533924

Department of Energy
Carlsbad Area Office
P. O. Box 3090
Carlsbad, New Mexico 88221

June 26, 2000

Mr. Frank Marcinowski
Office of Radiation and Indoor Air
Environmental Protection Agency
Center for Federal Regulation
Ariel Rios Building
1200 Pennsylvania Avenue, N. W.
Washington, DC 20460

[PLANS TO RAISE THE REPOSITORY HORIZON] 2/6/04

Dear Mr. Marcinowski:

The purpose of this letter is to inform the Environmental Protection Agency that the Carlsbad Area Office (CAO) plans to raise the repository horizon in Panels 3, 4, 5 6, and 9 by approximately two meters so that the roof is at clay seam G. The Waste Isolation Pilot Plant intensively monitors the geomechanical behavior of its underground excavations. Actual monitoring of underground excavations, specific underground studies, and geotechnical modeling (e.g., DOE-WIPP 94-025, Investigation of the Advantages of Removing Highly Fractured Roof Beams), all demonstrate that positioning the roof at clay seam G improves ground conditions in the repository and provide a more stable roof configuration without significantly impacting repository performance. Raising the repository horizon reduces the rate at which ground deteriorates (i.e., slower roof beam deformation rate and slower development of fractures), thus reducing risks during mining and waste handling operations.

The repository horizon for Panels 3, 4, 5, 6, and 9 will be raised so that the roof is at clay seam G (shown on the attached Figure 3-6). Raising the repository horizon will be initiated in the East 300 drift (shown on the attached Figure 3-2) which leads into Panel 3. Raising the repository horizon now and in this location will result in improvements in safety and in operational efficiencies. This does not imply that there are underground safety concerns associated with the present situation; however, by raising the repository horizon by about two meters, ground conditions will be improved and considerably less maintenance will be required to assure optimum ground conditions.

CAO has analyzed (qualitatively) the impacts of moving the repository horizon on the long-term performance predictions in the certified baseline. The change in horizon may have some small impacts on brine inflow, gas/brine outflow, and creep closure. However, these impacts are expected to be quite small and may only be observable, if observable at all, in the subsystem performance assessment (PA) computer codes. More importantly, it is expected that there will be an insignificant impact on the location of the Complementary Cumulative Distribution Function (CCDF) curve for the PA that was included in the Compliance Certification Application (CCA) and the Performance Assessment Verification Test. This insignificant impact on the CCDF is expected because of the simplifications and conservative assumptions (e.g., treatment of the disturbed rock zone (DRZ) and panel closure permeability) made in the PA-scale computer models regarding the repository horizon and long-term performance of the disposal system. This change in repository horizon is within the disposal horizon envelope presented in the CCA in Figure ES-1 of Appendix Panel Closure System (PCS) and in Figure 3-6 from Chapter 3.

Based on the demonstrated geotechnical improvements (i.e., slower roof beam deformation rate and slower development of fractures) and the insignificant impact on the long-term predictions for repository performance, as a result of raising the horizon, the CAO will begin the mining at the slightly elevated repository horizon on or about July 1, 2000. CAO is tentatively scheduled to provide technical discussions to the EPA staff on this improvement and other topics during the week of June 26th, 2000 in Carlsbad New Mexico.

Enclosures to this letter provide additional information on this item. If you have any questions, please contact George Basabilvazo at 505-234-7488.

Sincerely,

Inés Triay
Dr. Inés R. Triay
Manager

Enclosures:
A: Figure 3-2 from CCA Chapter 3
B: Figure ES-1 from CCA Appendix PCS
C: Figure 3-6 from CCA Chapter 3
D: Report DOE-WIPP 94-025, Investigation of the Advantages of Removing Highly Fractured Roof Beams

cc w/ enclosures:
M. Kruger, EPA-ORIA
C. Byrum, EPA Region 6

cc w/o enclosures:
D. Huizenga, EM-20
C. Zvonar, CAO
G. Basabilvazo, CAO.
B. Lilly, CAO
F. Hansen, SNL
B. Howard, SNL
M. Marietta, SNL
D. Haar, WID
D. Kump, WID
W. Most, WID

CAG:ORC:GTB 00-0090
UFC 6500

Enclosure A

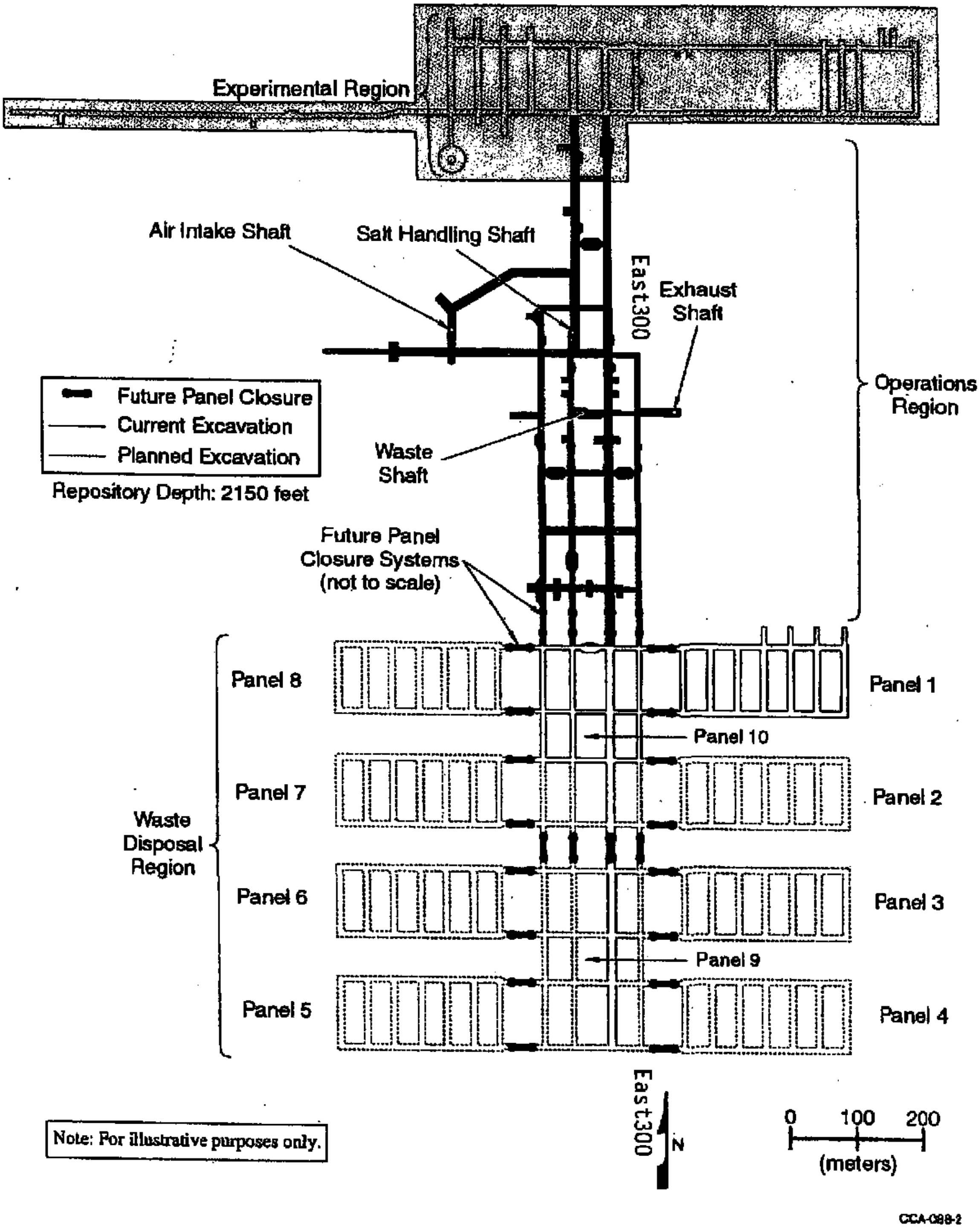
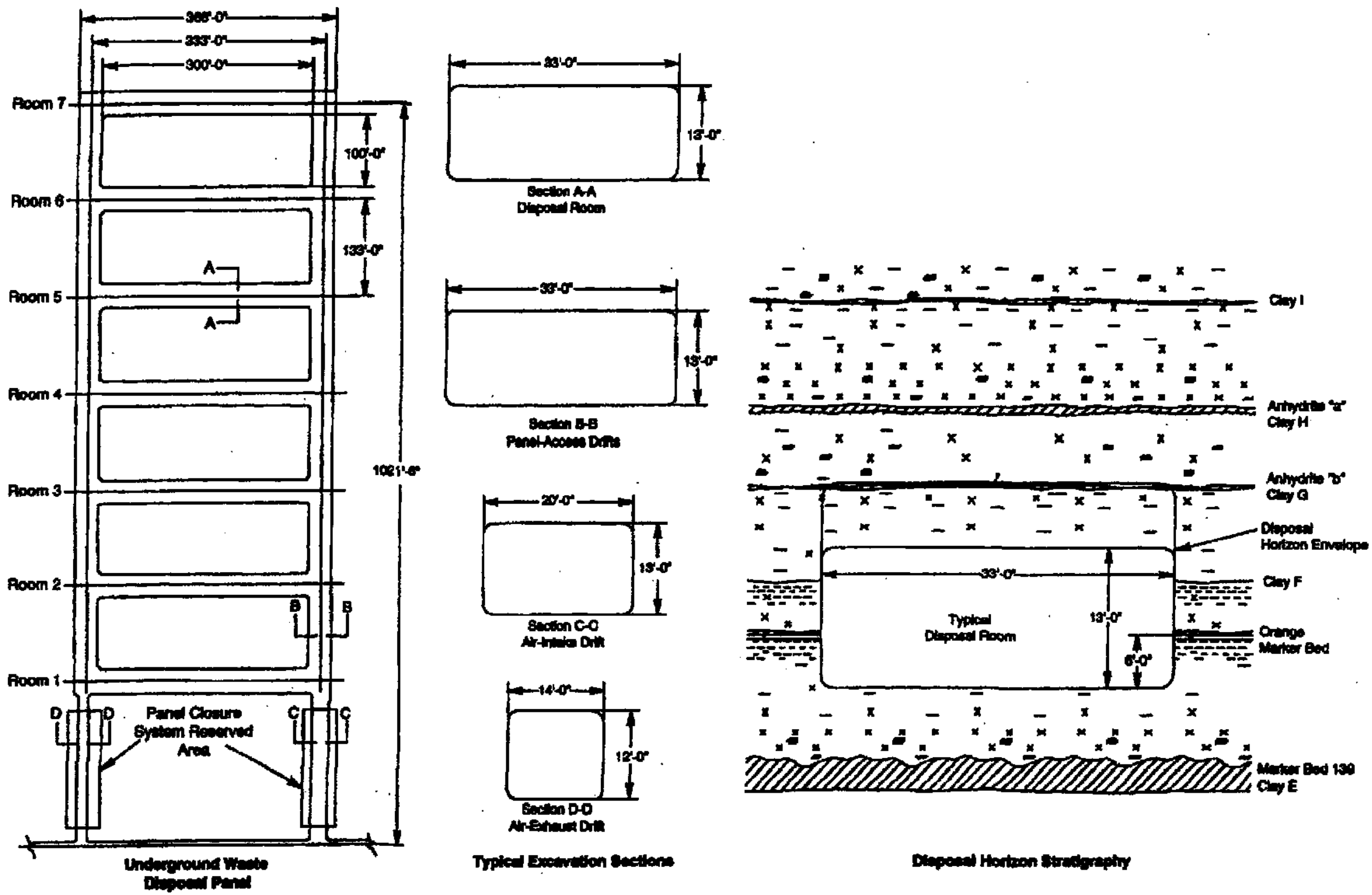


