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TITLE: INFORMATION EXTRACTION FROM NOISY TELEVIEWER LOGS OF INCLINED HOLES IN HARD ROCK

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INFORMATION EXTRACTION FROM NOISY TELEVIEWER LOGS OF INCLINED WELLBORES IN HARD ROCK

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ABSTRACT

A feature-extraction method was adapted from satelite image-processing to the problem of extracting information from extremely noisy and narrow-range televiewer imagery from GT-2 at Fenton Hill. From televiewer logs, 733 structures were recovered, compared with 42 from core. The average spacings were 3.13 and 0.55 feet, respectively, indicating that the televiewer yielded only 17.5% of the information available from core. Two televiewer runs overlapped between 4000 and 4275 feet depth, but no detectable structures were repeated on both runs. The lack of repetition was explained as due to random processes arising from thermally-induced electronic noise and manually-operated narrow-range recording.

Two new coefficients of association were defined, termed "coplanarity" P, and "collinearity", L, respectively. The coplanarity of foliations demonstrated that, despite no repetition of individuals, the two runs could be correlated. The coplanarity averaged 60 degrees, falling to 43.5 degrees at match, at a lag of -4.5 feet. There was no systematic maximum in the coplanarity for fractures, indicating that these were not serially-correlated. A periodicity in the collinearity for foliations indicated a set of folds with wavelength of 80 feet.

INTRODUCTION

Hole GT-2 was drilled at the Los Alamos National Laboratory Hot Dry Rock site at Fenton Hill in mid-1974. Televiewer runs made in December 1974 were, potentially, a unique source of mesoscopic structural information, because they were run in an uncased, clean, non-degraded hole with a high-resolution (optical) sensor. However due to high thermal noise and narrow recording range the structures were difficult to extract, to the point where individual structures could not be found repeated on different runs through the same section of wellbore. The imagery therefore posed major problems in signal processing, the problems being to extract structural features and to determine the quality (or reliability) of those extracted. This is a problem in any imaging system with weak signals and high noise, so a solution has applications to many kinds of logs in geothermal environments, not only to televiewers.

This problem previously arose with Landsat imagery due to atmospheric noise, low resolution and degradation of image quality due to multiple photographic copying in the early distribution system. Methods of treating the problem were developed under NASA auspices (Burns & Brown,1977). The methods developed for NASA were adapted for the televiewer. The results showed that structural information could be obtained from noisy, narrow-range logs, provided that systematic procedures were followed with stringent quality control.

DATA SOURCES

The starting points for feature-extraction were the magnetic field vector, reduced well-bore survey, caliper logs and televiewer logs. The regional field vector was adopted, interpolated from Gerlach (1970). The survey data was the gyroscope log "GT2gyd", reduced by Zora Dash using interpolation methods from Callas, Novak & Henderson (1979). The caliper log was a Birdwell log of 11 July, 1974. Nominal hole diameter was 9.63 inches, but ranged up to 13 inches.

The televiewer images were reportedly obtained by Scott Keys of the USGS in December, 1974. There were two runs. Run 1 was from 2536 to 4270 feet (depth downhole). Run 2 was from 4000 to 6340 feet. The two runs overlapped between 4000 and 4269 feet. The instrument used an optical transducer, rotating righthanded. Images were Polaroid photographs of a CRT display.

FEATURE-EXTRACTION

Figure 1 shows a typical trace. Due to an elliptical borehole and narrow range of the recording system, the images were vertically striped, with bands of varying reflectance. The only usable parts were restricted to narrow strips running along the wellbore. Structures were detectable only where they crossed those strips. The principal stages in the extraction method were manual annotation, pattern discrimination, and parameter estimation.

