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Processing and Interpretation of Seismic Reflection Data Near the Bane Dome in Bland County, Virginia

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ABSTRACT

The purpose of this study was to process and interpret a seismic reflection line from Bland County, Virginia, and to compare it to an earlier line in this location. A longer Vibroseis sweep with greater bandwidth was used for the new line, which provided a considerable improvement in signal to noise ratio and resulted in better residual statics. Additional processing steps, including crooked line CDP sort and predictive deconvolution, also led to improved resolution, particularly in the shallow section.

The geologic section interpreted from the seismic profile represents a series of fault slices between the St. Clair Narrows thrust plates above autochthonous Lower Cambrian shelf strata. A previously interpreted Eocambrian rift basin is clearly defined on this line; the basin is bounded by a large normal fault at its north end. Seismicity in Bland and Giles counties may originate in reactivated Eocambrian faults which presumably formed during opening of the Proto-Atlantic Ocean.

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PURPOSE OF STUDY

The objective of this study was to process and interpret a high frequency seismic reflection line (VTVC2A) collected by Virginia Tech in Bland County, Virginia in 1986 and compare these data to the seismic line (VTVC2) acquired over the same road bed and processed by Virginia Tech in 1982-1985. Both lines, approximately 7.5 km in length, are standard multifold seismic reflection data using a vibrator source. The results of the previous work were reported by Gresko (1985; 1984).

The two seismic reflection profiles used in this study, lines VTVC2 and VTVC2A, were collected along State Highway 608 near Mechanicsburg, Virginia in the Valley and Ridge Province of the southern Appalachians (Figure 1). The dominant structures in the study area are stacked thrust sheets formed as a consequence of thin-skinned thrusting during the Alleghanian orogeny (Figure 2). The seismic lines are located on the St. Clair thrust plate, a major geologic structure, about 30 km southwest along geologic strike from the Bane Dome, which has been the site of numerous geophysical and geological investigations (e.g. Moses, 1988; Gresko, 1985).

DATA ACQUISITION PARAMETERS

Seismic Line VTVC2 was collected in August 1982 as part of a larger data set to investigate geologic structure and study seismic acquisition problems in the Virginia Valley and Ridge Province. The line was intentionally sited to cross outcrops of clastic sedimentary rock because seismic data acquired over carbonate rock in the southeastern United States are extremely poor due to near-surface dissolution of exposed dolostones and limestones.

Seismic data were acquired with a 48 channel MDS-10 digital field system and a single Failing Y-1100 vibrator. The spread configuration was off-end with 70 m receiver group spacings and appropriate source moveups to yield nominal 24 fold data; the near and far offsets were 350 m and 3640 m respectively. A linear 56-10 Hz downsweep of 24 sec length was used throughout to give 5 sec of full correlation time and vertical stacking of individual sweeps was performed in the field.

Line VTVC2A was collected in July 1986 in the same location as the earlier line. All recording parameters, except for the vibrator sweep, were unchanged. For acquisition of Line VTVC2A a three octave 10-80 Hz linear upsweep of 27 sec duration was used to give 5 sec of full correlation time [illegible]

Summarized below are the recording parameters used during acqu[illegible] lines VTVC2 and VTVC2A:

Recording Parameters VTVC2 vs. VTVC2A

	VTVC2	VTVC2A
Date Recorded	August 1982	July 1986
Rec. Instruments	MDS-10 48 channels	MDS-10 48 channels
Source	1 Failing Y-1100	1 Failing Y-1100
Sweep	56-10 Hz 24 s 938 ms taper	10-80 Hz 27 s 938 ms taper
Group Interval	70 m	70 m
Spread	VP-350 m-3640 m	VP-350 m-3640 m
Geophone Array	20 min/max geophones	20 min/max geophones
Source Array	1X16/70 m inline	1X16/70 m inline
Sample Rate	2 ms	2 ms
Record Length	29 s	32 ms
Rec. Filters	Low 12 Hz High 125 Hz Notch in	Low 12 Hz High 125 Hz Notch in
Rec. Format	SEG-B	SEG-B
Gain Mode	Instantaneous Floating Pt.	Instantaneous Floating Pt.

The use of an upsweep versus a downsweep, outside of technical considerations, can be site dependent. Data previously collected by Virginia Tech over the Atlantic coastal plain suggested that a downsweep might be superior in those areas; however, Domoracki (1986) found that an upsweep yielded much better data in the Colorado foothills, and in a study in the Colorado San Juan Mountains a downsweep was appropriate (Phillips, 1985). From a technical standpoint, a downsweep can be desirable because the vibrator phase compensation circuitry is able to synchronize baseplate motion faster (Waters, 1987), but considering the long sweep lengths used with the VTVC data, this effect may be negligible. Use of an upsweep has the advantage that, because the problem of harmonic ghosts associated with a downsweep is avoided, long extended Vibroseis correlation may be performed to extend the data in time to study deep crustal reflections (Okaya and Jarchow, 1989).

The higher frequency band used for Line VTVC2A was chosen so that higher frequencies, if preserved in the field data, would lead to increased seismic resolution and greater accuracy in residual statics determination. Furthermore, selection of a wide bandwidth sweep leads to improvement in the signal to noise ratio over a narrower bandwidth sweep of same duration provided that the noise and sweep have the same bandwidth. Schneider (1983) gives the following formula for improvement in signal to noise ratio when a vibrator source is used:

$$\text{S/N improvement} = \sqrt{2TW}$$

where T is the duration of the sweep in seconds and W is bandwidth in Hertz. Hence, a theoretical increase in signal to noise ratio of ≈ 61.5 versus ≈ 47 could be expected using the longer, wider band sweep of Line VTVC2A as opposed to the shorter, narrower band sweep of Line VTVC2.

DATA PROCESSING PARAMETERS

Processing of Lines VTVC2 and VTVC2A was done at Virginia Tech in the Regional Geophysics Laboratory on a VAX 11/780 with an FPS 120-B array processor using DISCO (Cogniseis Inc.) software.

Line VTVC2 Data Processing

Line VTVC2 was processed during 1982-1984 with a processing sequence that included a geophone array compensation filter, vibroseis whitening, crooked line geometry, iterative velocity/residual statics, coherency stack, and finite-difference migration. The processing sequence appears below. The final stacked section appears in Figure 3.

```
                              Processing Sequence Line VTVC2

        Demultiplex/Resample to 4 ms
                  |
        Geophone array compensation filter
                  |
        Vibroseis whitening/
        Correlation with recorded sweep
                  |
        Trace edits/Datum statics
                  |
        CDP crooked line geometry
                  |
    --> Velocity analysis
    |             |
    ----Residual statics
                  |
        NMO correction
                  |
        Mute/Scaling
                  |
        CDP stack
                  |
        Coherency estimation/
        Combine with stack data
                  |
        Bandpass filter/Scaling ----------> Migration (after resampling to 8 ms)
                  |                                   |
        Display                             Bandpass filter/Scaling
```

Special note should be made of the use of vibroseis whitening (VSW) and the stacking velocities and residual statics gates used. The VSW process involves application of scaling (AGC) to the data before correlation in an attempt to balance the amplitude spectrum and enhance overall seismic data quality. VSW can be used in place of, or in addition to, the standard spherical divergence correction. Stacking velocity determination was by constant velocity stacks in conjunction with iterative surface-consistent residual statics to update the stacking velocities/statics. Four sets of velocity analyses were obtained at six locations along the profile, and two sets of residual statics were applied to the data. The residual statics gate was 600 msec, centered on the lower part of the section, starting at 1500 msec; 20 msec of total shift was allowed.

Line VTVC2A Data Processing

Processing of Line VTVC2A was directed towards improving overall section data quality, with particular emphasis on improving the shallower parts of the section and elucidating probable fault slice structures occurring between 800 and 1500 msec in the time section. The basic processing sequence followed was similar to that used with Line VTVC2, but also included spherical divergence (in lieu of VSW), predictive deconvolution, detailed mute schedules, and increased numbers of velocity analyses and residual statics sets. In addition, unlike Line VTVC2, the data were not resampled prior to processing. Non-standard processing steps included extended vibroseis correlation, crooked line CDP sort with redefinition of the CDP interval, F-K filters applied to moved-out CDPs and automatic line drawings.

The processing flow appears below and the final stacked section appears in Figure 4. The interpreted final stacked section appears in Figure 10.

```
                          Processing Sequence Line VTVC2A

      Demultiplex
         |
      Spherical divergence
         |
      Record pad
         |
      Vibroseis correlation with recorded sweep
         |
      Trace edits/datum statics
         |
      CDP crooked line sort
         |
      Predictive deconvolution
         |
      Bandpass filter
         |
  --> Velocity analysis
  |      |
  ----Residual statics
         |
      NMO correction
         |
      Mute/Scaling
         |
      F-K filter
         |
      CDP stack
         |
      Coherency estimation/
      Combine with stack data
         |
      Bandpass filter/Scaling ---------> Migration (after resampling to 4 ms)
         |                                  |
      Display                            Bandpass filter/Scaling
         |                                  |
      Automatic line drawing             Display
                                            |
                                         Automatic line drawing
```

Prior to vibroseis correlation, tests were run to determine whether VSW, spherical divergence, or both should be applied. The results of these tests indicated that the standard spherical divergence correction alone was appropriate for these data.

Following application of the spherical divergence correction, the record length was padded with zeroes to 45 sec and extended vibroseis correlation was carried out to produce 18 sec data. The additional 13 sec of data was necessary to study any lower crustal reflections and required no extra field effort. Unfortunately, the final stacked data exhibited no clear crustal reflections beyond 5 sec.

The crucial data processing step was redefining the CDP sort path. A crooked line results in reflection points strewn over a wide region instead of along a straight line common to successive surface points. In this situation sorting along the receiver line would lead to poor results due to the smearing of the reflection points over a large area. In addition, data interpretation is difficult because, due to line bends, the horizontal scale of the seismic section varies. To remedy the effect of line bends the data can be sorted along a handpicked CDP track that represents the straightest path through the densest collection of midpoints. This type of sort lessens the number of traces in the stacked section, but can both increase the CDP fold and result in a truer representation of geologic structure.