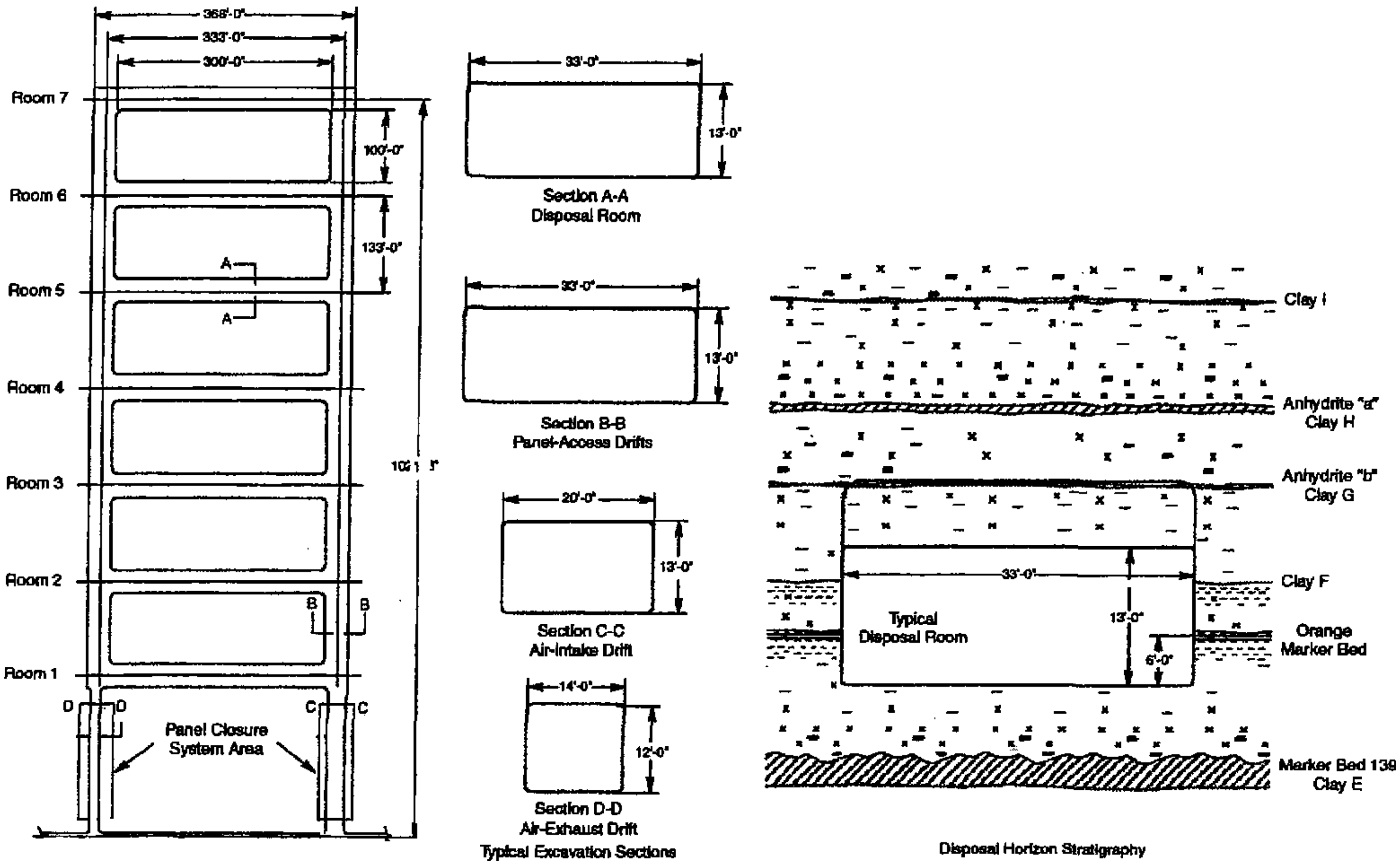
Figure 3-2. Plan View of WIPP Underground Facility and Panel Closure Systems

Enclosure B



Note: Figure is Not to Scale
All Dimensions Shown are Nominal

Figure ES-1
Typical Facilities-Typical Disposal Panel
(After Westinghouse, 1995c)



Note: Figure is not to scale. All dimensions shown are nominal.

CCA-089-2

Figure 3-6. Location of Panel Closure System

Enclosure D

DOE-WIPP 94-025

Investigation of the Advantages of Removing Highly Fractured Roof Beams

August 1994

Waste Isolation Pilot Plant

This document is issued by Westinghouse Electric Corporation, Waste Isolation Division, as the Management and Operating Contractor for the Department of Energy, Waste Isolation Pilot Plant, Carlsbad, New Mexico, 88221.

