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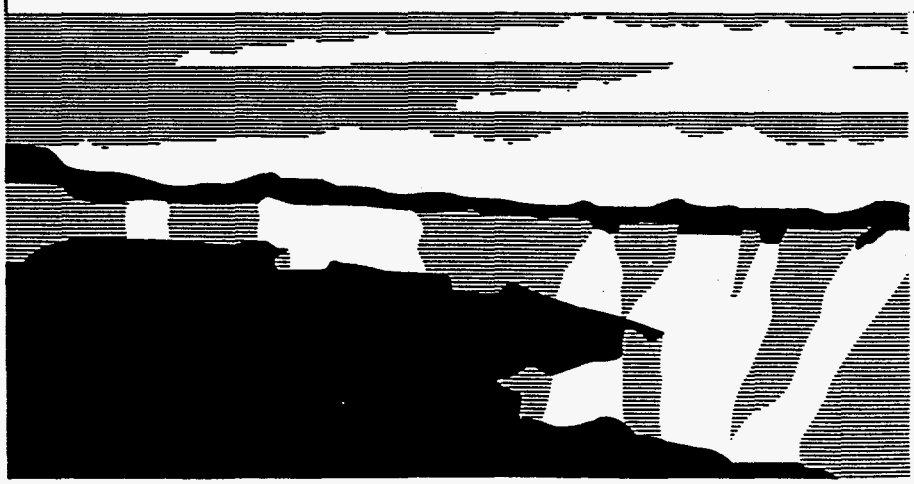

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Fractal Characterization of Explosive Morphology

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The effect of particle size on the details of the initiation and detonation of condensed explosives has long been known[1]. The effect of the three-dimensional nature of explosive particles as a neat pressings (with voids), or as dispersed in a second (or third) phase (with or without voids), has been the subject of many investigations of detonation phenomena (e.g. see references[2,3,4,5,6]) However, succinct and accurate descriptions of the compacts and pressings are difficult to achieve because the morphology and size distributions are generally altered by processing into useful configurations and densities. Three-dimensional measurements of near-full-density pressings are not easy and have not been done with great accuracy.

We attempt to develop a methodology using fractal concepts that will use detailed two-dimensional measurements of surfaces to characterize the three-dimensional materials. The relationship of scaling from profile-to-area and area-to-volume, when either profile or area are fractal, has been studied[7]. Fractal concepts have been applied to disparate natural phenomena, including the nature of the geomorphology of many earth structures such as coastlines and island size. Further, extension of these basic concepts into the characterization of surface roughness as it effects contact resistance between two materials pressed together has shown the fractal nature of the contact conductance[8]. For boiling where the surface characterization is important, power-law behavior over limited ranges of surface cavity size is observed[9]. This limited range of useful cavity size for boiling is similar to the limited particle sizes employed in explosive and limits the self-similar range over which some desired behavior is observed.

Reports of particle-size distributions for RDX[3] and HMX[10] are analyzed, for example, using the methods of fractal geometry. Initial investigation of particle size distributions are shown in Fig. 1 for the data of Burnside, *et al.* and Moulard. The cumulative number density-size distributions for both data sets follow power laws given by

$$N(d \geq d_p) \propto d_p^{-m}$$

where d is the particle diameter, d_p is any particular particle diameter, and m ranges from 2.2 to 2.4.

There are two salient features of this plot: 1. All the data lie within a remarkably narrow band, even considering the log-log plotting. The RDX and HMX data nearly overlay, even though the processing methods are very different. 2. For particle diameters below approximately 100 μm, this integral distribution is well represented by a power-law.

The data of Burnside, *et al.* are for neat HMX pressed to various fractions of maximum density. The breaking of the larger particles due to compaction is reflected in this representation by the increased number of smaller particles and the smoothing of the original distribution as intermediate particles are created. Flattening of the curves is observed for the smallest particles and may result from either measurement limitations or the finite size effect (the lack of very small particles). Larger particles disappear as compaction increases (finite size effect).

The data of Moulard is from three carefully prepared samples, each designed to have a very narrow size distribution with distinctly separate means. The fact that these data nearly overlay the HMX data is (at least) interesting considering they are two distinct materials processed by different methods.

We will further explore the analysis of various particle-size and morphological measurements using the formalisms of fractal geometry. We intend to show, by a combination of modeling and data analysis, that a three-dimensional description of the explosive, the binder, and the voids can be constructed from one- and two-dimensional measurements of surface. In the long term, we hope to correlate these descriptions with the measurements of explosive behavior.