The CDP sort path used for processing appears in Figure 5. Since the scattering of midpoints along the profile was uniform, it was decided to decrease the CDP interval, which would normally be 35 m, to 30 m. Thus, the increase in CDP fold was traded for increased spatial resolution and a greater number of traces in the stacked section. In addition, a shorter CDP interval should improve migration results.

Although autocorrelograms show that near surface reverberations are not a problem in this area, predictive deconvolution was applied to to the CDP gathers. Predictive deconvolution in this instance was used to shorten/shape the vibroseis wavelet; that is, reduce side-lobe ringing, and increase reflection resolution. The technique was particularly effective in resolving the reflections between 1.4 and 2.4 sec in the time section (Figure 4).

Stacking velocities were determined by constant velocity stacks in conjunction with iterative surface-consistent residual statics to update the stacking velocities/statics. Seven sets of velocity analyses were obtained at about the same six locations as for Line VTVC2 and nine sets of residual statics applied to the data. Inasmuch as selection of stacking velocity functions is an interpretative step as well as a processing step, it is the final stacking velocity functions for both seismic lines to 3 sec that appear in Figure 6.

In general, the stacking velocities determined for Line VTVC2A are lower than for Line VTVC2. This in itself is not significant because stacking velocity determination by best stack criteria can depend on sort geometry. A stacking velocity inversion is present in Line VTVC2A from below ≈ 900 msec to ≈ 1500 msec. This inversion occurs due to higher velocities needed to correctly stack steeply dipping events (fault slices?) below the strong reflection at 700 msec. In Line VTVC2 a stacking velocity inversion occurs beneath the strong reflection package at 1700 msec. This stacking velocity inversion may indicate the presence of low velocity Precambrian-Cambrian strata or could result from the stacking of multiples into the section. No such stacking velocity inversion was picked for Line VTVC2A, but reflection continuity is somewhat poorer in this area than in the other line.

The residual statics time gate used was 1500 msec starting at about 600 msec and 15 msec of total shift was allowed. This time gate was more than twice as wide as that used for Line VTVC2. Also, the time gate was centered over the middle part of the section as opposed to the lower part of the section used previously. Use of a wider time gate should smooth static values and enhance overall section appearance.

Mute schedules were picked by examination of stack response versus increasing offset. Four different mute schedules were determined along the line as opposed to a single mute schedule used for Line VTVC2. The detailed mutes determined by this method considerably improved the upper 400 msec of the section. To further enhance the seismic data an F-K filter with a pass band of -5/+5 msec/trace was applied to the CDPs after NMO to attenuate coherent noise trains.

The final stacked traces were combined with traces derived from coherency estimates of the data in a seven trace moving window. This process (DISCO DIGISTK) greatly enhanced the more horizontal reflections without degrading dipping reflections. Line VTVC2 was also processed with DIGISTK.

Prior to migration the data were resampled to 4 msec and migrated to 8 sec with 95 percent of the stacking velocities using a DISCO finite difference scheme. Because the line is short, only the central part of the section is correctly imaged (Figure 7). For this reason most of the interpretation was based on the unmigrated seismic sections.

The final processing step was to apply an automatic line drawing (ALD) algorithm (Çoruh and others, 1987). The unmigrated and migrated ALD are shown in Figure 8 and Figure 9.

GEOLOGY, SEISMICITY AND PREVIOUS GEOLOGIC INTERPRETATION

Geology

The major geologic structures in the Valley and Ridge Province are the result of thin-skinned deformation during the Alleghanian orogeny. Specifically, this deformation style is manifested by eastward stacking of large displacement thrust sheets above low-angle detachment faults. Within the study area the Narrows, St. Clair and Saltville thrusts bound thrust sheets that trend N 60-65° E (Figure 2). Although the crystalline basement is not involved in the thrusting, pre-existing basement structure may control the location of fault splays (Scott, 1987). The basement structures in the area were formed during the opening of the proto-Atlantic Ocean (Iapetus) during Late Proterozoic-Cambrian time.

The stratigraphic column in vicinity of the VTVC seismic lines consists of mostly dolostones and shales ranging in age from Cambrian through Mississippian (Figure 11). Carbonate rocks, mostly dolostones, dominate the Cambrian through mid-Ordovician system. The upper section is largely composed of shales. Several formations in the area are distinctive seismic marker horizons. The Cambrian Nolichucky-Rome interval is a distinctive reflection package pervasive in the southern Appalachians. Another key seismic marker is the Silurian Clinch (Tuscarora) Sandstone.

The VTVC seismic lines begin forward of the leading edge of the Saltville fault and continue northward, mostly perpendicular to geologic strike, and end about 6 km short of the Narrows fault (Figure 2). Devonian siltstones and shales outcrop along the profile. Mapped just north of the seismic line are minor faults and an anticline-syncline pair. The anticline is a continuation along strike of the Bane Dome; the syncline is the Pearisburg syncline.

The Bane Dome has been the subject of numerous geological and geophysical studies as well as the site of an unsuccessful exploratory well (Moses, 1988). Three balanced cross sections across the Bane Dome are shown in Figure 12. Inasmuch as the Bane Dome is located along geologic strike from the VTVC seismic lines, these cross sections may be considered reasonable representations of structure that might exist in the study area. In the Woodward (middle, 1985) and Bartholomew (bottom, 1987 in Moses, 1988) cross sections the Bane Dome is formed by stacking large fault slices within the St. Clair thrust sheet below the Narrows fault. Gresko's cross section (top, 1985) is based on interpretation of shear-wave seismic data and Line VTVC2. He depicted the Bane Dome as cored by small imbricate fault slices within the St. Clair thrust sheet. Unlike the other two cross sections, Gresko also interpreted a rift structure in the crystalline basement that involves the lower sedimentary section and is separate from the thin-skinned thrusting above.

Seismicity

In Bland and Giles counties a band of low intensity seismicity is present trending approximately N 20-27°E (Figure 2). In general the hypocenters of the earthquakes within the Giles County seismic zone are deeper than the thickness of the Phanerozoic sediments involved in the thrusting apparent on the surface. The depth of the earthquakes and the trend of seismicity oblique to surface geologic features led Bollinger and Wheeler (1983) to suggest that the earthquakes may originate from movement on reactivated Eocambrian faults associated with a rifting event. These faults presumably formed during the opening of the proto-Atlantic Ocean and became inactive during the Cambrian. Reactivation of these faults in the present compressive stress regime results in primarily strike-slip motion and the observed low intensity seismicity (Munsey and Bollinger, 1984).

In the VTVC2 seismic data Gresko interpreted high-angle normal faults originating beneath the Cambrian shelf strata. He interpreted these faults to be the Eocambrian faults postulated by Bollinger and Wheeler (1983) and responsible for seismicity in the Giles County seismic zone. In addition, the faults cut through the the Lower Cambrian section, but do not seem to have influenced deposition of those units which suggests that the faults may have been periodically reactivated.

There is no widely accepted explanation for the origin of intraplate earthquakes. The Giles County, Virginia, seismic zone, like other seismically active intraplate areas, is a spatially isolated area of persistent, diffuse earthquake activity. Costain and Bollinger (1987a,b) suggested that rainfall plays a key role in the generation of intraplate seismicity ("Hydroseismicity"). The basis for the Hydroseismicity hypothesis was a spatial correlation in the southeastern U. S. between 1) seismogenic crustal volumes, 2) large gravity-driven groundwater basins that can provide an adequate supply of water to the upper- and mid-crust, and 3) a fractured and permeable crust under horizontal compression from ridge push. In this hypothesis, long-period (10-30 years) changes in rainfall generate intraplate seismicity by diffusion of pore pressure transients from recharge areas of groundwater basins to depths as deep as the brittle-ductile transition. Using commonly accepted values of intrinsic fracture permeability and hydraulic diffusivity for crystalline rocks, such long-term changes in the elevations of water tables can be propagated downward as pore pressure transients into a fractured, hydraulically diffusive crust to depths as deep as the brittle-ductile transition ($\simeq$15-18 km).

The seismicity data set in Giles County is not complete enough to analyze in the same way as was done for central Virginia; however, some results are similar. Streamflow, f(t), and earthquake strain, s(t), for a 62-year sample from 1925-1987 in the central Virginia seismic zone were cumulated, and a least-squares straight-line fit was subtracted to obtain residuals, F(t), and S(t), respectively. [illegible] face residual streamflow, F(t), was differentiated to obtain the rate of change of residual streamflow, F'(t). Fr[illegible]ctral analyses, Costain and Bollinger (1987a,b) observed common cyclicities with periods of 10-30 years for F(t) and S(t). Similar results were obtained for the Giles County seismic zone (Bollinger and Costain, 1988).

From the diffusion equation, Costain and Bollinger (1989) determined the impulse responses at depths, ψ, of a hydraulically diffusive crust to an impulsive change in fluid pressure in the surface recharge area of a groundwater basin. The impulse responses, $h(\psi, D, t)$, were convolved with surface streamflow residuals, F(t), or, [illegible] use of results from reservoir-induced seismicity, with F'(t). Root-mean-square values (rms) of the convolutions, $C(\psi, D, t) = h(\psi, D, t) * F'(t)$, were computed for $\psi = 5, 10, 15,$ and 20 km and various values of D.

For central Virginia, the number of earthquakes, N, within a crustal slice that straddles the depth, ψ, was found to be proportional to the rms value of $C(\psi, D, t)$ within the slice, suggesting that the number of intraplate earthquakes generated depends upon the magnitude of the rms changes in fluid pore pressure within the crustal slice. That is, the larger the magnitude of the fluctuations in pore pressure over a crustal interval, the greater is the number of earthquakes over that interval. At hypocentral depths, these fluctuations in pore pressure, in concert with stress corrosion and hydrolytic weakening, are hypothesized to trigger intraplate earthquakes in a crust stressed by ridge-push. The seismicity data set in the Giles County seismic zone is not complete enough to permit a similar analysis at the present time.

Crosscorrelation of $C(\psi, D, t)$ with residual strain, S(t), provides a measure of similarity, $\phi_{F'S}(\tau)$, between S(t) and $C(\psi, D, t)$; i.e., the shape of the crosscorrelation function depends upon the similarity in shape between $C(\psi, D, t)$ and S(t). Optimum values of crustal diffusivity, D, were considered to be those values for which $\phi_{F'S}(\tau) \simeq \phi_{F'S}(-\tau)$, that is, those values of D for which the crosscorrelation function, $\phi_{F'S}(\tau)$ is approximately even. That this occurs only over a reasonable range of diffusivities is consistent with the hypothesized causal relationship between streamflow and intraplate seismicity (Costain and Bollinger, 1989).