DOE CONTRACT NUMBER: DE-AC04-86AL31950

This document has been reproduced directly from the best possible copy. It is available to DOE and DOE contractors at the following address:

Office of Scientific and Technical Information
P. O. Box 62
Oak Ridge, TN 37831

Prices available from (615) 576-8401

Author C. Francke

Available to the public from the
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

992B:3

TABLE OF CONTENTS

LIST OF FIGURES

INVESTIGATION OF THE ADVANTAGES OF REMOVING HIGHLY FRACTURED ROOF BEAMS

1.0 Introduction

The behavior of the underground excavations at the Waste Isolation Pilot Plant has been intensely studied for over ten years. All excavations have performed their intended functions safely with normal maintenance and ground support. The deformation characteristics and mechanisms are well understood. Many openings such as the main access drifts and shaft stations must remain open for the life of the facility. With many openings now ten years old or older and a twenty-five year operational (disposal) phase planned for 1998, these drifts are required to be usable for over forty years. It has been proposed that mining out the roof of the excavations up to the nearest clay seam may extend the useful life of some excavations. This report reviews available rock mechanics information relevant to improving drift stability by removing the roof beam. For the purposes of this document, a "roof beam" is defined as the section of rock between the roof of the excavation and the nearest clay seam above the roof. A drift with a clay seam forming the roof is defined as having no roof beam. Theoretical deformation mechanisms believed to be at work at WIPP are briefly discussed. Field data from excavations with a clay seam forming the roof are reviewed. Finally, numerical modeling results compare the performance of excavations with and without roof beams. Only the geomechanical effects of the roof beam are discussed in detail here. Economics are only considered in passing. The removal of a roof beam in an existing drift would have several non-geomechanical consequences. The ventilation balance would change with the drift cross-section. Utilities would also need to be removed and reinstalled.

2.0 Conceptual Model for Excavation Stability at WIPP

The stability of excavations at WIPP is assessed by analysis of creep displacement and fracture formation. Fracturing and increasing displacement are closely related and in the absence of increased stress levels or increased temperature, displacement rate increases can only be caused by forming and opening fractures.

The general scenario for unsupported WIPP excavations is: 1) excavation is mined and displacement rates begin decreasing (Figure 1, Curve A). Localized (one to ten feet long) shallow spalls associated with poor rock conditions are frequently observed soon after excavation; 2) excavation deforms smoothly according to creep properties of salt (Curve B). Low angle shear fractures form near the ribs and separations and horizontal offsets form at clay seams; 3) large scale fracturing that goes deep into the rock develops and closure rates increase (Curve C). Given sufficient time, the roof of an unsupported excavation will probably continue to fracture until the roof falls (Point D). The formation of the large scale fractures in the roof is influenced by several factors. A conceptual model for the fracturing is summarized below.

Zones of high shear stress develop in the roof near the ribs immediately after excavation. These zones are weakened relative to the rest of the roof beam. At the same time, the pillars expand horizontally into the excavation. Clay seams located in the roof (usually either Clay G or Clay I) or floor (usually clay E) slip under the horizontal displacement of the pillar (Figure 2). This effectively concentrates the pillar expansion between the clay seam in the roof and the clay seam in the floor. The high horizontal load is partly relieved by roof sag and partly by the formation of fractures. The weak zones in the roof formed by the early high shear stress are the most probable locations for fracture formation under the high horizontal stress from the pillars. These fractures are usually diagonal originating near each rib and terminating near the clay seam. Once the fractures are large and extensive enough, gravity forces due to the dead weight of the slab become dominant. As the fractures become more extensive, the ability of the slab to support its own weight is reduced, which in turn causes more fracturing. This is why displacement rates increase exponentially as extensive fracturing develops.

Since this scenario is generally accepted, it has been suggested that an excavation with a clay seam forming the roof would be more stable. The thought is that the clay seam at the roof would slip as the pillar expanded, thus reducing to a minimum the transmission of load to the roof and therefore the fracturing in the roof (Figure 3). According to the conceptual model, an excavation with clay seams forming both the roof and floor would be even better. Field data and numerical analyses will be used to evaluate both the scenario and the suggestion in order to determine what geotechnical benefits might be obtained.

3.0 Field Observations

Field observations, in the form of displacement measurements and fracture mapping, support the concept of removing the roof beam to enhance stability. Because many of the drifts that require long lives have already been mined, the effect of removing the roof beam well after initial mining must be investigated as well as mining the roof at Clay G from the beginning. Figure 4 is the WIPP underground layout with locations discussed in this and the following sections highlighted.

3.1 Roof Beam Removed in Existing Drift - Salt Handling Shaft Station

The only excavation at WIPP that has had the roof beam removed up to a clay seam well after initial mining is the Salt Handling Shaft Station. The station was mined (by drill and blast) in 1982 with a 14 to 18 foot high roof (Figure 5). The roof up to Clay G began deteriorating soon after excavation, at least partially because of poor charge control during mining. By 1987, the roof had deteriorated to the point that it was decided to remove the roof beam. The roof beam was removed (Figure 6) between November 1987 and February 1988 using a Tamrock scaler. Because this is a one of a kind excavation for WIPP (in terms of size, shape, and mining method), strong conclusions cannot be drawn from it. However, it must be examined here because its roof beam has been removed.

3.1.1 Fracturing in the Salt Handling Shaft Station

Since the roof beam was removed in the Salt Station, large scale fracturing has not redeveloped. Figures 7 and 8 show fracturing in the roof in May 1987 before roof beam removal and six years after the roof was removed. There are far fewer fractures with much smaller openings even six years after the roof was removed than there were before the roof was removed. Removing the roof beam has improved the condition (in terms of fracturing) of the Salt Shaft Station roof.

3.1.2 Geomechanical Instrumentation in the Salt Handling Shaft Station

Geomechanical instrumentation in the Salt Station also indicate that the roof is much more stable since the roof beam was removed. Figure 9 shows the roof displacement rate in the station 65 feet south of the shaft. This extensometer is located in the thickest part of the station roof where the roof was about seven feet below Clay G. Displacement rates after the roof was removed are about 25 percent of the earlier rates. This indicates that the new roof is considerably more stable since the old roof was removed. Figure 10 shows the roof displacement rate in the station 30 feet south of the shaft. The old roof beam here was only three to four feet thick. The reduction in displacement rate after the beam was removed is not as obvious for the thin roof beam. Recalling that the roof was both highly fractured and extensively rockbolted, this is probably due to the ground support and the weight of the beam. Once the roof became highly fractured, the thinner beam would be subject to less dead weight load. The smaller dead weight load would be more easily supported by the rockbolts. The lighter slab would also be less likely to form additional fractures due to its own weight. The thicker slab would be heavy enough to continue fracturing and would be harder to support with the rockbolts. Once the fractured roof was removed, excessive displacement due to fracturing no longer occurred. Thus the reduction in displacement and closure rates.

Roof to floor convergence measurements at S65 show similar results (Figure 11). After roof beam removal, convergence rates dropped to about 33 percent of the earlier rates. Again, the convergence points under the thinner section of the roof did not show such dramatic drops. Horizontal convergence rates remained about the same for all stations before and after roof beam removal.

3.2 Drift Originally Mined Without Roof Beam

Several drifts have been mined with Clay H or Clay I as the roof. These include the eastern N1100 drift with roof and floor formed by clays H and G, respectively, and the A, B, and D Rooms which have Clay I and G within a foot below and above the roof and floor, respectively. The performance of each of these drifts will be examined to determine the effect of their stratigraphic location.

3.2.1 N1100 and N1420 Drifts Comparison

These drifts are both 14 feet wide and were mined in 1984. N1420 is 12 feet high and N1100 is eight feet high. However, the configuration of the roof and floor beams are different in each drift. N1420 and N1100 at the experimental level have Clay G forming the floor. Clay H forms the roof in N1100 while N1420 has a five foot roof beam bounded by Clay I. Figure 12 shows the relative stratigraphic location of the drifts. The effect of a clay seam forming the roof can be examined by comparing the performance of the two drifts.

3.2.1.1 Fracturing in the N1100 and N1420 Drifts

Roof fracturing is relatively intense in the N1420 drift, which has a five foot thick roof beam and no floor beam. Large scale diagonal fractures have developed along with vertical cracks in the roof (Figure 13). The N1100 drift, which has no roof or floor beam, has very little fracturing (Figure 14). It is clear from the fracture observations that of these two drifts of nearly the same age and size, the N1100 drift, with no roof beam, is in much better condition than the N1420 drift with a roof beam and no floor beam.

3.2.1.2 Geomechanical Instrumentation in the N1100 and N1420 Drifts

The only instrumentation in the N1100 and N1420 drifts are vertical and horizontal convergence gauges. Vertical convergence rates in the N1420 drift between Room B and Room A2 are about 150% of the rates in N1100 (Figure 15) at the same relative location. The difference is probably due to bending and breakup of the roof beam in N1420. Horizontal rates are only slightly higher in the N1420 drift, indicating that the location of the clay seams at the roof and floor lines in N1100 does not cause high horizontal convergence rates (Figure 16).