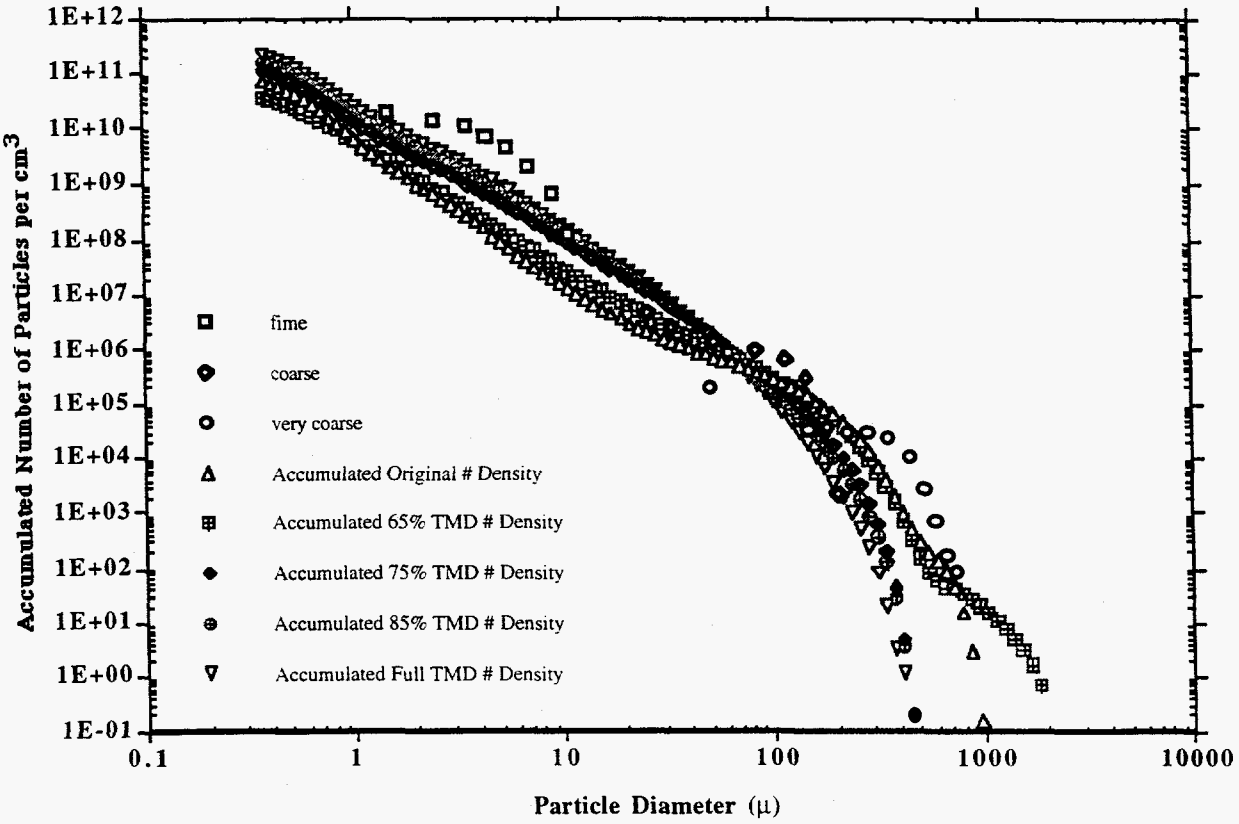

Fig. 1. HMX and RDX Particle Size

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[3] H. Moulard, "Particular Aspect of the Explosive Particle Size Effect on Shock Sensitivity of Cast PBX Formulation," Ninth Symposium (International) on Detonation, Portland, OR, 18-24 (1989).

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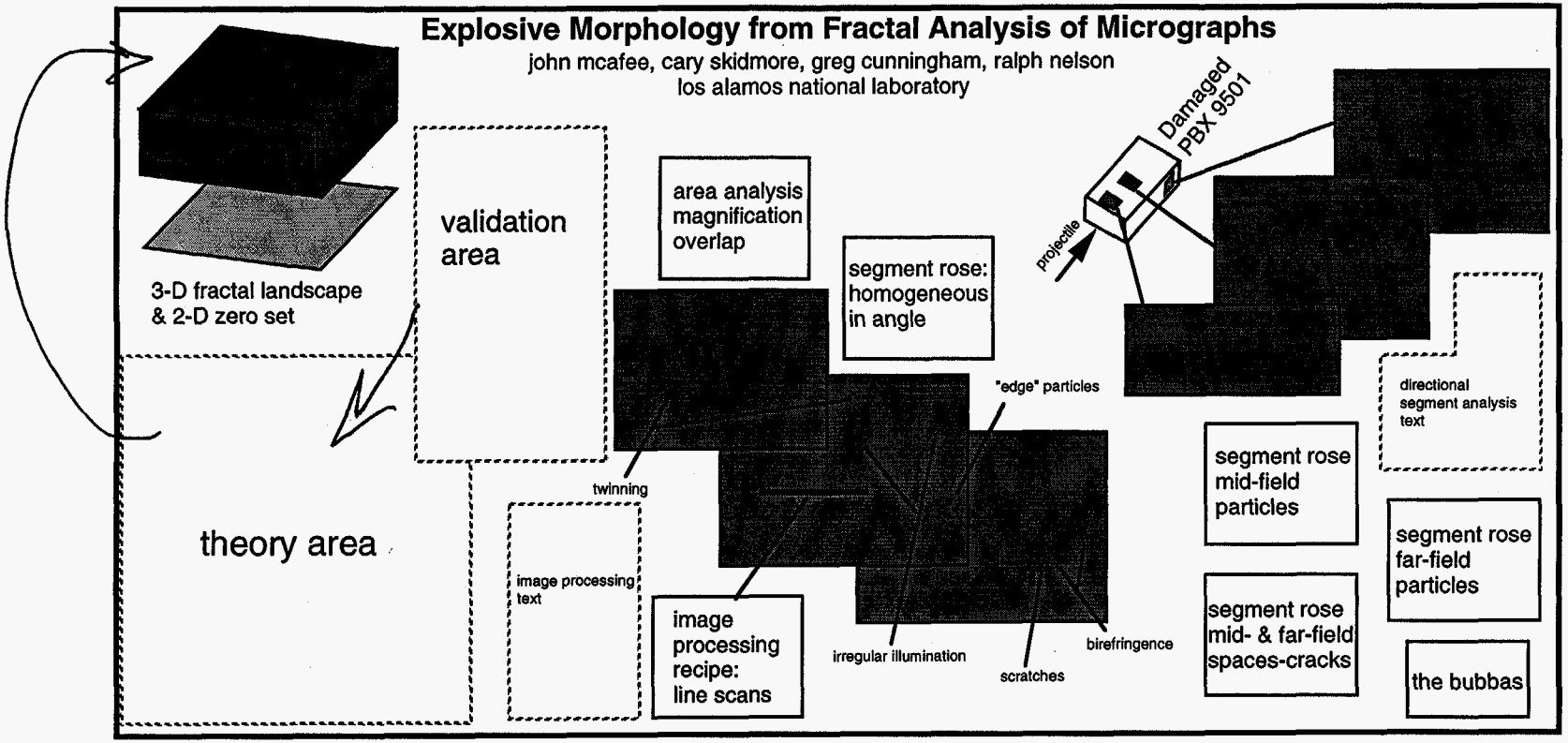
[8] A. Mujumdar and C. L. Tien, "Fractal Network Model for Contact Conductance," ASME J. Heat Transfer **113**, pp. 516-525 (1991).

[9] R. A. Nelson, D. B. R. Kenning and M. Shoji, "Is Nucleate Boiling Chaotic?, If so, why?," Invited paper, Proceedings of 4th Experimental Chaos Conference, Boca Raton, FL, August 6-8 (1997)

[10] N. J. Burnside, S. F. Son, C. B. Skidmore, and B. W Asay, "Particle Characterization of Pressed Granular HMX," 10th APS Topical Conference on Shock Compression of Condensed Matter, Amherst, MA, July 27-August 1 (1997).