During annotation, structures were identified where possible by textural type such as foliation, joints, faults, veins, and cleavage. Annotation was simple line-tracing for discrete structures such as joints, but required fitting a vector trend (Agterberg, 1974, p.494) for penetrative fabric elements (the so-called "preferred orientations" of Turner & Weiss, 1963, p.394) such as foliations. For vector trends, the problem was to fit a streamline to a set of tangents, rather than a line to a set of points. This was done interactively by the observer responding to a computer-generated visual display which compared digitized segments to a computer-constructed streamline.

The pattern-discrimination procedure was acceptance or rejection of traces or vector trends according to a statistical test of goodness-of-fit of the prescribed functional form. Figure 2 shows that a plane structure intersects a circular wellbore in an ellipse. Figure 3 shows that the projection of the ellipse onto the image is a trigonometric curve of the form

$$y = C + A \cos(x) + B \sin(x) \quad \ldots\ldots\ldots\ldots (1)$$

The effects of an elliptical hole, off-centred televiewer and non-plane structure are inseperable, so the pattern sought was equation (1). The root-mean-square error (e2) in fitting the function is shown in figure 6. The error rarely exceeded 0.2 feet. Traces were accepted if the sum of the errors (e3) in fitting function (1) met a chi-square test at the 90% level and were rejected otherwise. About 50% of annotations were rejected. The test was found to be suitable for discrete structures, but not so consistent for penetrative fabric elements. The statistic e3 had the distribution shown in figure 7. The discriminant was 0.6 feet.

Parameter estimation used coefficients of the functional form, the the magnetic field vector, the reduced well-bore survey and the hole diameter to estimate the strike and dip of the structure and the location of the point where it crossed the axis of the wellbore. Figures 4 and 5 show directions associated with a vertical and an inclined hole, respectively. Vectors p,s,t are also shown in figure 2. Projections of vectors r,s,t,u,v onto the image are shown in figure 3. The directions r,s,t,u,v were found from the trace by using the coefficients of the best-fit functional form (1). From these,the orientation of the plane (p) is found, using the geometric relations shown in figure 5. Repeated measurements of a well-defined joint found that orientations were measured to better than 1 degree and locations to better than 0.1 feet.

RESULTS

From 22.97 feet of recovered core, some 42 structures were measured (Laughlin, Eddy, Laney, & Aldrich, 1983). From 2294.73 feet of televiewer logs, 733 structures were recovered. The average spacings of detected structures were 0.55 and 3.13 feet, for core and televiewer, respectively, indicating that the televiewer was yielding only 17.5% of the information obtainable from recovered core.

The two televiewer runs overlap between 4000 and 4275 feet depth. It would be expected that well-defined fractures would be visible on both runs. None are, which requires explanation. There were about 50 structures visible on either log for the interval of overlap. On each run, this represented 0.175 of the structures visible in core(=50/.175=286). If they were selected randomly on each run, the number that that would expect to be repeated was 286 by .175 squared, or 9. If the CRT intensity setting was changed between runs, then the usable part of the image would change between runs. Only 5% of the images were in usable contrast range, so the area of overlap could change substantially with alterations to the CRT intensity level. If there is 10% overlap between the usable portions of the two images, then the number of repeated structures would be expected to be 9 by 0.1, or less than 1. This demonstrates that random selection processes may lead to a very low probability of repetition of individuals. At these high noise levels and narrow recording range, structures were randomly detected from amongst those present. The noise was probably electronic noise generated by temperature effects. This would change in time, and therefore between different parts of images made at different times, so that the likelihood of detecting a particular structure would vary from run to run. The effect of recording only a narrow range of intensities was to compound the problem.