3.2.2 Rooms D, B, and A

Rooms D, B, and the A's are 18 feet high by 18 feet wide and were all mined in 1984. The roof of these rooms is formed by Clay I and the floor by Clay G (Figure 17). Heaters in Room B and the A Rooms raised the air temperature about 50° F for about three years. Because salt creep is very sensitive to temperature, the discussion will focus on Room D which was not heated.

3.2.2.1 Fracturing in Rooms D, B, and A

Room D has six-foot rockbolts installed on a wide (6'-8' x ~10') pattern. Shallow fractures less than two feet deep were first observed in the roof soon after excavation. The slabs formed by these fractures do not appear to go much deeper into the roof and would be easily supported with standard rockbolts. Room B was rockbolted after long, thick slabs formed in the roof. There has not been a roof fall in Room B. There have been several roof falls in the A Rooms, which were not rockbolted. The fallen slabs were about 18 inches thick. The falls were allowed to occur because of the experimental use of the rooms. The rooms had been barricaded and normal maintenance was not performed. Considering that the high temperatures significantly accelerated deformations in the A rooms and Room B, all the 18'X18' drifts have performed very well.

3.2.2.2 Geomechanical Instrumentation in Room D

Both vertical and horizontal convergence in Room D have been very low considering the size of the room. Vertical convergence is about 1.1 inches per year versus a predicted rate of 1.7 inches per year. Horizontal convergence is about 0.8 inches per year versus a predicted rate of about 1.3 inches per year. Predicted values are from an empirical analyses of convergence at WIPP (USDOE, 1993). The low convergence rates may be attributed to the good condition of the roof, floor, and walls which in turn may be attributed to the presence of the clay seams forming the roof and floor.

3.3 Summary of Field Observations

Field observations in the form of geomechanical instrumentation and fracture mapping have been examined in all rooms without clay seams forming the roof or floor and in the only room that has had the roof removed to a clay seam. In all cases, the drifts with a clay seam forming the roof performed much better than their counterparts with a roof beam. Without exception, the field data demonstrate that initially mining drifts with a clay seam forming the roof makes for long-lasting, stable excavations. The field data also demonstrates that removing a roof beam well after excavation improves the stability of a drift.

It should be noted here that given a drift with a closure rate of two inches per year, after 40 years the drift will have lost 80 inches of its initial height. An originally 13 foot high excavation would be about six feet high after 40 years. Obviously the excess convergence cannot be completely mitigated by trimming the floor. Eventually at least part of the roof beam would have to be removed. However, the thinner roof beam would be expected to fracture even more than the original beam. Therefore, removal of the roof beam may be necessary just to maintain operating clearance in the access drifts.

4.0 Numerical Analyses

Numerical analyses, in the form of finite difference modeling, can be used to investigate the effect of roof beam removal and the advantages of mining drifts without roof beams. The finite difference code used was Fast Lagrangian Analysis of Continua (FLAC) (Itasca Consulting Group, 1993). Models of the Salt Handling Shaft Station and the N1420 and E140 drifts were developed to investigate the effect of removing the roof beam well after excavation. Models of Room D and N1100 drifts were developed to investigate the effect of initially mining drifts without roof beams and for comparison to the other drifts. Although the models cannot simulate fracturing, the potential for fracturing can be related to zones of high strain concentration in the models. Therefore, the discussion will concentrate on examination of shear strain results in the models.

4.1 Salt Shaft Station Roof Beam Removal

About 5.33 years after initial excavation, between three and eight feet of salt were removed from the roof of the Salt Handling Shaft Station to bring the roof up to Clay G. Figures 18 and 19 show accumulated strain calculated by the FLAC Salt Station model. Figure 18 shows the condition at 5.33 years after excavation immediately before the roof beam was removed. The roof beam has deformed considerably with a large separation at Clay G. Figure 19 shows the condition at ten years after excavation, about five years after the roof beam was removed. Note that there is very little roof sag. Accumulated strain in the roof is just reaching levels found in the original roof beam five years earlier. The model results indicate that removing the roof beam in the Salt Shaft Station provided a more stable roof with much less deformation.

4.2 N1420 Roof Beam Removal

The FLAC model of the N1420 drift was run in two configurations. One model with the five foot thick roof beam removed after ten years and one with the roof beam left in place. Figure 20 shows deformation ten years after excavation and immediately before the roof beam is removed in the model. Figure 21 shows conditions at twenty years after excavation with the roof beam left in place. Figure 22 shows conditions at twenty years after excavation with the roof beam removed ten years earlier. At ten years, the roof beam in the model has undergone high strains. If the roof beam is left in place, as in Figure 21, the strains only continue to build. However, with the roof beam removed at ten years, the highly strained material is removed and the new roof does not build up new high strains, even after twenty years. The model results indicate that removing the roof to Clay G in the N1420 drift will provide a much more stable roof, and fracturing will not be a problem for at least ten years and possibly longer.

4.3 E140 Roof Beam Removal

The FLAC E140 Drift model was also run in two configurations. One model has the six foot thick roof beam removed after ten years and one leaves the roof beam in place to twenty years. Figure 23 shows deformation after ten years immediately before the roof beam is removed in the model. Figure 24 shows conditions at twenty years with the roof beam left in place. Figure 25 shows conditions at twenty years with the roof beam removed ten years earlier. The results are very similar to the N1420 drift models. With the beam removed, strain is less in the roof after twenty years than it was in the roof beam before removal at ten years. Because Clay H is fairly close to the new roof in E140, there is more concentration of strain in the new roof of the E140 drift than in the new roof of the N1420, which does not have a nearby clay seam. Again, the removal of the roof beam in the model leaves a more stable and presumably longer lived excavation.

4.4 South E140 Drift Enlargement

The E140 Drift south of S2180 was mined in early 1983 with dimensions of about 8' to 9.5' high by 25' wide. The drift is not rockbolted and has been barricaded since 1989. No geomechanical measurements or visual observations have been made in the drift since it was barricaded. Figure 26 shows the stratigraphic location of the drift as it is currently configured. To accommodate excavation of Panel 2, the E140 Drift south of S2180 will need to be enlarged to allow large equipment to pass.

Two ways of enlarging the E140 drift have been modeled. One model lowers the floor of the south E140 drift eleven years after initial excavation. The other model removes the roof beam up to Clay G after eleven years. Figures 27 and 28 show strain around the drift for each configuration after twenty years (nine years after enlarging). Strain in the roof of the drift that had the floor lowered (Figure 27) is about twice that of the drift with the roof beam removed (Figure 28). This indicates that fracturing will be much more intense in the configuration with the stratigraphically lower roof. This suggests that removing the roof beam, which gives a 16 foot tall excavation, will both ease maintenance and provide a longer useful life than lowering the floor.

4.5 Room D and N1100 Drift Models

FLAC models of Room D and of the N1100 drift in the experimental area were developed for comparison to other models. Figure 29 shows strain around the N1100 drift twenty years after excavation. Strains are low in the roof of the N1100 model, particularly compared to the N1420 with the roof beam at twenty years (Figure 21). The Room D model also shows low strains in the roof (Figure 30). Both of these models show high strain in the ribs, although field data do not indicate that excessive sloughing occurs.

4.6 Summary of Numerical Analyses

Numerical models were developed for a variety of excavation sizes both at the repository level and the experimental level of the facility. Models were developed for drifts mined without a roof beam from the beginning and for drifts with substantial roof beams removed later in the model's life. In all cases, the models indicate that drifts originally mined with a clay seam at the roof line perform very well. Excessive strains do not develop in the roof. In all cases where the roof beam was removed well after initial excavation, the drift performed better after the beam was removed. Again, fracturing is not simulated in the models, although the total shear strain may be used as an indication of the propensity of the rock to fracture. Also, these models cannot adequately address the performance of the floor of excavations because MB139 does not creep and is very strong. Neither of these factors significantly influence the results, so the numerical models clearly demonstrate that roof beam removal enhances the stability of WIPP excavations.

5.0 Summary of Results

The geomechanical advantages of removing old roof beams or mining drifts without roof beams from the beginning were examined in a variety of ways. A conceptual model for WIPP excavation performance was extended to postulate the effect of roof beam removal. Field data from drifts without roof beams and from drifts that had roof beams removed after initial excavation were examined to see if the effect was measurable. Finally, numerical models of various excavations were developed to examine the effect of roof beam removal or the lack of a roof beam.