Explosive Morphology from Fractal Analysis of Micrographs
john mcafee, cary skidmore, greg cunningham, ralph nelson
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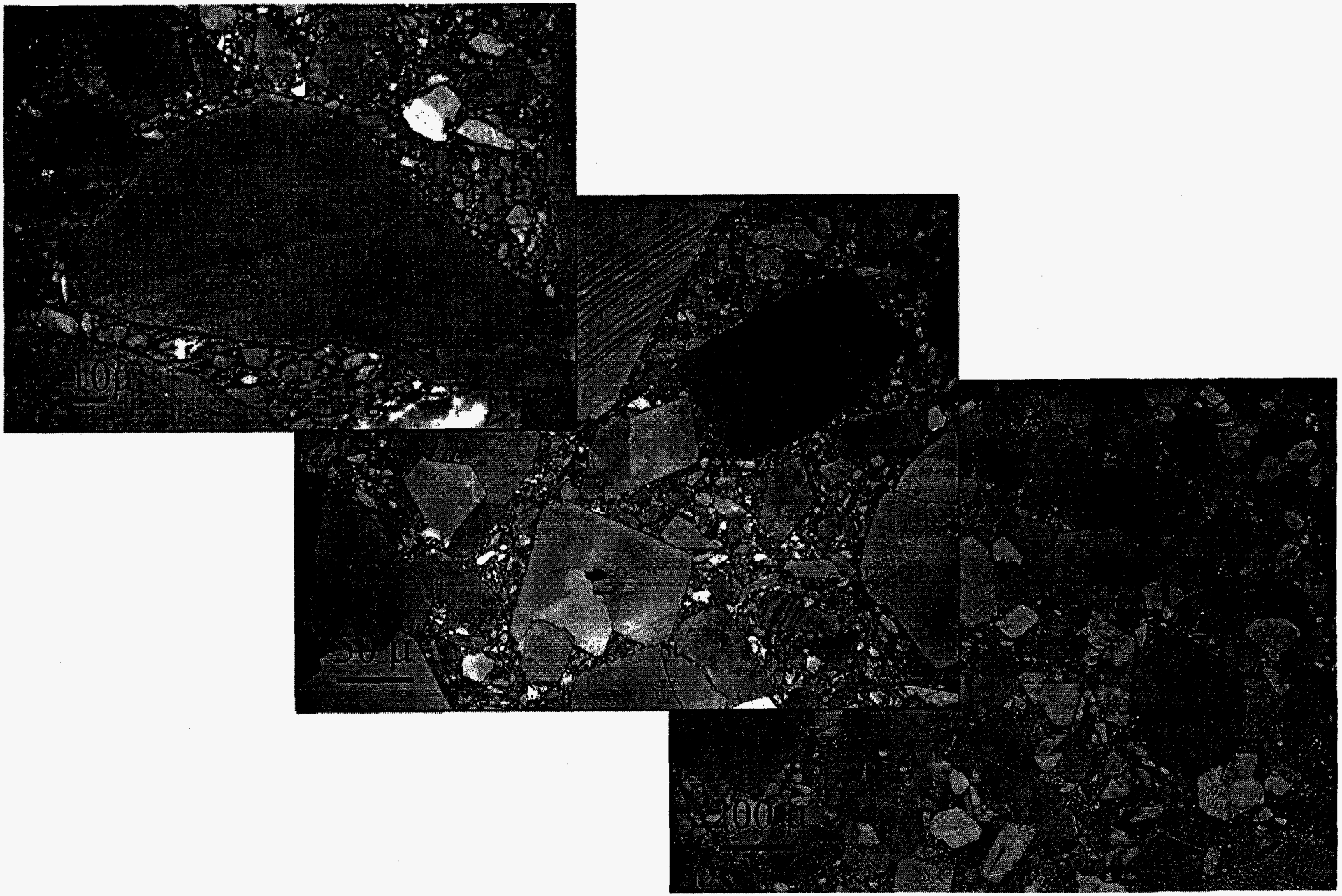
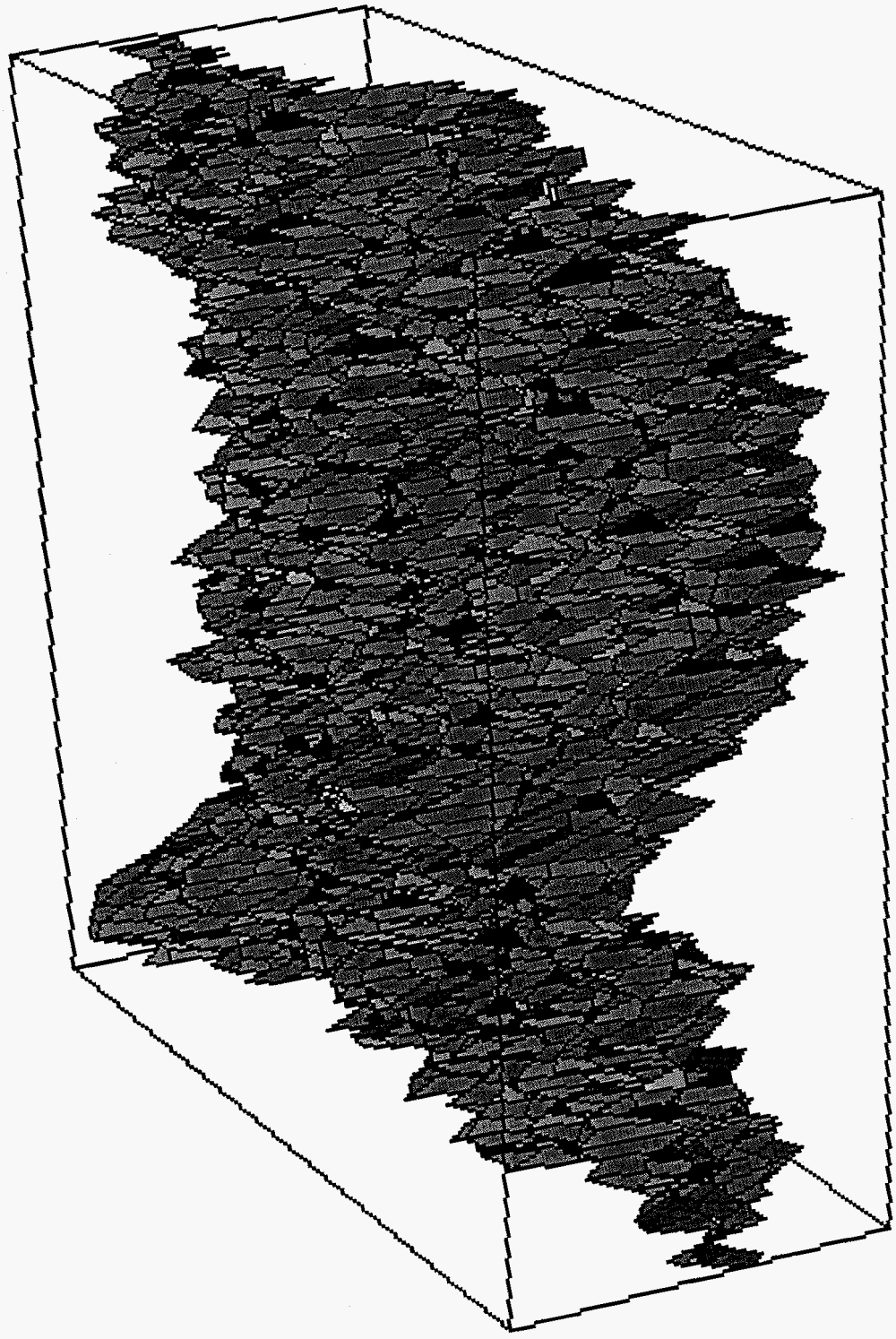
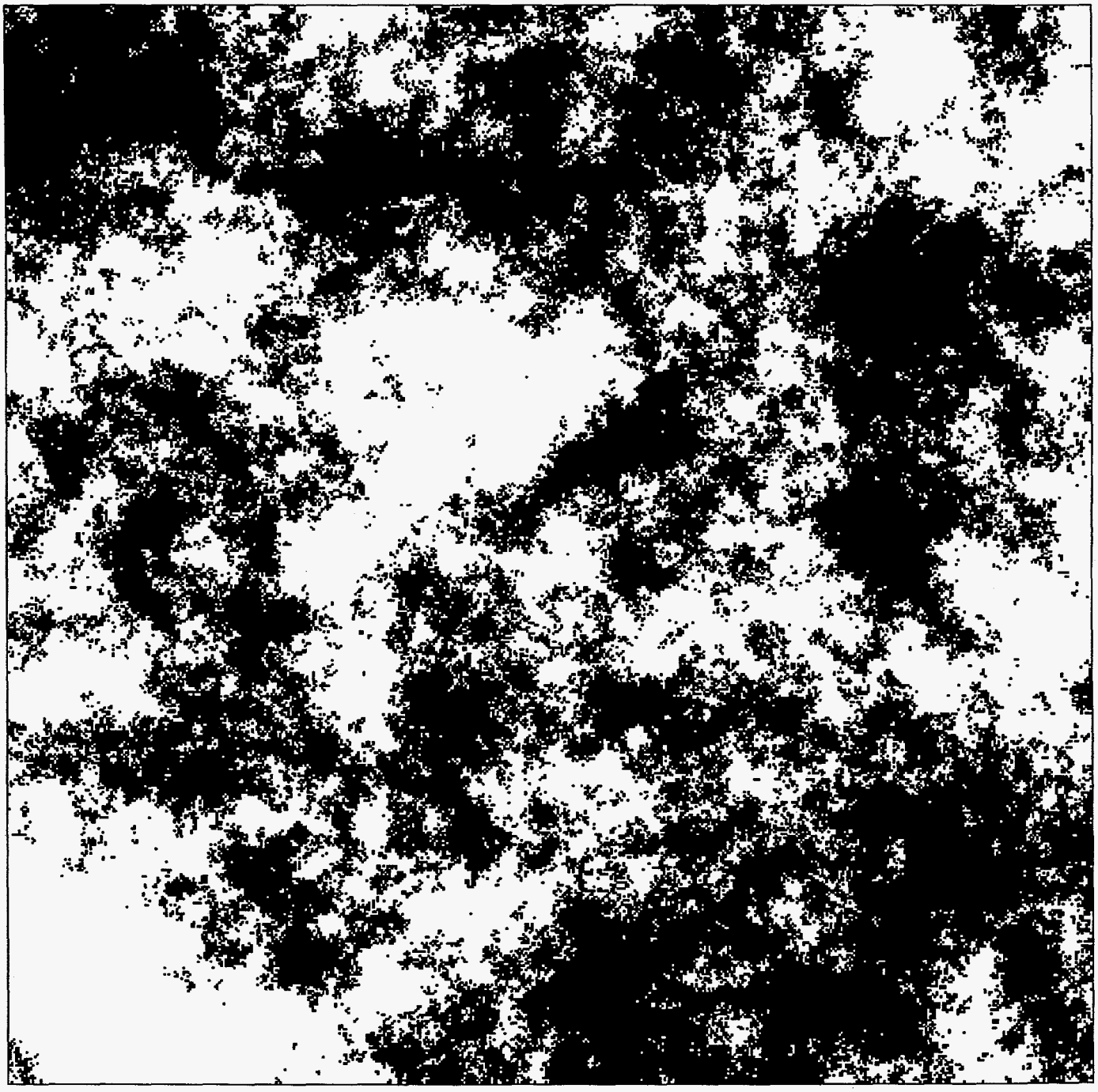
3-D fractal landscape
& 2-D zero set
validation
area
theory area
area analysis
magnification
overlap
segment rose:
homogeneous
in angle
Damaged
PBX 9501
projectile
directional
segment analysis
text
"edge" particles
twinning
image processing
text
image
processing
recipe:
line scans
irregular illumination
scratches
birefringence
segment rose
mid-field
particles
segment rose
far-field
particles
segment rose
mid- & far-field
spaces-cracks
the bubbas