Finally, storm tracks over the eastern United States and Canada indicate that north of 50° N, the average latitude of storm tracks during December, January, and February is about 2.5° further south at sunspot maximum than at sunspot minimum. Others have shown that the atmospheric response to the 11-year sunspot cycle is now known to be masked by the Quasi-Biennial Oscillation (QBO) of zonal winds in the stratosphere. By sorting data on 30 mbar temperatures at the North Pole according to the phase (direction) of the QBO, a clear correlation with the 11-year solar cycle has been discovered by Labitzke (1987). These remarkable correlations between the solar cycle and pressure/temperature data are widely distributed over the Northern Hemisphere (Labitzke and van Loon, 1988). There appears to be a clear relationship between the 11-year solar cycle and storm track latitudes in the North Atlantic. Such studies have only been possible for the last three and a half solar cycles, because the phase of the QBO cannot be defined before 1952. Significantly, Costain and Bollinger (1989) recognized a clear peak near 11 years and about 22 years in the Fourier spectra of streamflow in the James River in the central Virginia seismic zone. We have not yet analyzed the flow spectra for the New River.

Previous Geologic Interpretation

Gresko's interpretation of Line VTVC2 appears in Figure 13. The dominant structures are an overthrust and a fault slice (called a horse by Gresko) controlled by the St. Clair fault. The Lower Cambrian formations lie autochthonous atop Eocambrian sedimentary rocks and are disturbed only by high-angle normal faults that originate in the crystalline basement.

Unlike the cross sections drawn by Woodward (1985) and Bartholomew (1987 in Moses, 1988) in Figure 12 which show the St. Clair and Narrows faults to be separate faults originating from the Saltville fault root zone, Gresko interpreted the Narrows fault to be a break-back imbricate fault of the St. Clair fault. The fault slice is interpreted to exist within the Martinsburg Shale and have little lateral displacement. Minor thrusts occur within the fault slice. No other faults associated with the major thrust faults are interpreted to exist.

INTERPRETATION OF THE SEISMIC DATA

Much of the interpretation of the seismic data shown in Figure 10 is speculative due to the relatively short line length $\approx$ 6 km; however, reflection continuity and resolution is considerably greater in Line VTVC2A than Line VTVC2 and more detail is discernible in the section.

The most easily identifiable reflections in the seismic data are interpreted to be from the Lower Cambrian Erwin-Nolichucky interval. Within this interval occurs the Rome Formation, a relatively incompetent mudrock unit that is often a major glide horizon for thrust faulting in the southern Appalachians. Because the Erwin-Nolichucky interval appears undisturbed on the south part of the section, these rocks are probably autochthonous, as interpreted by Gresko, and not involved in thrust faulting. Above the Nolichucky Formation truncation of subhorizontal reflections in the overlying Knox Group suggest the presence of faulting. The St. Clair thrust is interpreted to ramp through the section in this area. Another fault dips from 1025 msec to 1400 msec across the section in Figure 10 at what might be the top of the middle Ordovician. This fault appears to form the roof of a fault slice structure floored by the St. Clair fault. The reflection dipping to the south from 800 msec to 1200 msec is interpreted to be to be a the floor of a fault slice that merges into the Narrows fault. This last fault slice appears to occur within the Martinsburg Shale as Gresko suggested. The Narrows fault is indicated by truncation of dipping reflections by subhorizontal reflections at 800 msec to 1000 ms north to south across the section. Overall, at least three major fault slices or duplex structures are interpreted to occur between the St. Clair and Narrows faults. Several small thrusts may exist within the individual fault slices. In cross section the structure along Line VTVC2A may be similar to Bartholomew's (1987 in Moses, 1988) cross section in Figure 12 (bottom).

The stratigraphic section above the Narrows fault would seem to be relatively intact from the Rome/Honaker formation contact upward. Apparent thickening in the units above the strong reflection at 500 msec could be related to a hidden bedding plane fault. Interval velocities across the upper part of the section do not change appreciably and preclude the possibility that thickening is related to a lateral velocity change. The strong reflection dipping from 100 msec to 380 msec in Figure 10 is probably the Silurian Clinch Sandstone. This unit does not outcrop along the profile and does not appear on the mute test panels beyond CDP 140. Because only Devonian rocks are exposed, the Clinch Sandstone is likely to be just beneath the surface. The strong "v" patterns in the upper 200 msec to the end of the line may denote refractions or scattered waves from the high-velocity Clinch Sandstone in the weathering or subweathering layer.

The Eocambrian rift basin interpreted by Gresko (1985) is clearly defined in the ALD of the unmigrated new data (Figure 8). The graben is bounded to the north by a south dipping listric normal fault that continues into the upper sedimentary section, as previously interpreted by Gresko. Some minor faults appear to splay from the main fault. The major graben bounding fault occurs to the south off profile. In the migrated section (Figure 7) the main north bounding fault is imaged and reflections are seen to terminate against it. Between CDP 1 and CDP 130 crystalline basement occurs at about 2.5 sec; however, correlation of reflections across the fault is speculative. A maximum of 1600 m of basin fill is present.

Reflection patterns within the basin indicate at least two facies types (Figure 10). The first type distinguished by hummocky, discontinuous reflections comprises the first 600 m (200 msec) of basin fill. These reflections might represent siltstones and conglomerates in the Unicoi Formation or glacial drift and volcanic rocks in the Mt. Rogers Formation either formation of which can overlie Grenville crystalline basement in southwest Virginia (Simpson and Eriksson, 1989). The second facies type identified by continuous reflections could represent infill by terrigenous and shallow marine siltstones and sandstones in the Unicoi Formation as rifting progressed.

Divergence in reflection dip at the top of the basin at 1900 msec indicates a sedimentary sequence boundary that might occur at the base of the Hampton Formation and thus denote transition from rifting to a passive margin. According to Simpson and Eriksson (1989) the topmost Unicoi Formation and the basal Hampton Formation record transgression associated with rapid drowning of the shelf margin and development of a passive margin. They also suggest that deepening may have been aided by renewed faulting as shown by abrupt gravity flow deposits at the base of the Hampton Formation which are in turn abruptly overlain by black outer-shelf mudstones. Hence it is likely that renewed movement on listric faults that presaged onset of passive margin sedimentation would be expressed as a seismic sequence boundary.

Although no clear deep crustal reflections were noted, a small package of north-dipping reflections occurs at 4 sec in the data (Figure 8). The origin of these reflections is unknown, but similar reflections within Grenville basement have been interpreted as mylonite zones (Green and others, 1988).

SUMMARY

The data quality of Line VTVC2A is superior to Line VTVC2, although both seismic lines were collected in the same area using the same field equipment and nearly identical field acquisition parameters. The improvement in data quality may be attributed to the following factors:

- Use of a longer, wider bandwidth vibroseis sweep. The theoretical improvement in signal to noise ratio using the VTVC2A sweep as opposed to the VTVC2 sweep is over 30 percent. The higher frequency content may have resulted in better residual statics.

- Redefinition of the CDP path. This reduced the effect of line bends and resulted in a truer depiction of structure. Decreasing the trace interval increased the spatial resolution of the data set.

- Predictive deconvolution. Use of deconvolution to shape the vibroseis wavelet increased resolution of individual reflections.

- Detailed mute schedules. The improvement in the shallow reflections, especially the Clinch Sandstone reflection, is evident.

- Additional velocity analysis and residual statics sets. The wider residual static gate used may have led to better overall statics/velocity determination over the narrower gate used previously.

- F-K filtering. Airwave and surface wave trains were effectively reduced with this technique.

The geologic structure along the seismic profile is interpreted to represent a series of fault slices or duplexes between the St. Clair-Narrows thrust plates above an autochthonous sequence of Lower Cambrian shelf strata. The roof of the Narrows thrust is particularly well imaged and appears to be at the level of the Rome Formation. The section above the Narrows thrust is relatively undisturbed, but could contain at least one bedding plane fault. The position of the St. Clair thrust is less certain, but may occur within the Knox Group and ramp through the geologic section across the profile. At least two, perhaps three, or more fault slices are present. Several small thrusts occur within the individual fault slices.

The Eocambrian rift basin interpreted by Gresko (1985) is clearly defined. Within the rift basin reflection patterns suggest the presence of a lower, basal facies followed by infill. A large normal fault bounds the north end of the basin and appears to continue into the overlying Cambrian-Ordovician strata. Several similar, but smaller faults may exist along the profile. Divergence in reflection dip at the top of the basin may denote transition from rifting to passive margin sedimentation. No additional insight was obtained about Eocambrian or early Paleozoic rift structures in crystalline basement, and their possible relation to the Giles County Seismic Zone. Reactivation of the basin faults by strike-slip movement has previously been interpreted by Bollinger and Wheeler (1983) to account for present-day seismicity in the area.

The seismicity in Giles County appears to be controlled by those parameters that characterize the Hydroseismicity hypothesis: that is, fractured crystalline rocks, an abundant supply of water associated with the New River drainage system that reaches the shallow and intermediate crust, and relatively steep stream gradients that encourage transient disturbances in fluid pore pressure from the surface recharge area to depths of 15-18 km.

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FIGURES

Figure 1. Seismic lines superimposed on Mechanicsburg, Virginia USGS 7.5′ topographic map.