5.1 Conclusions

The following conclusions were reached after examination of all the factors discussed above.

1. The conceptual model for WIPP excavation effects indicates that much of the fracturing and resulting instability in the roof of WIPP excavations is caused by the relative location of the clay seam above the roof of the excavation.

2. The field data indicate that fracturing and displacement are minimized in the roof of excavations without a roof beam.

3. The field data indicate the removal of a highly fractured roof beam significantly improves the stability of excavations.

4. The field data indicate that roof beam removal eventually will be necessary in order to maintain operating clearance *in life of mine* drifts.

5. Numerical analyses indicate that over equivalent times drifts without roof beams develop less strain in the roof than drifts with roof beams.

6. Numerical analyses indicate that the removal of a highly deformed roof beam significantly improves the condition of the roof.

7. The conceptual model, field data, and numerical analyses are reasonably consistent in their conclusions.

8. The E140 drift south of S2180 should be enlarged by removing the roof beam entirely rather than by lowering the floor and trimming the roof beam.

9. Drifts, such as Room D, that are originally mined with a clay seam forming the roof and floor will be much longer lived and require less maintenance than drifts with a roof beam.

10. The life of drifts with highly fractured roof beams can be significantly lengthened by removing the roof beam to the nearest clay seam.

5.2 Recommendations

In light of the conclusions reached by examination of the conceptual model, field data, and numerical analyses, the following recommendations are made concerning removal of roof beams.

1. New excavations requiring long useful lives should be mined with the roof at a clay seam. At the facility level, the roof should be at Clay G.

2. The roof beam should be removed from old excavations with highly fractured roofs once they require high maintenance efforts.

3. The timing of roof beam removal should be based on the level of effort required to maintain the existing roof. There is no need to remove the roof beam if maintenance is low.

6.0 References

Itasca Consulting Group, Inc., 1993, "FLAC User's Manual," Minneapolis, Minnesota.

USDOE, 1993, "Geotechnical Field Data and Analysis Report, Volume I of II, July 1991 - June 1992," Waste Isolation Pilot Plant, Carlsbad, New Mexico.