A means of comparing two random selections from the same geological structure was required to determine if the results from the two runs were comparable. A multistate coefficient of association was defined by Burns, Shepherd & Berman(1977). For real-valued variables, correlation or covariance are usually employed. None of these were suitable for this problem, so new coefficients of association were defined, termed "coplanarity", P, and "collinearity", L, respectively, where

$$P_{12} = 1 - E\{ a_j . b_i x b_k / |b_i x b_k| \}$$
$$P_{21} = 1 - E\{ b_j . a_i x a_k / |a_i x a_k| \}$$
$$L_{12} = 1 - E\{ a_j . b_i x b_k \}$$
$$L_{21} = 1 - E\{ b_j . a_i x a_k \}$$

Where, for P_{12} and L_{12},

$i+1=k$; $i=1,B-1$; $j=1,A$;

$d(b_i) < m+d(a_j) < d(b_k)$;

and, for P_{21} and L_{21},

$i+1=k$; $i=1,A-1$; $j=1,B$;

$m+d_i(a) < d(b_j) < m+d_k(a)$;

Where E{s} is the mean value of scalars in the set {s}; qxr is the vector product of q and r; p.qxr is the scalar triple product of vectors p,q and r; |v| is the magnitude of the vector v, a and b denote orientations from runs 1 and 2, respectively; m is the lag; d(a) is the depth downhole of the structure oriented a; A and B are the numbers of structures in runs 1 and 2, respectively.

The coefficient P_{12} might be termed the crosscoplanarity of run 1 given run 2. It varies from 0 (no association, the run 1 structure being oriented at right angles to the plane formed by the two bracketing structures from run 2), to 1 (complete agreement, the run 1 structure lying in the plane formed by structures from run 2). The other coefficients are described similarly.

Figure 8 shows coplanarity as a function of lag for foliations. There was a well-defined maximum, so the foliations were reproducible between the two televiewer runs. The coplanarity measured angular deviation from a plane. The angle is ACOS(P). From figure 8, the angle was about 60 degrees when the runs were not matched, falling to 43.5 degrees when the runs were matched. The best match was at a lag of -4.5 feet. Figure 9 shows coplanarity as a function of lag for fractures. There was no systematic maximum, indicating that fractures were unsuitable for well-to-well correlation with this data. The probability of a low coplanarity decreases with increasing angular separation of the two reference vectors. This effect may be allowed for by multiplying P by the vector area formed by the reference vectors. The result is the coefficient termed "collinearity". Figure 10 shows collinearity as a function of lag for foliations. The result was similar to figure 8. The periodicity in the difference $(L_{12}-L_{21})$ was interpreted as due to folds, with an indicated wavelength (if symmetrical) of 80 feet.

CONCLUSIONS

Foliations and other penetrative fabric elements are intrinsically serially-correlated, whereas fractures are usually not. An optical sensor is therefore preferred for operations in metamorphic rocks, or in sedimentary rocks with a mesoscopic frabric. Some methods of correlating wellbores depend upon matching distinctive individuals. This method fails if, by virtue of weak or incomparable signals, or by narrow intensity range in recording, the likelihood of individuals being repeated is vanishingly small. This will always be the case with foliations and other penetrative elements, which are not discrete traces on the log but vector trends. Methods were therefore required for determining whether the results were selected from the same geological structure. The coplanarity was found to be a suitable coefficient of association. It yielded a match between the two runs at a lag of -4.5 feet. This lag error could easily have arisen with manual methods of photographing and labelling images.

These methods were developed for a special problem, where the imagery represented unique and unrepeatable information. The problem is not likely to arise with modern recording and playback systems (Hinz & Schepers,1981). However the method should be applicable more generally, to cases such as the comparison of measurements made with sensors that respond to different material properties, for example, comparison of televiewer and dipmeter; or to cases of extremely high noise level relative to signal strength, such as for weak signals or sensors not hardened to geothermal environments. The collinearity has potential for finding folds in a variety of applications not limited to well logging.

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Figure 1. Typical image. The vertical stripes are due to a narrow intensity range in recording. About 8 discrete structures can be seen crossing the rightmost light band between 3935 and 3950 feet. They disappear elsewhere due to high random noise. The inclined banding between 3955 and 3965 feet is coherent noise.