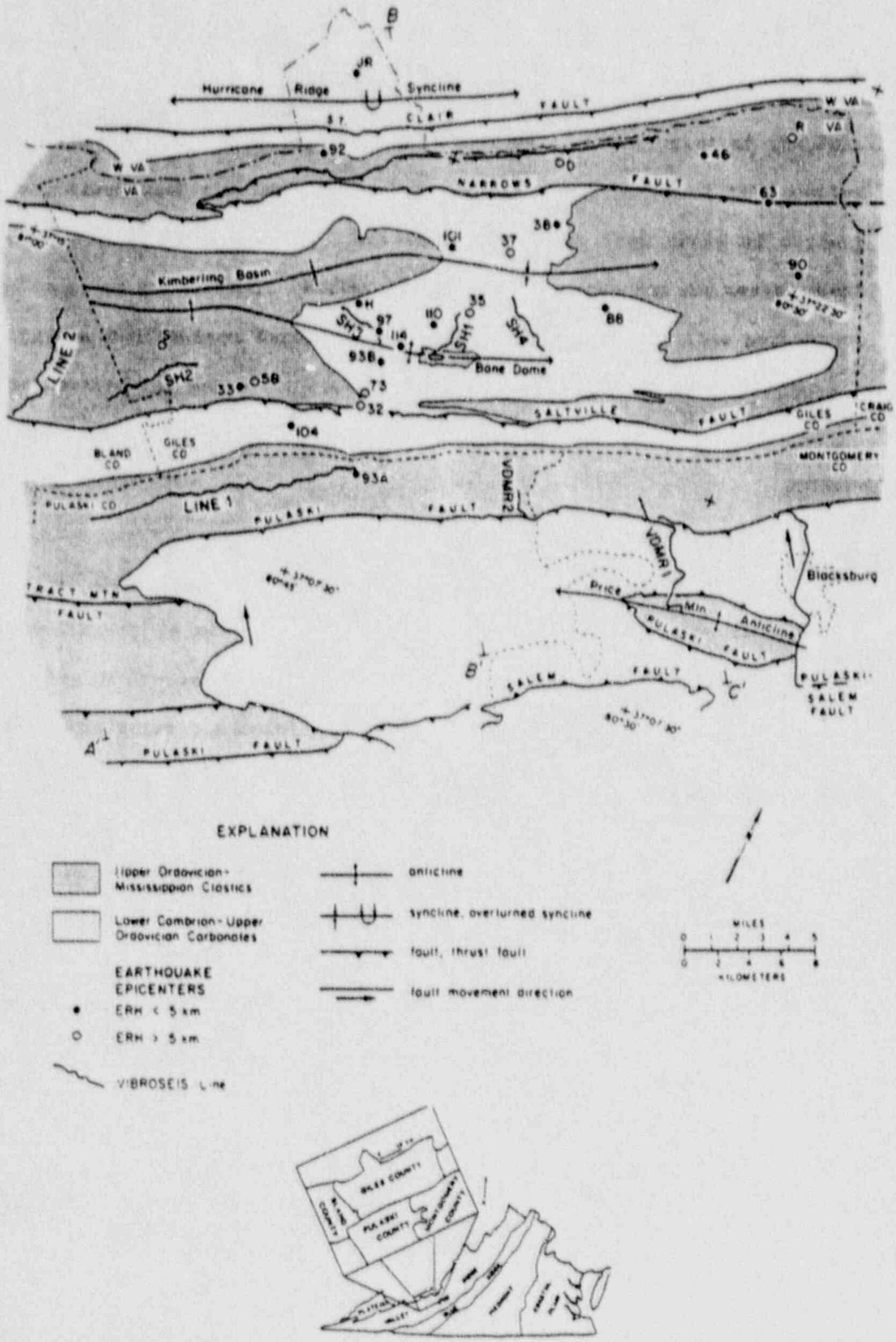


Figure 2. Seismic lines located on geologic sketch map: Geologic map from Gresko (1985, Fig. 2).

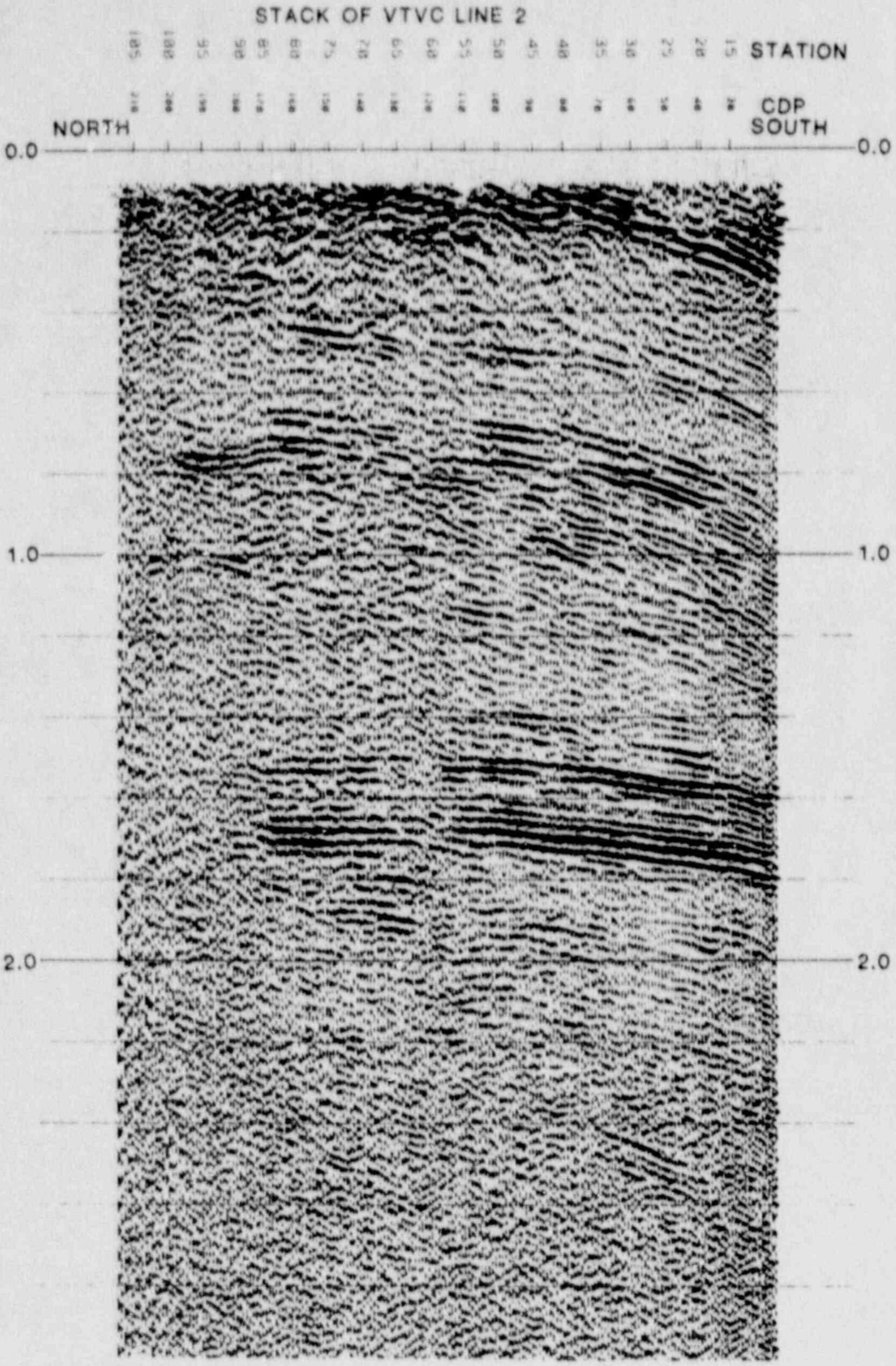


Figure 3. **Stack (unmigrated) Line VTVC2:** From Gresko (1985, Fig. 7).

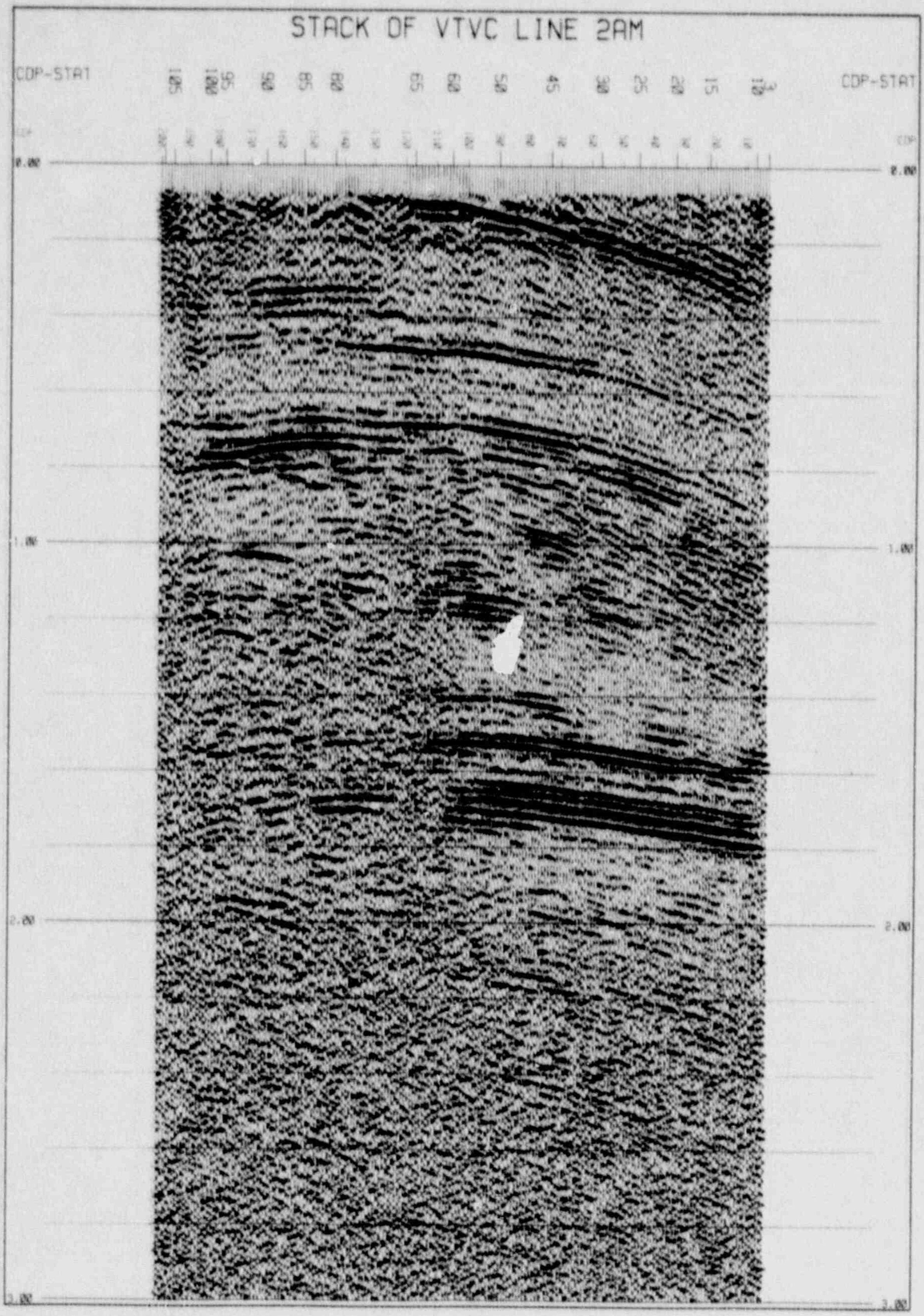


Figure 4. **Stack (unmigrated) Line VTVC2A:** Note improvement in reflection continuity and increase in spatial and temporal resolution over Figure 3. The dimensions of the plot are the same as Figure 3; however, the trace spacing is reduced from 35 m to 30 m. Filter: 6-10-80-85 Hz. Horizontal scale ≈ 1" = 1500 m. This figure is the same as Plate 1.