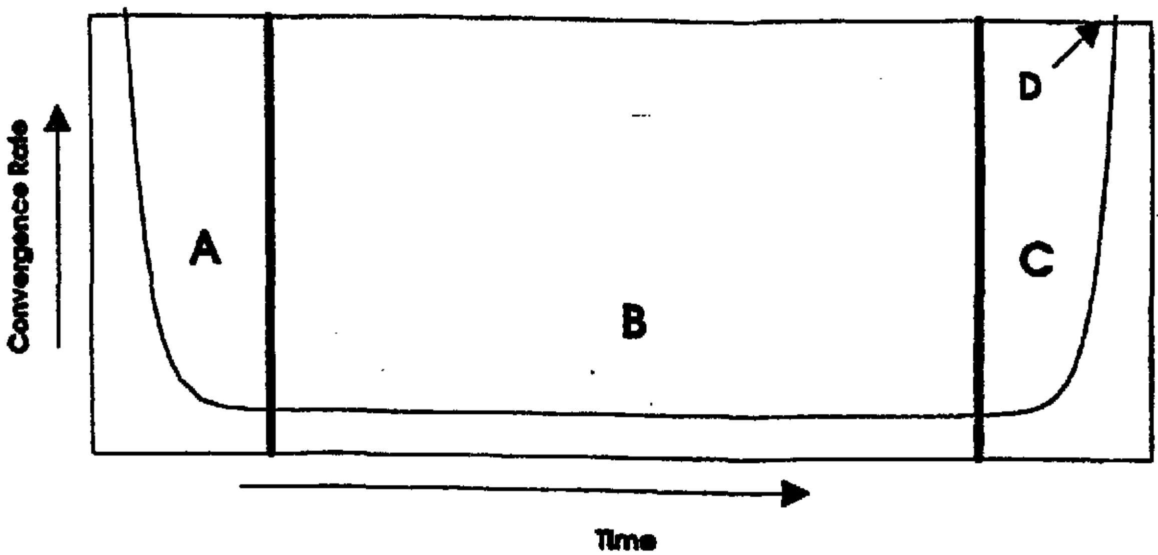


Figure 1
Typical Convergence Rate Curve Leading to Failure

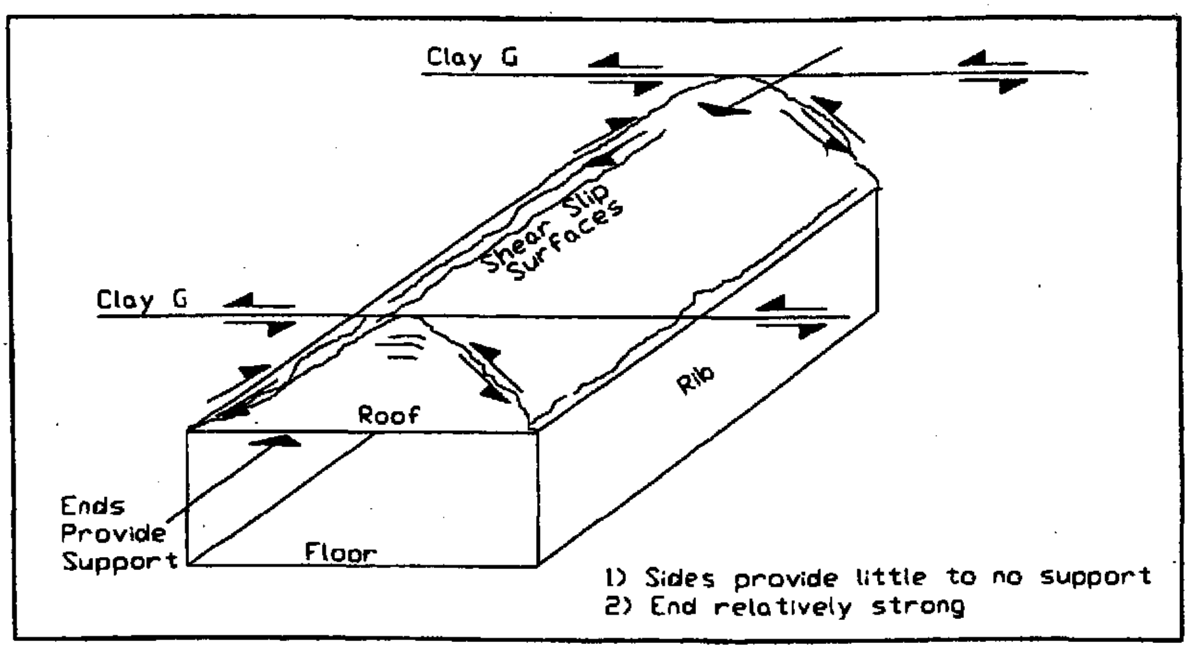


Figure 2
Advanced Fracture Formation in Roof

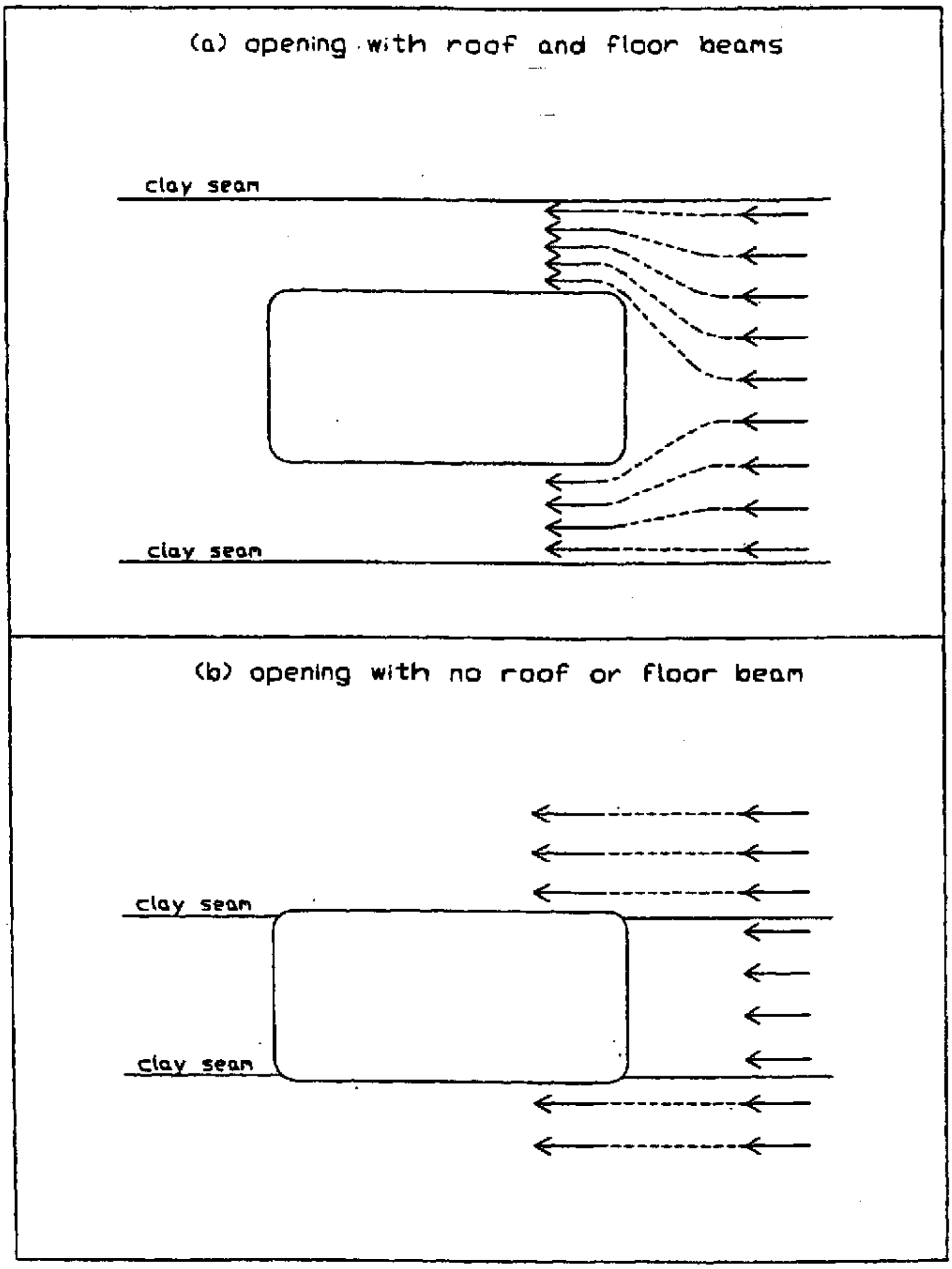


Figure 3
Stress Concentration Comparison for Two Different Roof Beam Geometries