10μ
50μ
100μ





THEORY

Zero sets:

e.g., elevation(x,y) - constant = 0 ⇨ contour

Each zero set has a fractal dimension of d-1 where d is the dimension of the original set.

Number and length scale relationship:

$N(L<l_{reference}) \propto L^{-d}$

where d is the fractal dimension

Number and area scale relationship:

$N(A<a_{reference}) \propto A^{-d/2}$

Validation Using Various Fractal Landscapes

Line fractal dimension			
Line orientation	Theoretical (zero set #)	measured	difference (theory-measured)
0°	0.75 (1)	0.87	-0.12
90°	0.75 (1)	0.88	-0.13
0°	0.70 (1)	0.80	-0.10
0°	0.70 (2)	0.81	-0.11
0°	0.70 (3)	0.87	-0.17
0°	0.50 (1)	0.57	-0.07
90°	0.50 (1)	0.58	-0.08
0°	0.50 (2)	0.49	0.01
0°	0.50 (3)	0.62	-0.12
30°	0.50 (3)	0.62	-0.12
45°	0.50 (3)	0.63	-0.13
60°	0.50 (3)	0.64	-0.14
90°	0.50 (3)	0.63	-0.13
135°	0.50 (3)	0.59	-0.09
0°	0.50 (4)	0.68	-0.18

Image Processing - Using "NIH Image" on Macintosh and PCs

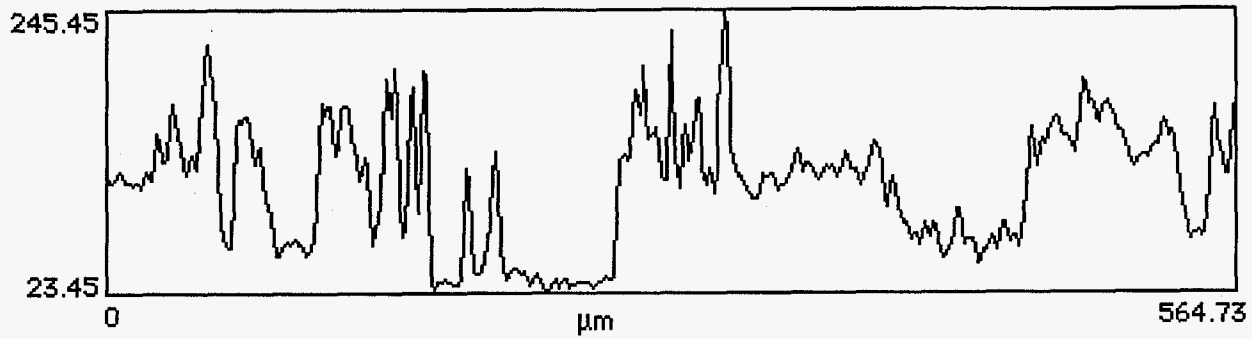
Accurate measurements of the particles requires a method that overcomes several manifestations of the sample preparation and lighting used to obtain the micrograph. Noted on the periphery are examples of irregular illumination, birefringence of the HMX resulting in "light and dark" appearance of different particles, scratches from sample polishing, twinning within the particles (probably due to the pressing during formulation), and incomplete images of particles on the edges of the images.

