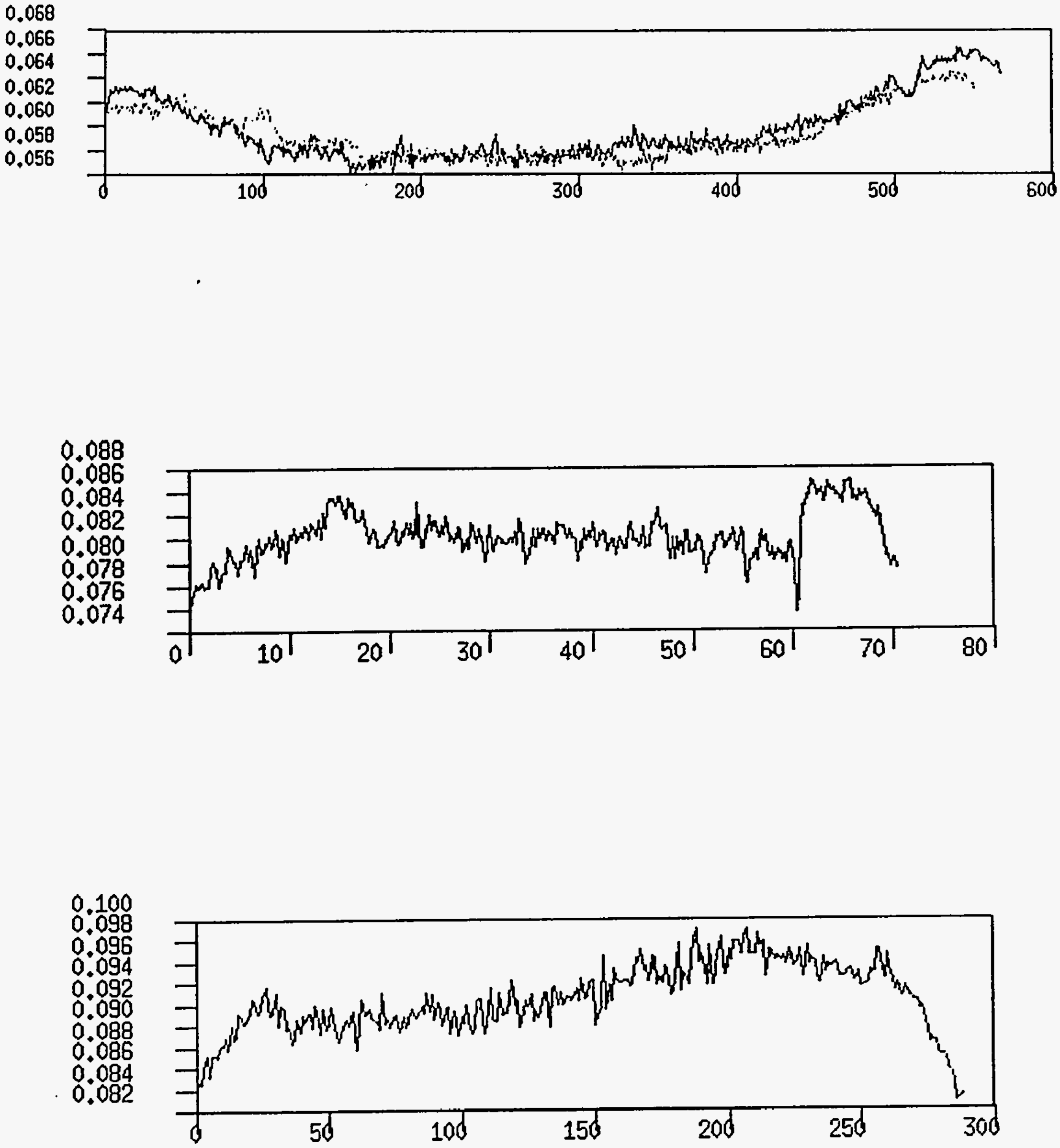

Figure 2a, b, c. Attenuation profiles for the 918 ft samples. after drilling, and before and after drying to room humidity and backfilling with tap water.