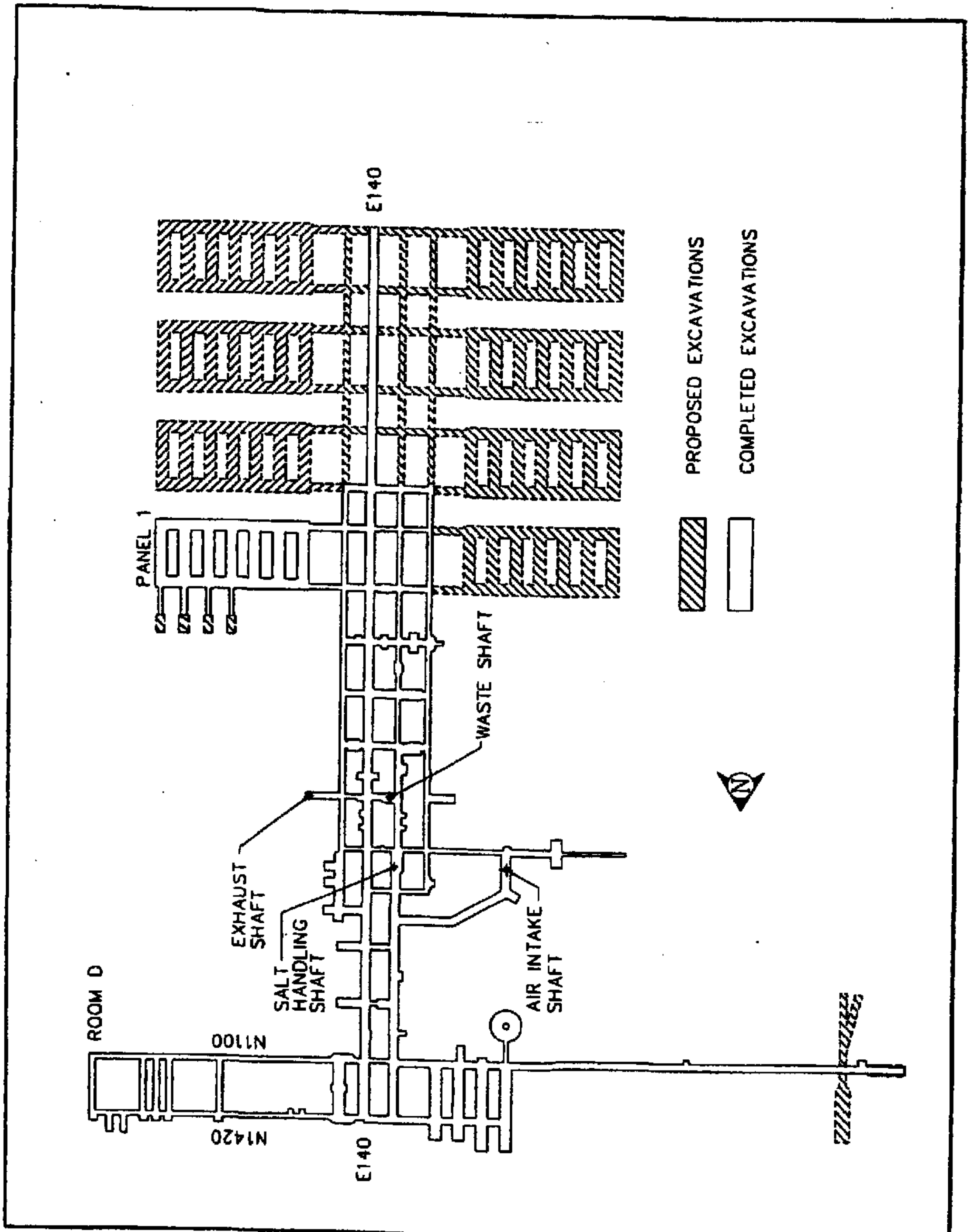


Figure 4
Waste Isolation Pilot Plant Mine Layout

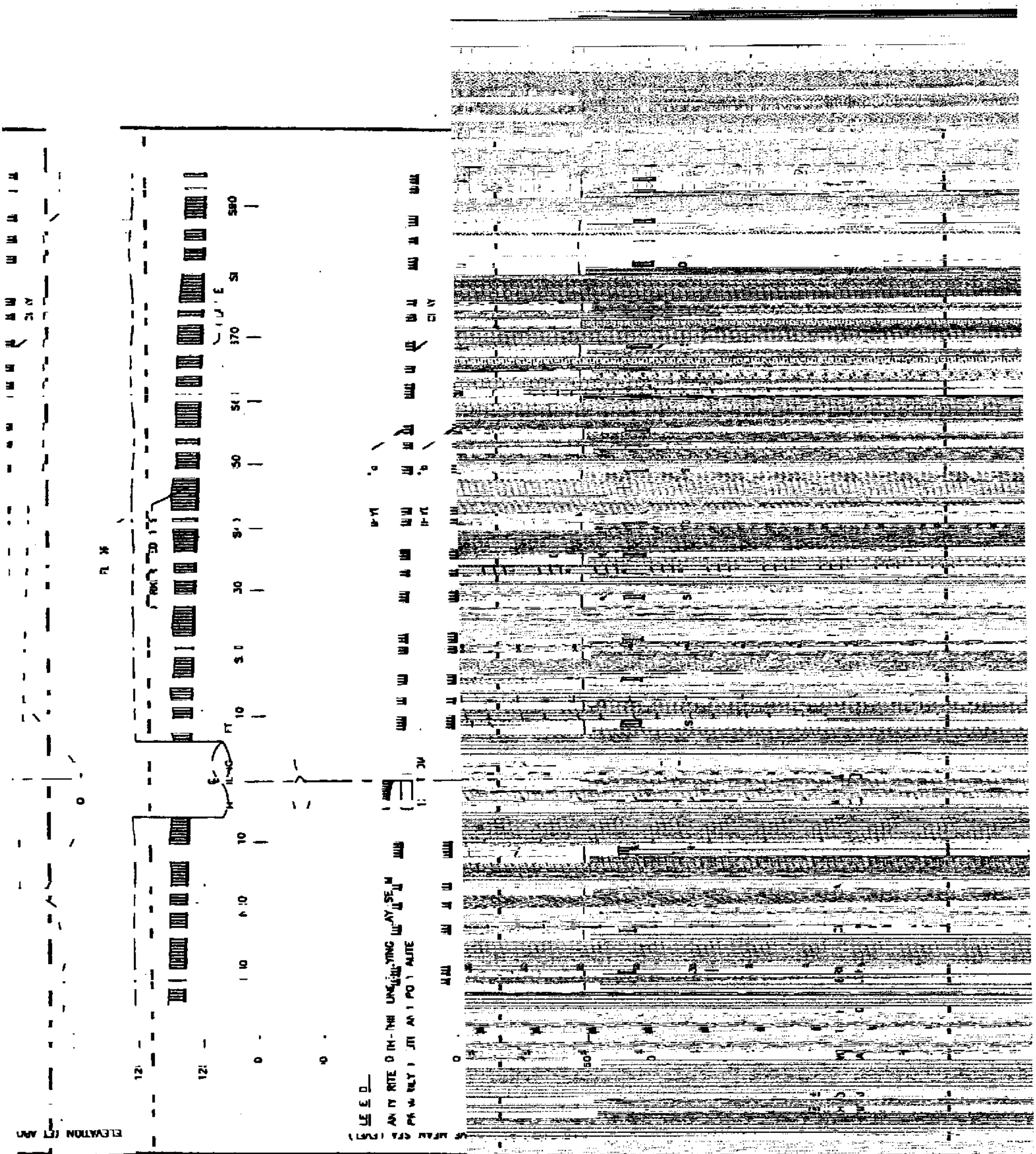


Figure 5

Before Roof Beam Removal

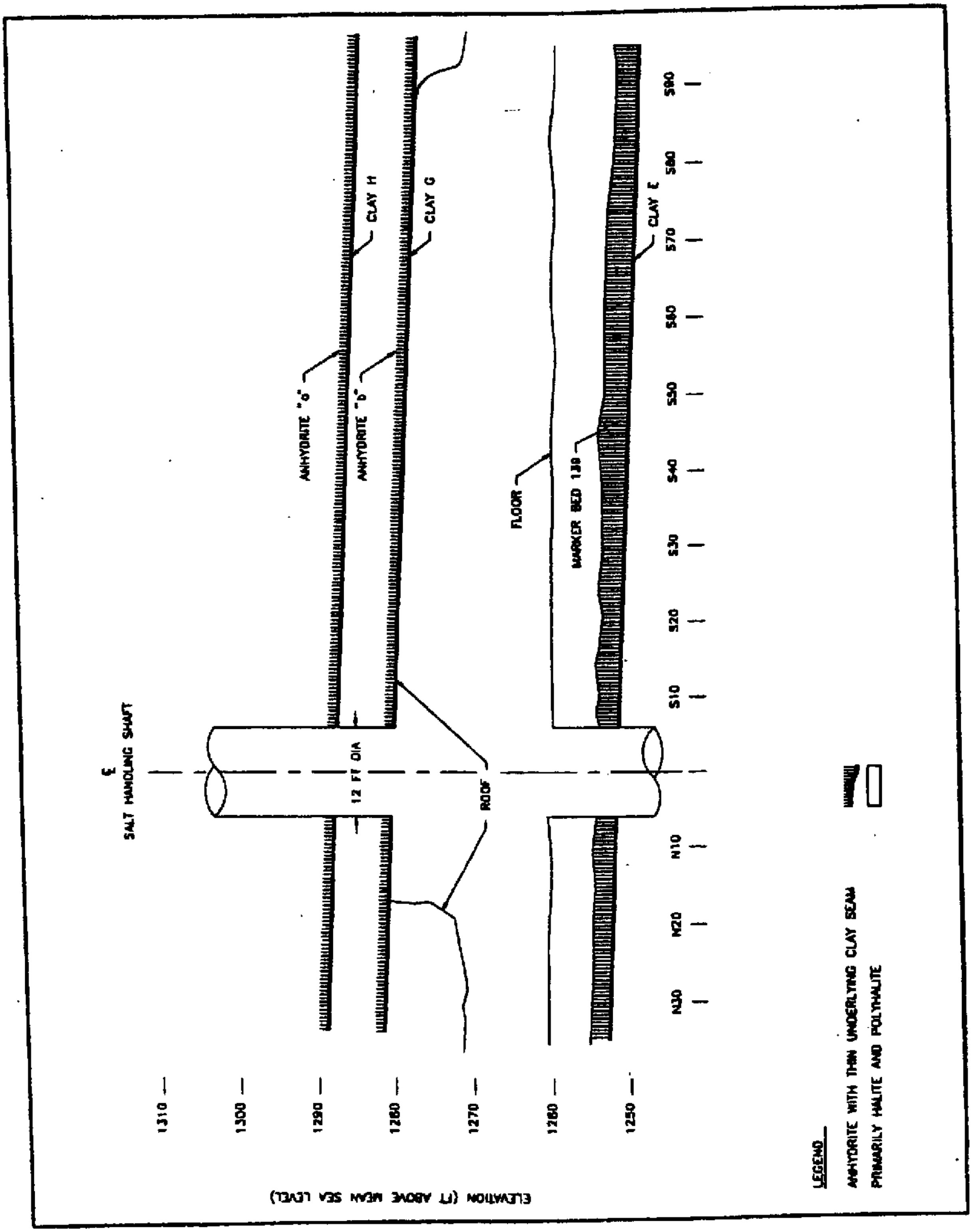


Figure 6
Salt Handling Shaft Station Profile After Roof Beam Removal