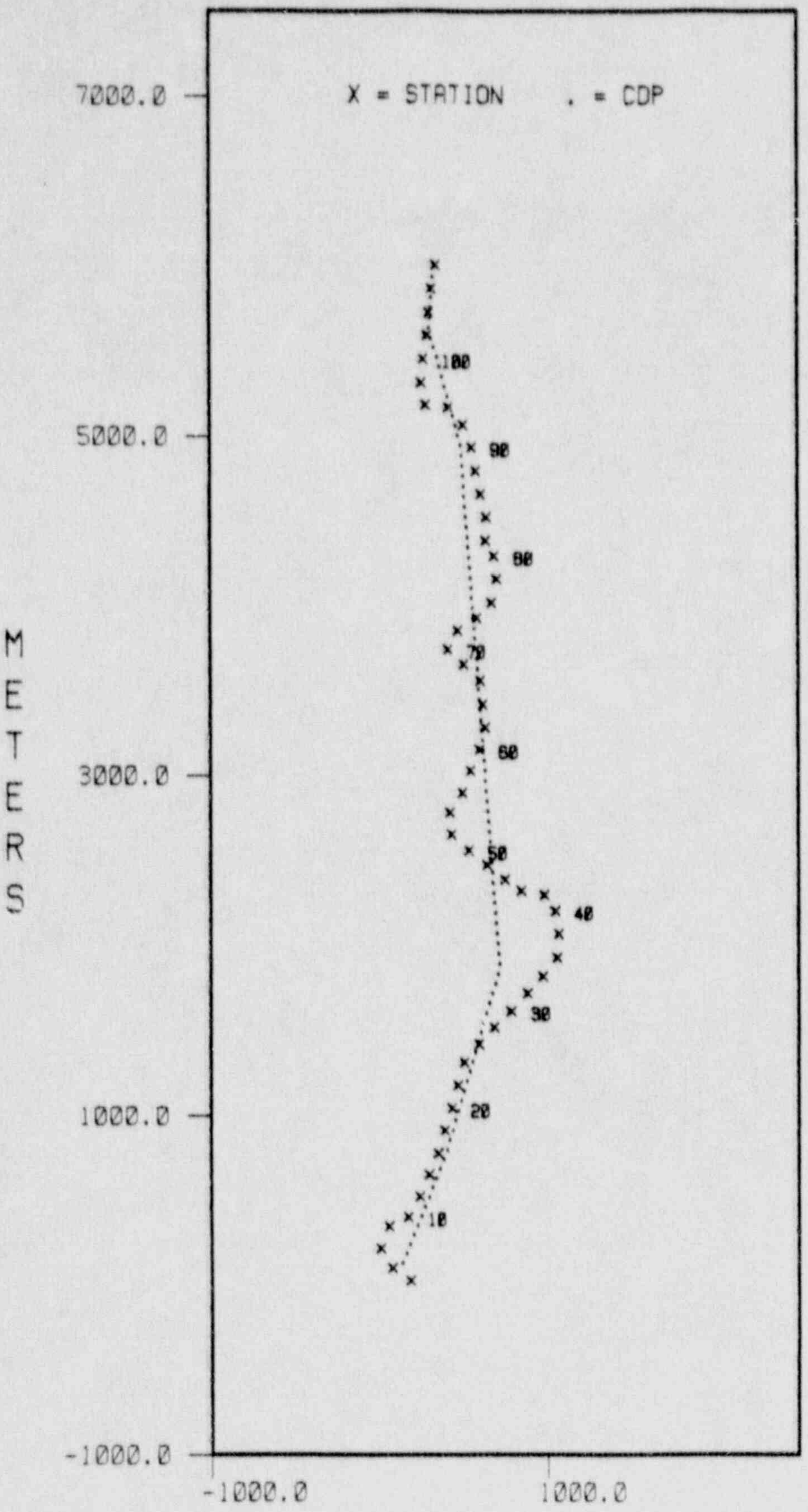


Figure 5. **Sort path for Line VTVC2A:** Every tenth station location is annotated. Small dots mark every second CDP location. Figure scale 1" = 1000 m.

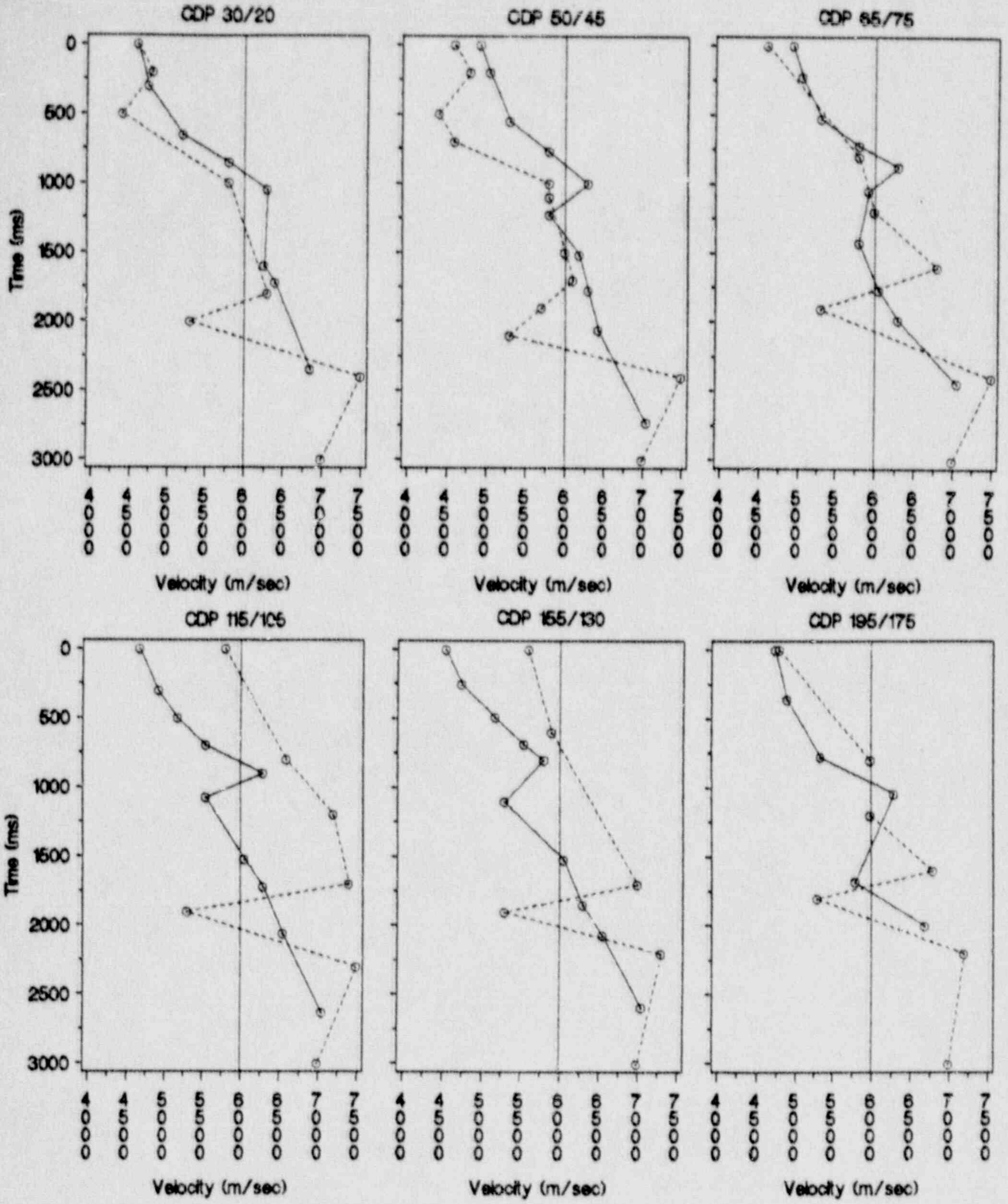


Figure 6. Stacking velocities Lines VTVC2 & VTVC2A to 3 sec: Dashed line = stacking velocities VTVC2. Solid line = Stacking velocities VTVC2A. Note inversion in stacking velocities in VTVC2 starting ≈ 1700; possibly indicating presence of very low velocity Precambrian-Cambrian sedimentary strata or stacking of multiple events. Stacking velocity inversion in VTVC2A from ≈ 900 ms to ≈ 1500 ms results from picking high velocities to stack steeply dipping reflections, which may indicate the presence of fault slices, in the data immediately above. The overall lower stacking velocity functions for VTVC2A compared to VTVC2 may be a result of different sort geometries. Vertical 6000 m/sec reference line denotes average crustal velocity for this area.