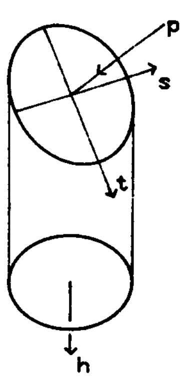

Figure 2. Perspective view of a structure intersecting a wellbore. Vectors are p : normal to the structure; h : axis of the bore. The intersection of planes normal to p and h is a space curve. For a plane structure, centred televiewer and circular wellbore, the space curve reduces to an ellipse with semiaxes s,t,where s = h x p, t = p x s.

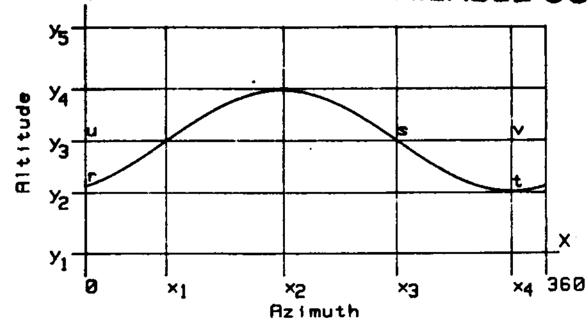

Figure 3. Appearance of a structural trace on a televiewer image. This is the projection of the space curve onto the sensor. The line y = constant, 0<=x<=360 deg, is a scan line. The line x = constant, 0<=y, is a generator of the wellbore. The locus of the magnetic meridian on the scan lines is the scan line trigger, x=0. Projections of the righthanded strike, dip direction, are (x_3,y_3), (x_3,y_4), respectively. Points r,s,t,u,v are projections of orientations shown in figures 4,5.

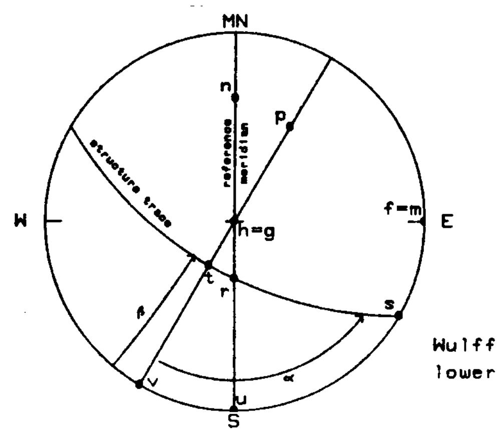

Figure 4. Directions associated with a vertical wellbore. The projections onto the sensor are shown in figure 3.

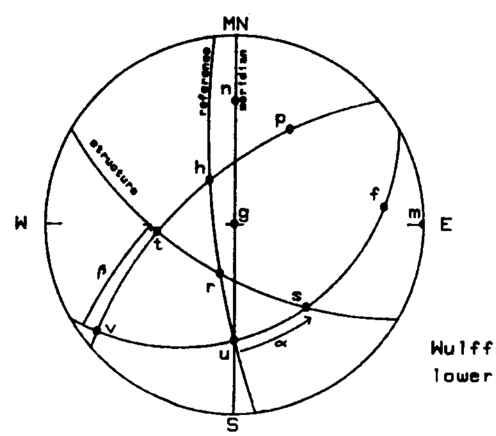

Figure 5. Directions associated with an inclined wellbore. The projections onto the sensor are shown in figure 3.

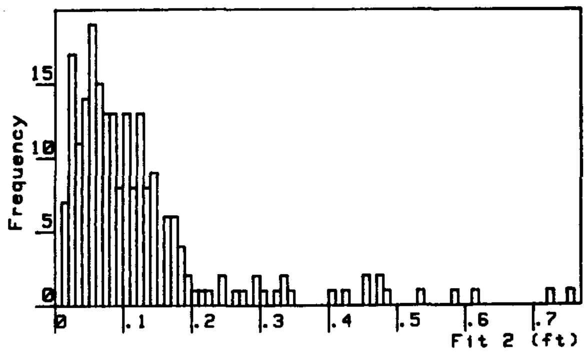

Figure 6. Fitting error : histogram of statistic e2 (run 1,4000-4545 ft. depth). The error in fitting a trace rarely exceeds 0.2 feet.