We developed a recipe of contrast enhancement and background subtraction that (when combined with our line-segment analysis technique) suppresses all these effects except the scratching.

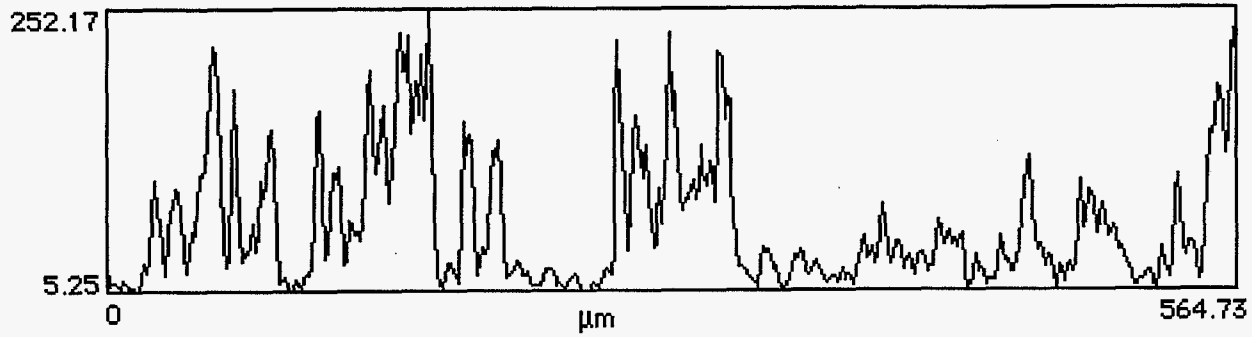
Three line scans from the middle micrograph are shown on the right. The topmost plots the gray-scale values from the unprocessed image. The edges are easily found by manual comparison to the image. However, the gray-scale value for individual particles varies by a large fraction of the 0-to-255 scale. Application of a standard 'edge-finder' routine yields the center trace. Here, the large particles are re-coded to near the same values, but the smaller particles still have widely varying gray-scale values.

The bottom line scan shows the results obtained with our processing recipe. Edges are distinct and particles have similar gray-scale values.