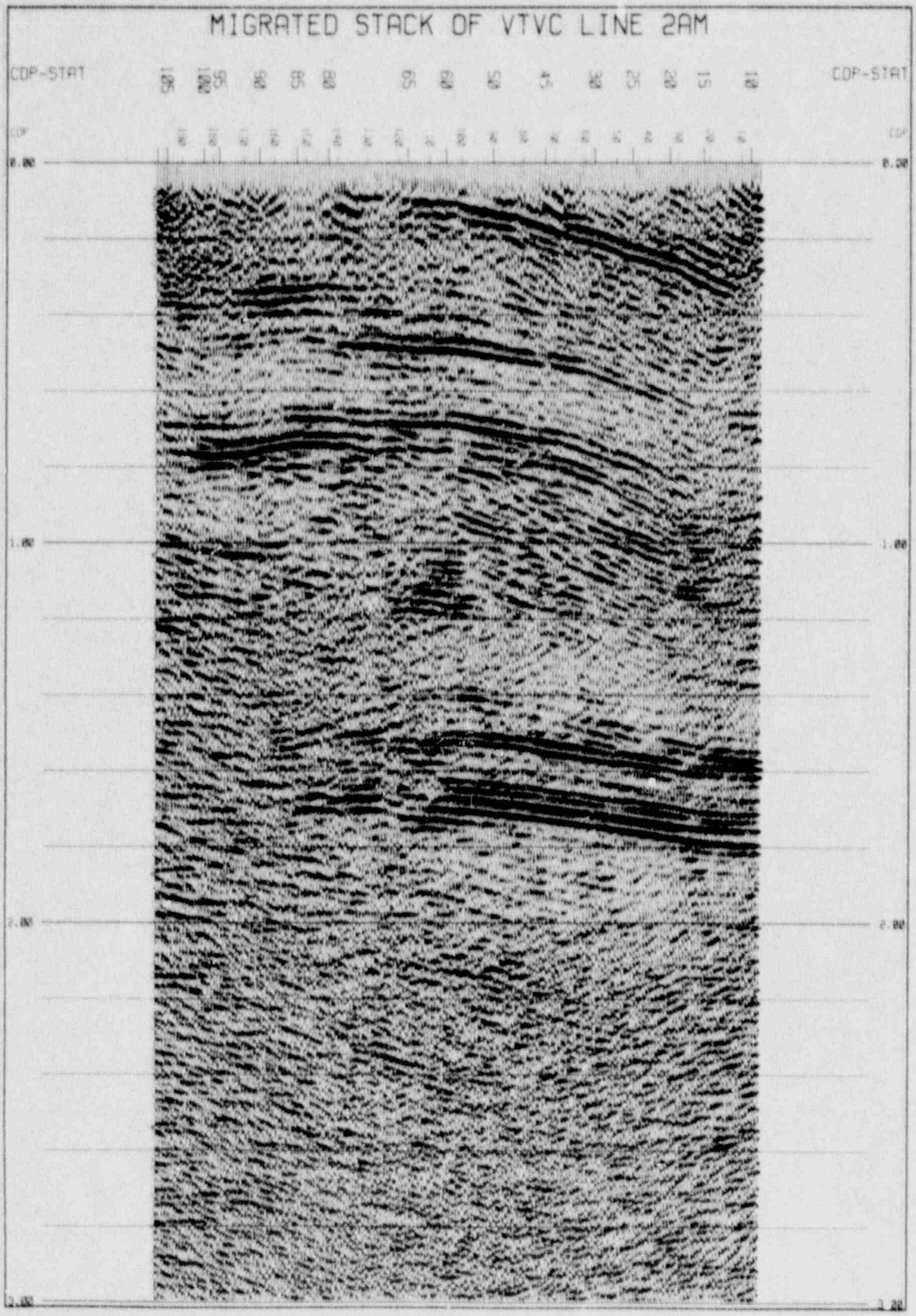


Figure 7. Stack (migrated) Line VTVC2A: Finite difference migration using 95 percent of stacking velocities. Horizontal scale same as Figure 4. This figure is the same as Plate II.

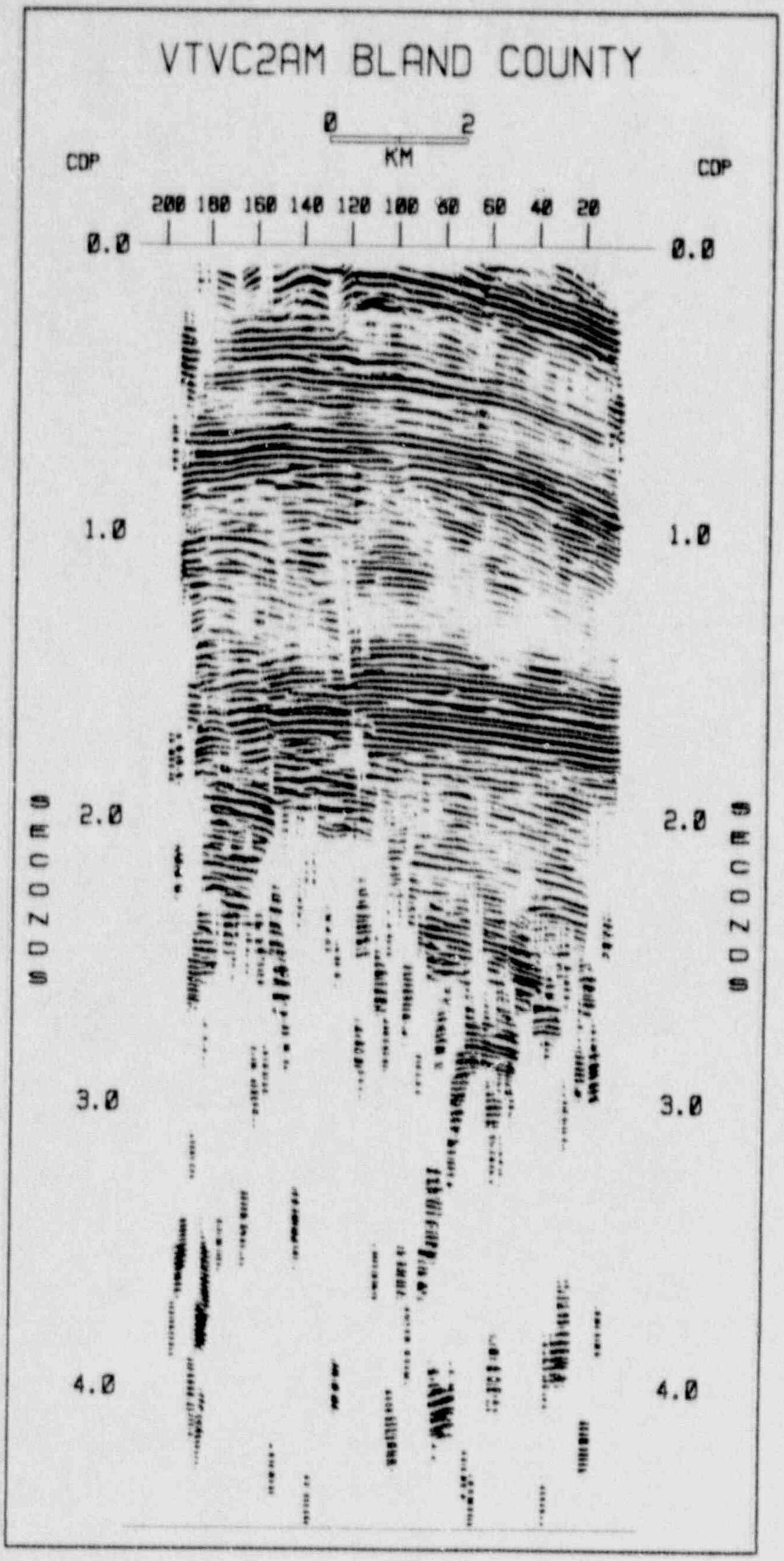


Figure 8. Automatic line drawing of Line VTVC2A (unmigrated).

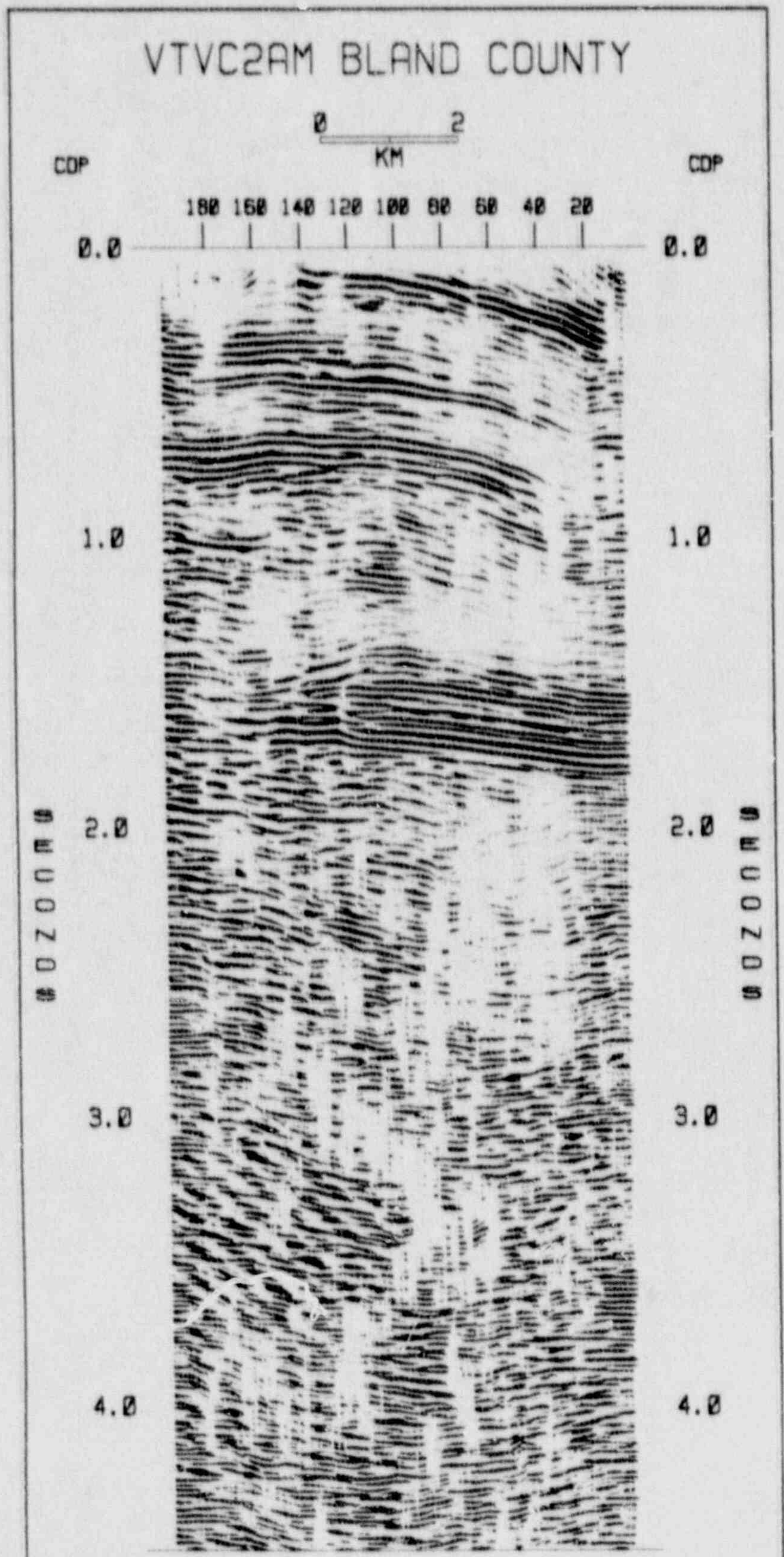


Figure 9. Automatic line drawing of Line VTVC2A (migrated).