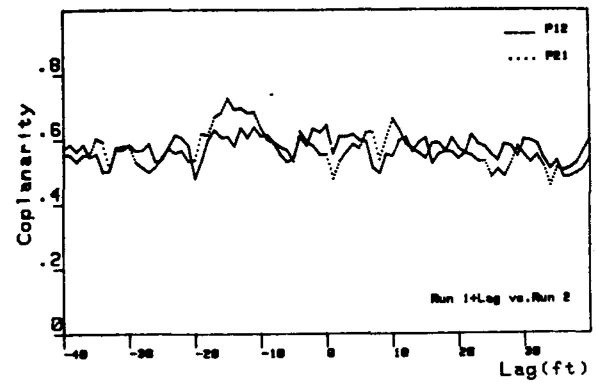

Figure 9. Coplanarity of fractures (run 1+lag versus run 2,4000-4275 ft depth)

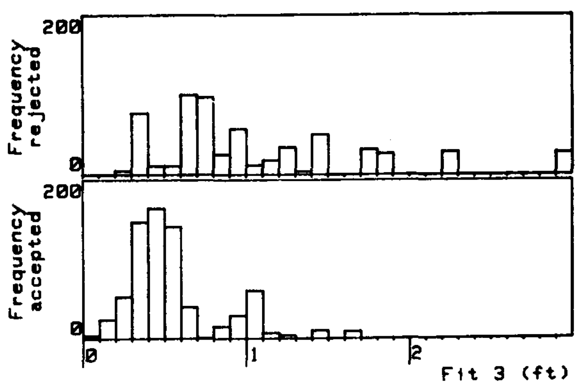

Figure 7. Recognition error : histograms of statistic e3 (runs 1&2,2536-4545 ft depth). The top diagram shows the histogram for rejected traces, the bottom diagram for accepted traces. The discriminant is about 0.6 feet.

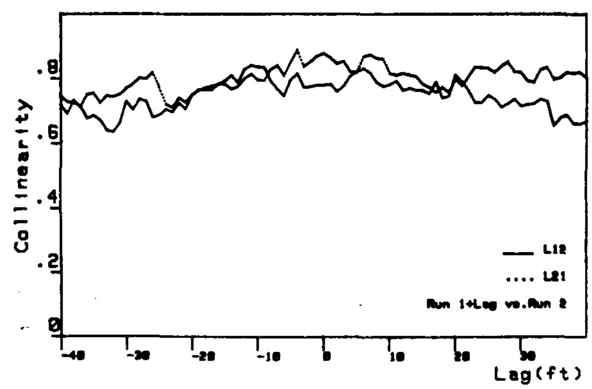

Figure 10. Collinearity of foliations (run 1+lag versus run 2,4000-4275 ft depth)

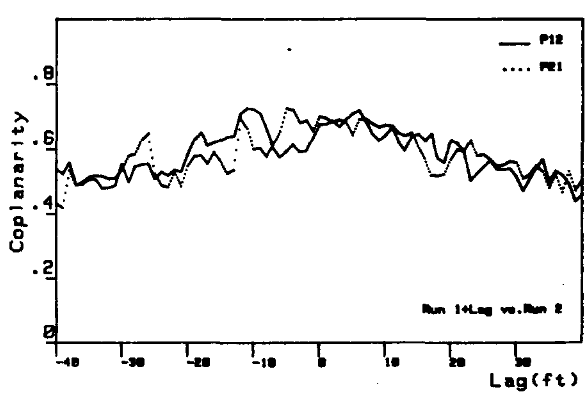

Figure 8. Coplanarity of foliations (run 1+lag versus run 2,4000-4275 ft depth)