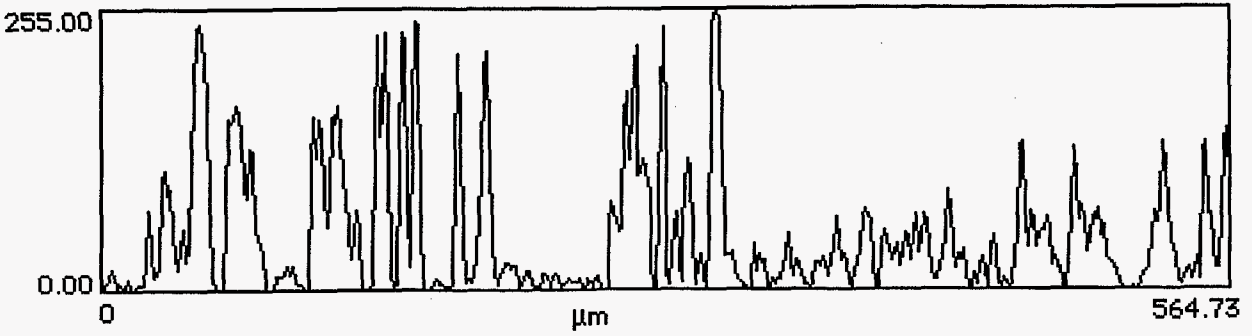
Original micrograph, Fig 4



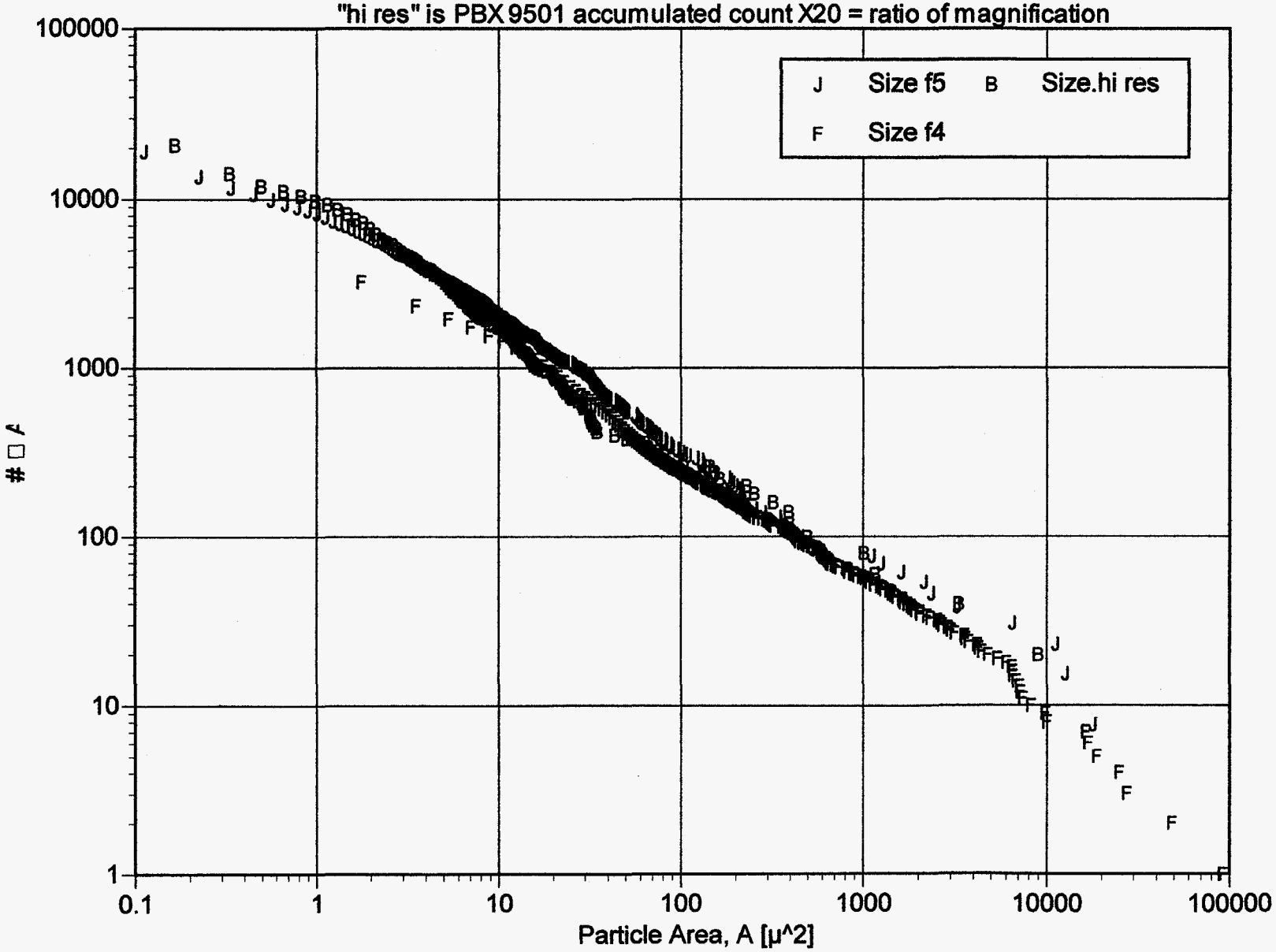
After "Edge-Finder" Routine



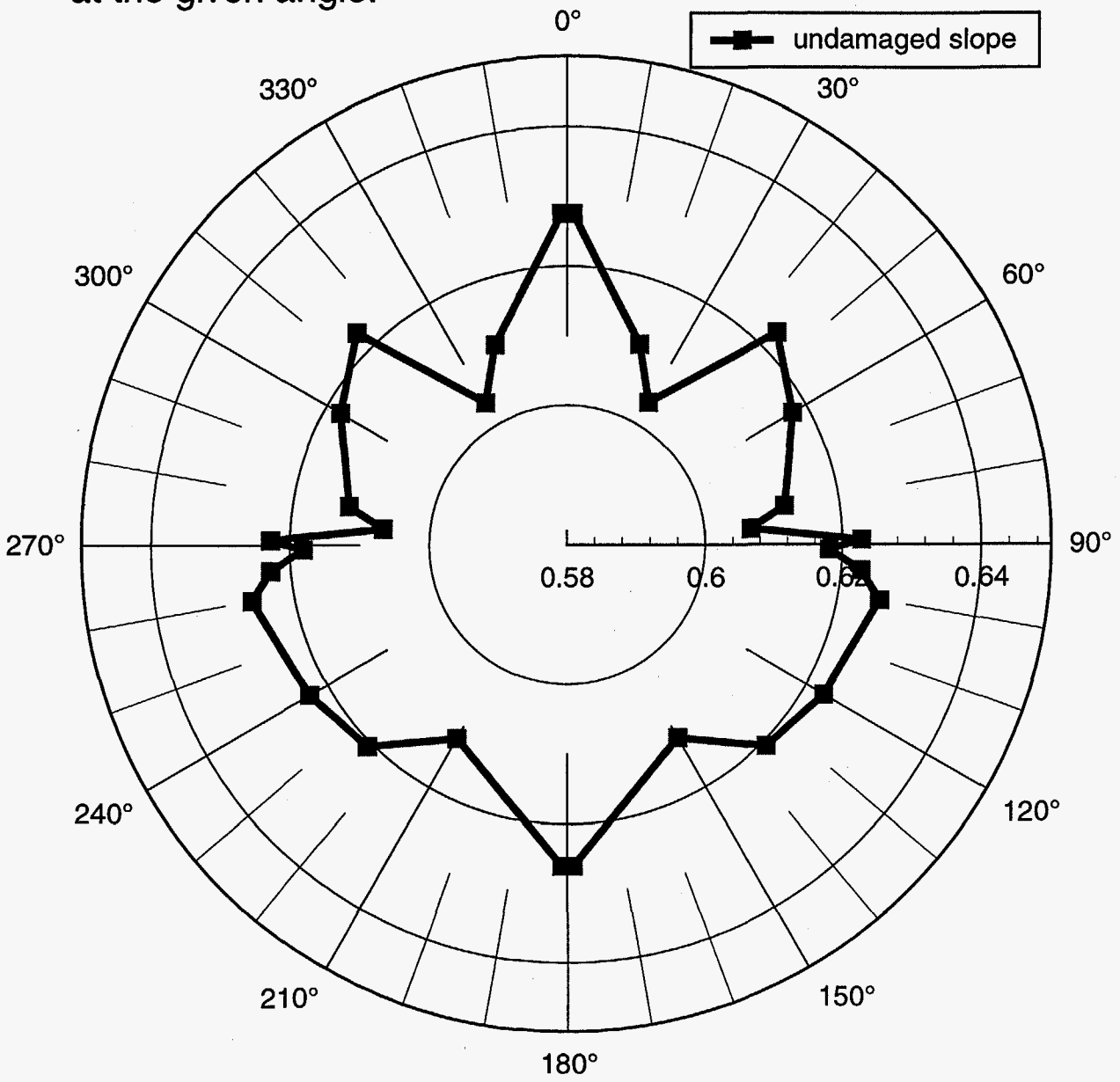
After Image Processing Recipe



Figures 4 & 5:
fig 5 accumulated count X7.717 = ratio of micrograph areas
"hi res" is PBX 9501 accumulated count X20 = ratio of magnification



Power-Law Slope fromLine Segment Analysis of PBX 9501
The radius in the figure is the slope of the segment analysis at the given angle.



Directional Line-Segment Analysis

Visual comparison of the PBX 9501 to the "Damaged" PBX 9501 micrographs shows evident qualitative differences in appearance. Using our Line-Segment Analysis technique on processed images results in a quantitative measure of the differences between damaged and pristine PBX 9501, and between different areas of the damaged PBX 9501.

Below the micrographs of the damaged explosive are polar plots of the power-law slope obtained from line-segment analysis at different angles to the direction of the initial projectile insult. In these plots the radius is the value of the power-law slope, and the angle is the direction of the lines in the analysis. Note that the radius scales are different for each plot. This is done to more clearly show the systematic variation of the slope.