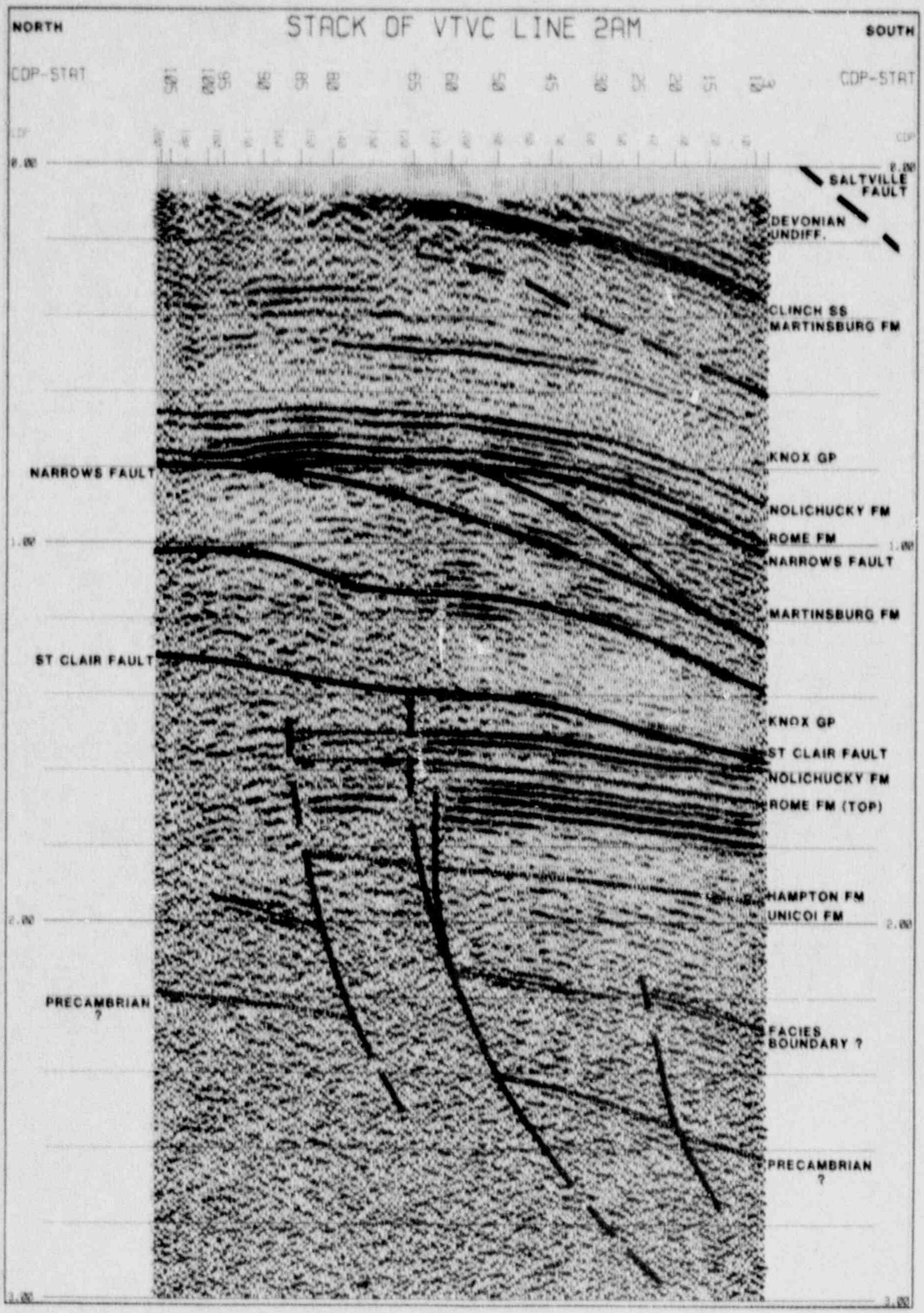
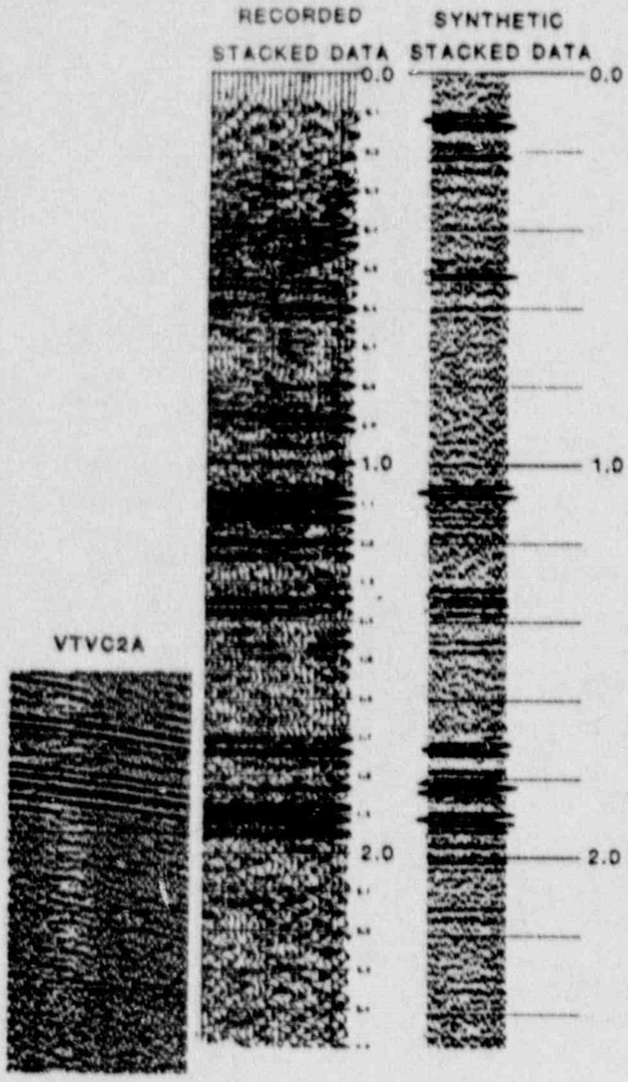


Figure 10. **Interpreted stack of Line VTVC2A (unmigrated):** Three major fault slices are interpreted to occur between the St. Clair and Narrows faults. The Eocambrian basin interpreted below 2 sec is bounded by a large listric normal fault. Reflection patterns within the basin indicate a lower basal facies followed by infilling. Divergence in reflection dip at the base of the Hampton Formation may denote change from rifting to passive margin sedimentation.



	LITHOLOGY	FORMATION	H m	V km/sec	ρ gm/cm³
MISSISSIPPIAN	SANDSTONE SHALE INTERBEDDED LIMESTONE	BLUEFIELD	300	5.00	2.67
	SKELETAL LIMESTONE GRAINSTONE	GREENBRIAR	300	6.30	2.70
	RED MUDSTONE SILTSTONE SOME EVAPORITES	McCRADY	490	5.20	2.62
	LITHIC SANDSTONE COAL NEAR TOP	PRICE	207	5.20	2.67
DEVONIAN	THICK BEDDED SANDSTONE SILTSTONE SHALE	CHEMUNG	212	4.55	2.61
	THIN BEDDED SANDSTONE SILTSTONE SHALE	BRALLIER	790	4.98	2.70
	BLACK SHALE	MILLBORO	289	4.70	2.74
SIL.	L. DEVONIAN SILURIAN U. ORDOVICIAN QUARTZ ARENITE SHALE LIMESTONE		AVERAGE 245	5.50	2.72
ORDOVICIAN	THIN SKELETAL LIMESTONE SHALE	MARTINSBURG	400	4.55	2.70
	RED MUDROCK	MOCASSIN	100	5.35	2.66
	MIDDLE ORDOVICIAN LIMESTONES		300	6.30	2.70
CAMBRIAN	DOLOMITE WITH QUARTZ ARENITE	KNOX	930	6.50	2.80
	DOLOMITIC SILTSTONE	NOLICHUCKY	17	5.63	2.71
	DOLOMITE	HONAKER	360	7.30	2.66
	RED MUDROCK	ROME	160	3.70	2.67
	DOLOMITIC REEFS	SHADY	100	6.70	2.84
	QUARTZ ARENITE	ERWIN	300	6.00	2.59
	SHALE SILTSTONE	HAMPTON	300	5.40	2.71
	ARKOSIC SANDSTONE SOME VOLCANICS	UNICOI	300	6.20	2.67
	PRECAMBRIAN BASEMENT AND SEDIMENTS		-	6.00	2.80

Figure 11. Stratigraphy of Bland County with correlations to seismic data. Part of Line VTVC2A correlated with synthetic seismogram and stacked data in region. The velocity and density values are derived from laboratory analysis of core samples. Figure modified from Gresko (1985, Fig. 3).