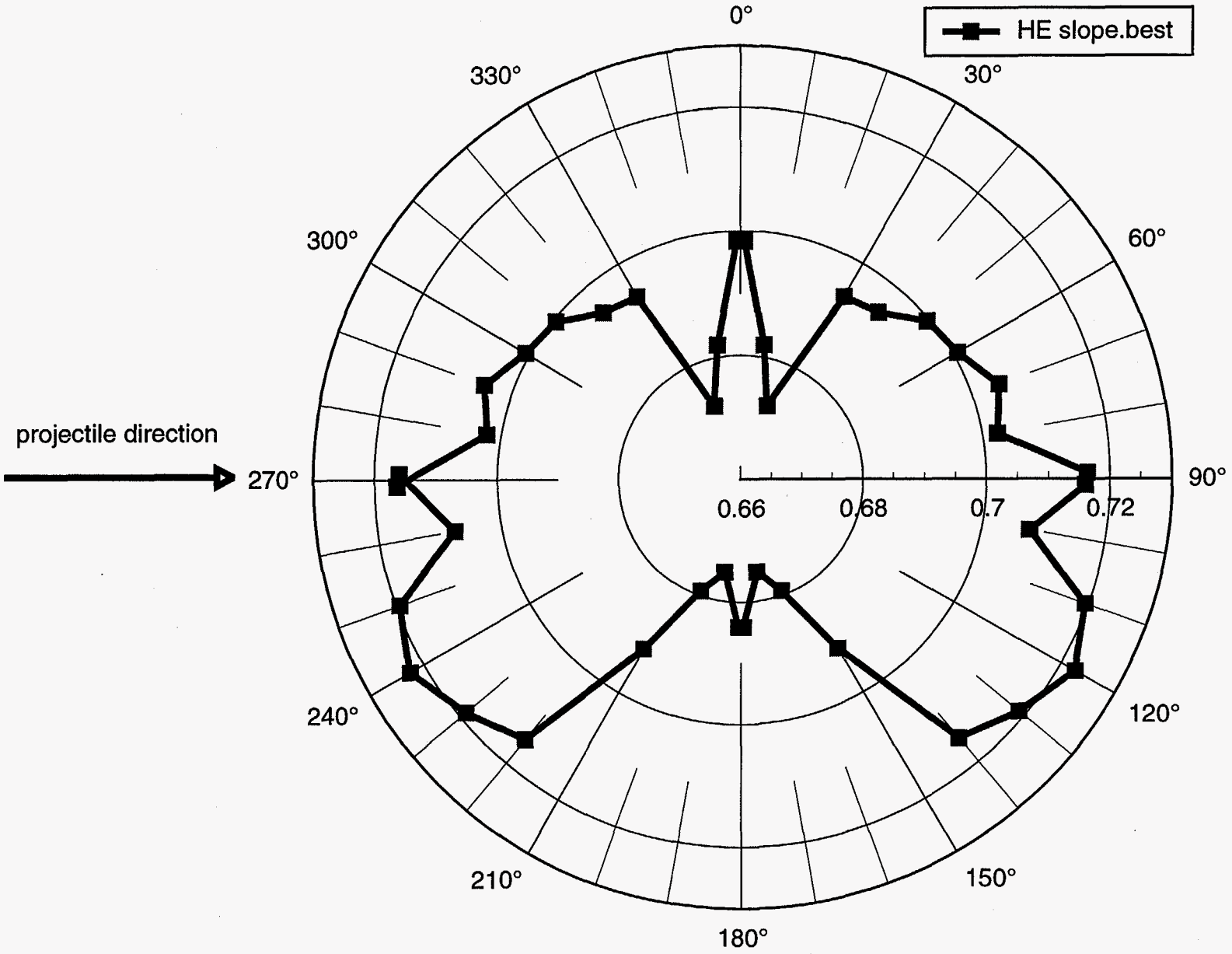
Most notable is the dissimilarity of the particle plots for the mid- and far-field regions. Visual inspection of the micrographs tends to support this difference. Also of note are the plots for the cracks and spaces. The values of the power-law slopes are greater than one, thus the distribution of sizes for these features is not fractal. Also, the directional characteristics are substantially different for the two regions.

We are unwilling to further interpret these results at this time. Interesting speculations concerning resolution of uni-axial strain, and hot-spot generation have occurred to us, but are not yet supported.

This is a work in progress. In the near future, we will continue analysis and experimentation on PBX 9501 and other explosives.

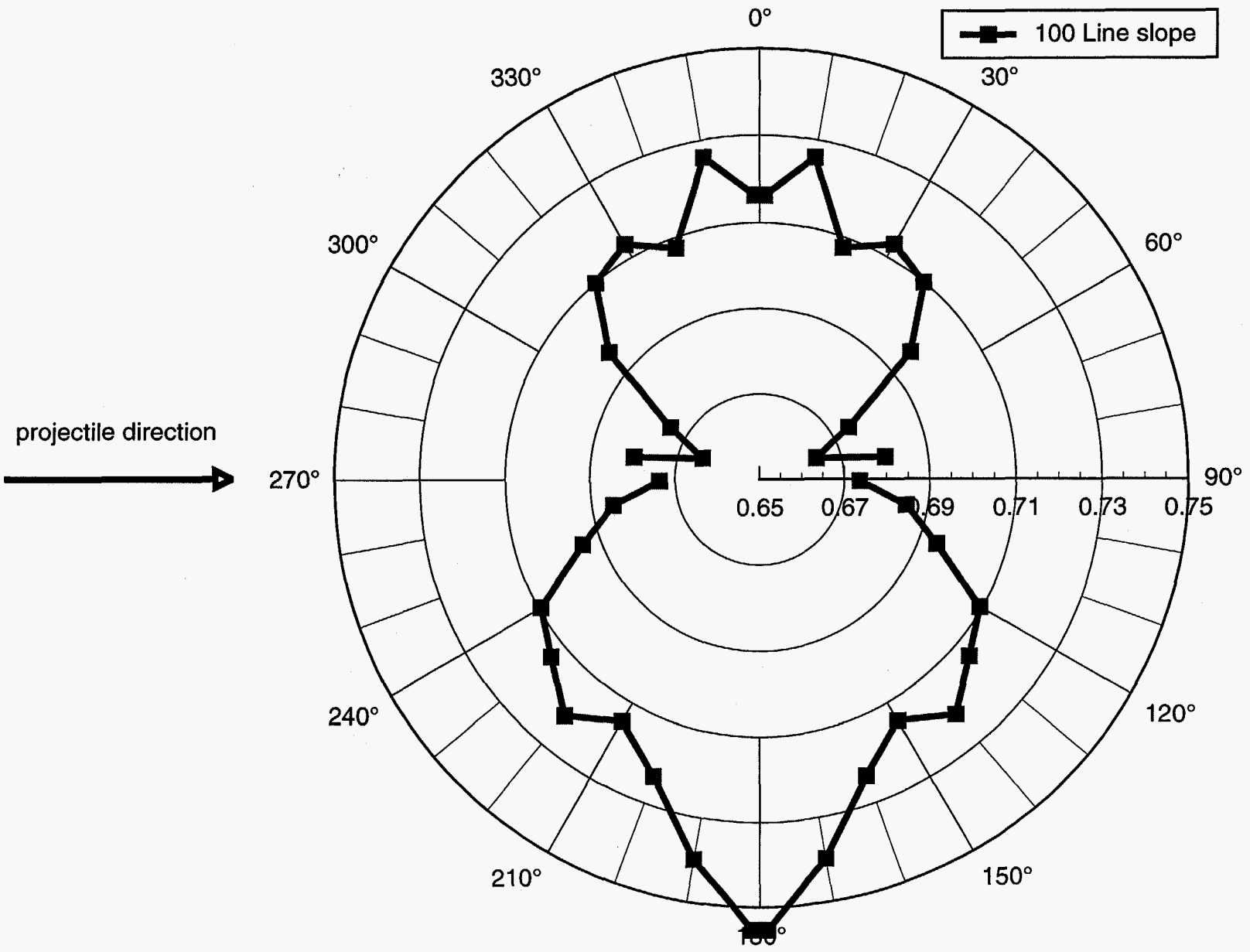
PowerLaw Slope from Segment Analysis of Damaged PBX 9501 - Mid-Field Region

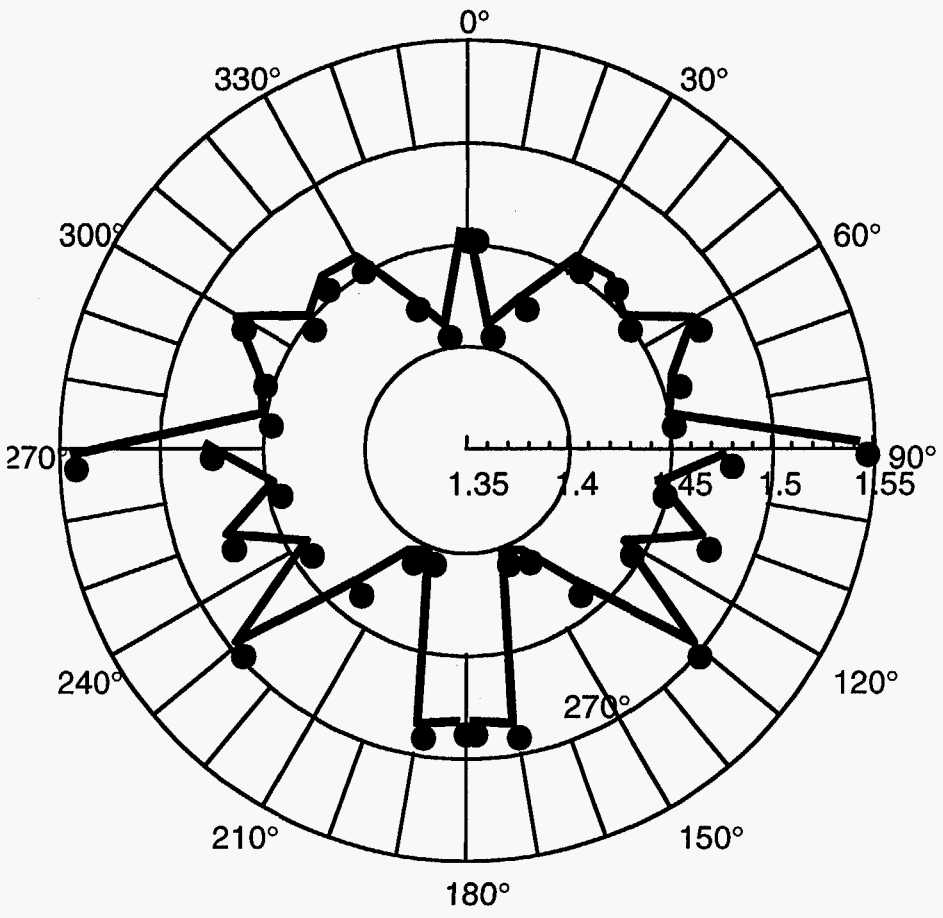
Note the difference of the value of the slope from the pristine material in addition to the strong directional (angular) differences



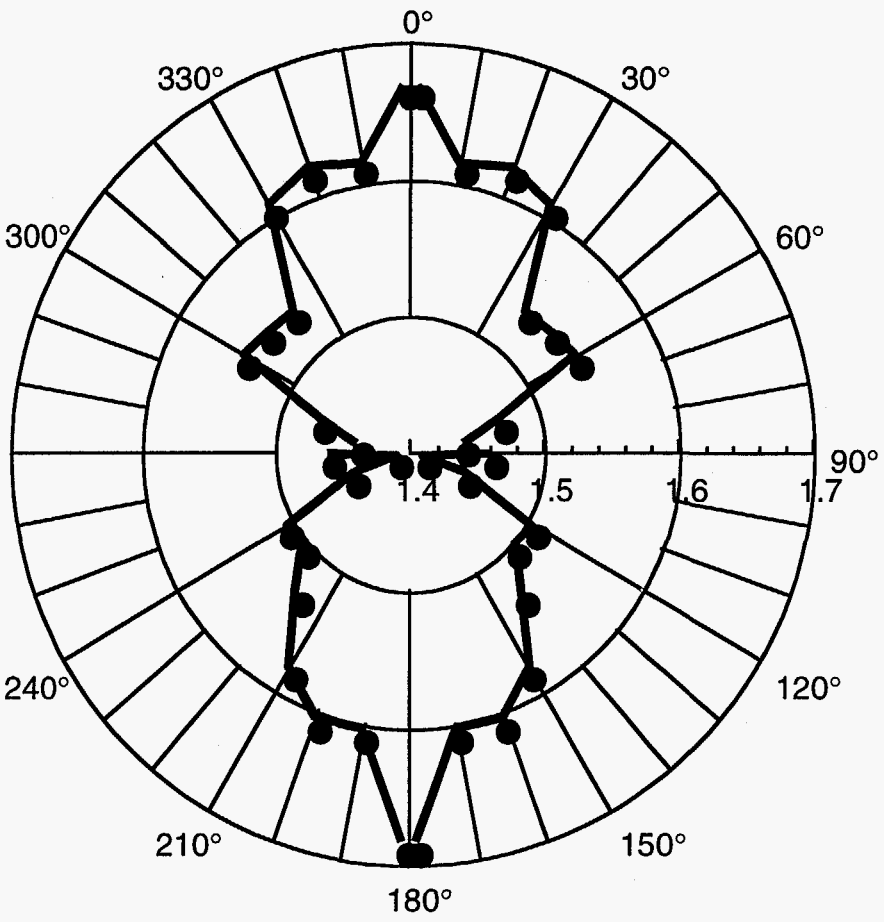
Power-Law Slope fromSegment Analysis of damaged PBX 9501 - Far Field Region

Note the clear dependence of the slope on the angle of analysis





Mid-Field



Far-Field

Power-Law Slope from Segment Analysis for the Spaces and Cracks in Damaged PBX 9501
Note two important points: 1. The power-law slopes are significantly greater than one, therefore the distribution of cracks and spaces is <u>not</u> fractal. 2. There are large directional differences (compare the mid- and far-field micrographs by eye).