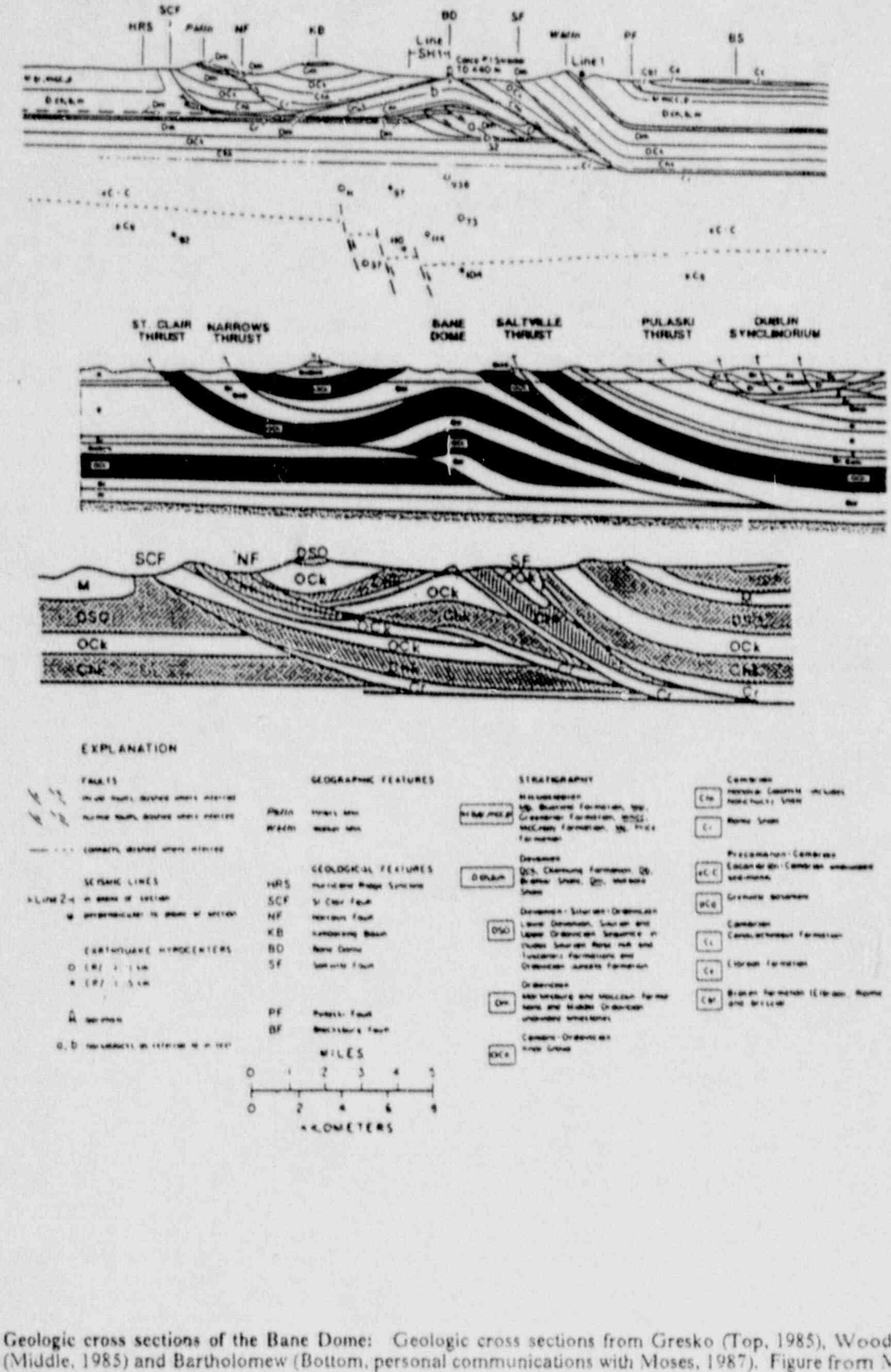


Figure 12. Geologic cross sections of the Bane Dome: Geologic cross sections from Gresko (Top, 1985), Woodward (Middle, 1985) and Bartholomew (Bottom, personal communications with Moses, 1987). Figure from Moses (1988, Fig. 4).

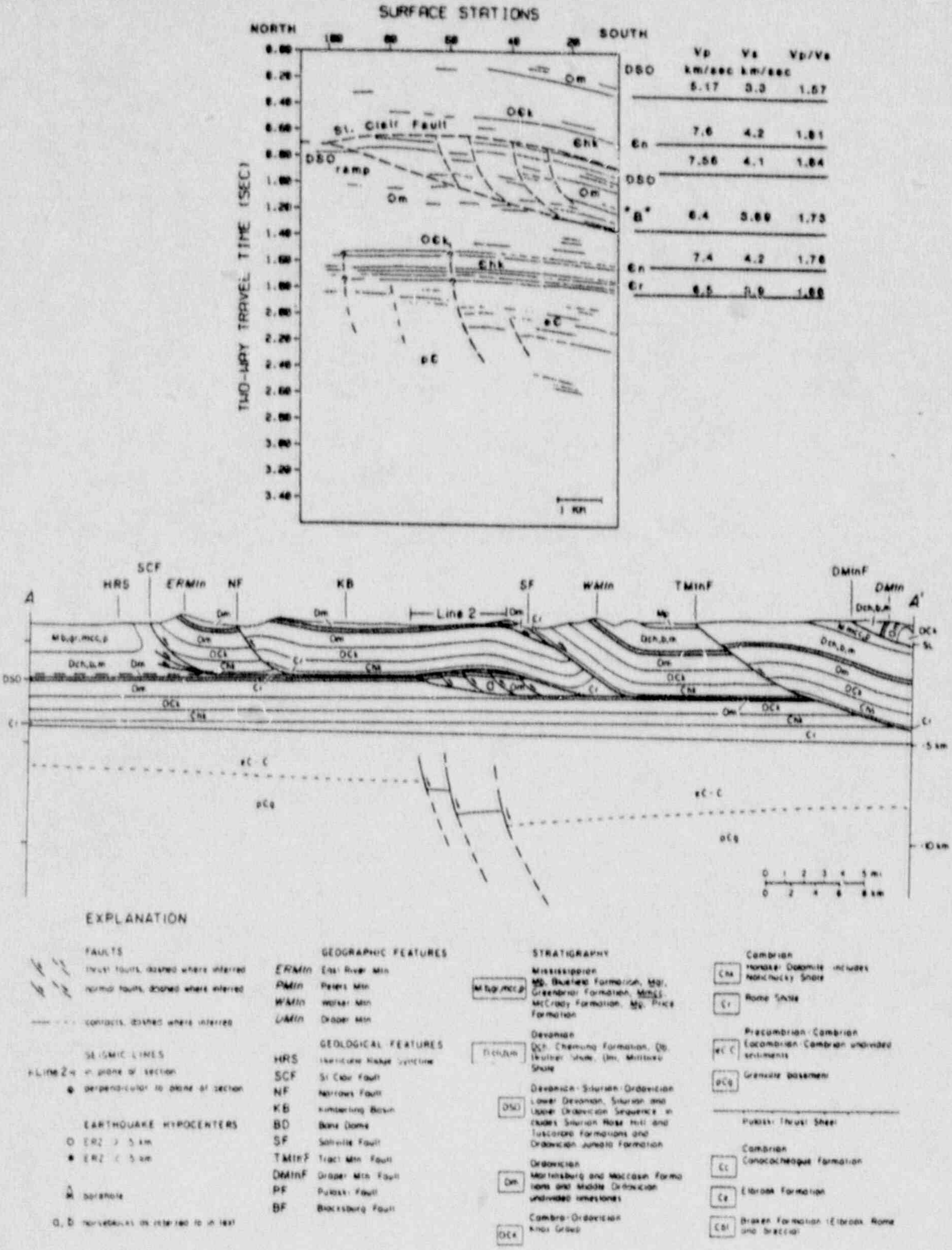


Figure 13. **Interpretation of VTVC2 by Gresko:** Upper figure shows interpretation of Line VTVC2 by Gresko (1985, Fig. 8). Included are P-wave and S-wave interval velocities and Vp/Vs ratios. Only the St. Clair fault and a single fault slice are interpreted to cut through the section. The Narrows fault is interpreted to be a break-back imbricate fault of the St. Clair fault and does not appear in the seismic section. Note the high angle normal faults indicated in the Eocambrian sediments.

Lower figure shows a regional cross section through the study area as interpreted by Gresko (1985, Fig. 18). The St. Clair, Narrows, and Saltville faults are shown in relation to each other.

APPENDIX

AVAILABILITY OF VTVC2A SEISMIC DATA

Copies of the unmigrated and migrated versions as well as the unmigrated and migrated ALDs of Line VTVC2 are available on magnetic tape in SEG-Y format for a nominal fee to cover transcription costs. To obtain copies contact:

Dr. John K. Costain
Regional Geophysics Laboratory
Department of Geological Sciences
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061.

Please mention the file name and archive tape number of the data sets from the table below when ordering.

Line VTVC2A Seismic Data

Data Set	File Name	Archive Tape
Unmigrated Stack	VTVC2A.DSK	V1791
Migrated Stack	VTVC2AM.DSK	V1791
ALD Unmigrated Stack	ALD2A.DSK	V1791
ALD Migrated Stack	ALD2AM.DSK	V1791

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

The purpose of this study was to process and interpret a seismic reflection line from Bland County, Virginia, and to compare it to an earlier line in this location. A longer Vibroseis sweep with greater bandwidth was used for the new line, which provided a considerable improvement in signal to noise ratio and resulted in better residual statics. Additional processing steps, including crooked line CDP sort and predictive deconvolution, also led to improved resolution, particularly in the shallow section.

The geologic section interpreted from the seismic profile represents a series of fault slices between the St. Clair Narrows thrust plates above autochthonous Lower Cambrian shelf strata. A previously interpreted Eocambrian rift basin is clearly defined on this line; the basin is bounded by a large normal fault at its north end. Seismicity in Bland and Giles counties may originate in reactivated Eocambrian faults which presumably formed during opening of the Proto-Atlantic Ocean.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

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Virginia
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PROCESSING AND INTERPRETATION OF SEISMIC REFLECTION DATA
NEAR THE BANE DOME IN BLAND COUNTY, VIRGINIA

NOVEMBER 1989