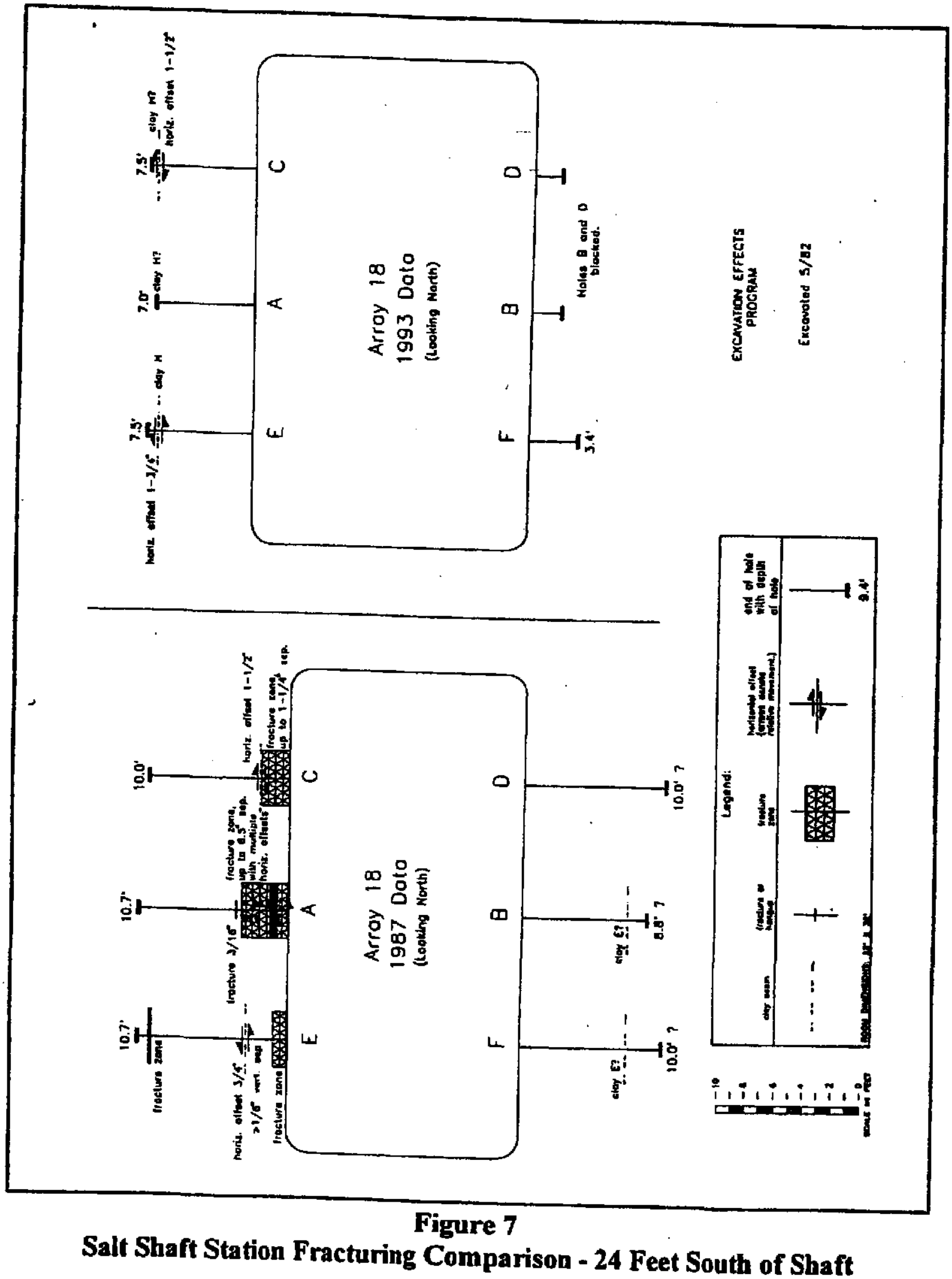
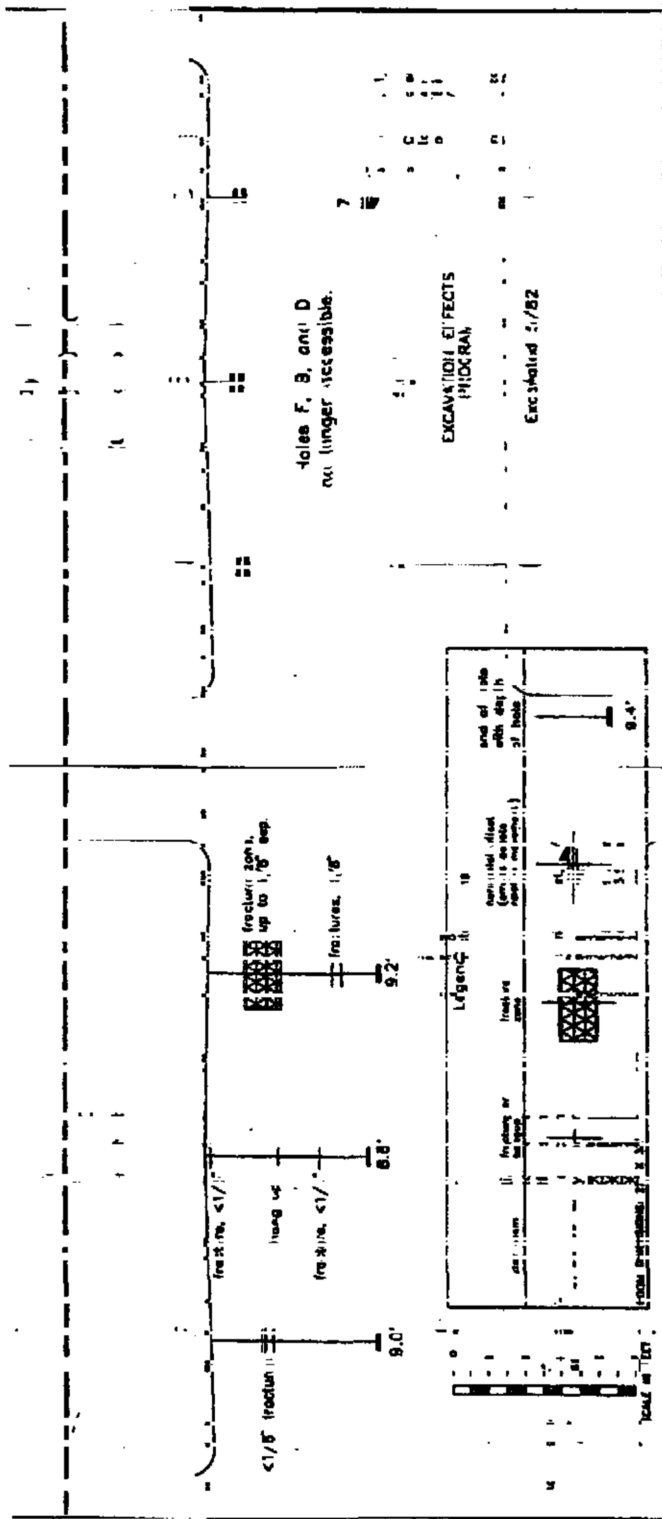


Figure 7
Salt Shaft Station Fracturing Comparison - 24 Feet South of Shaft



ison 56 Feet South of Shaft

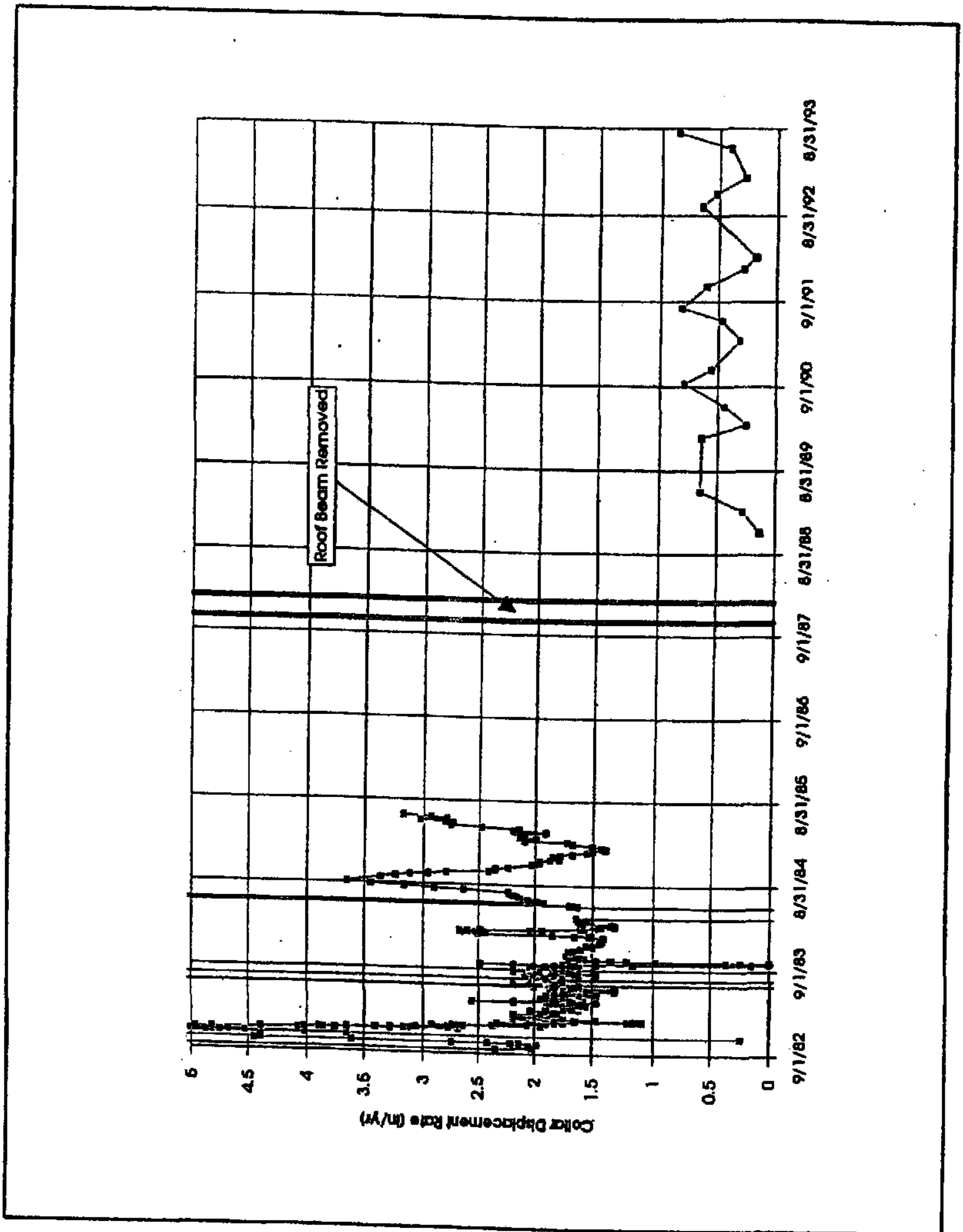


Figure 9
Salt Handling Shaft Station E0/S65 Roof Extensometer

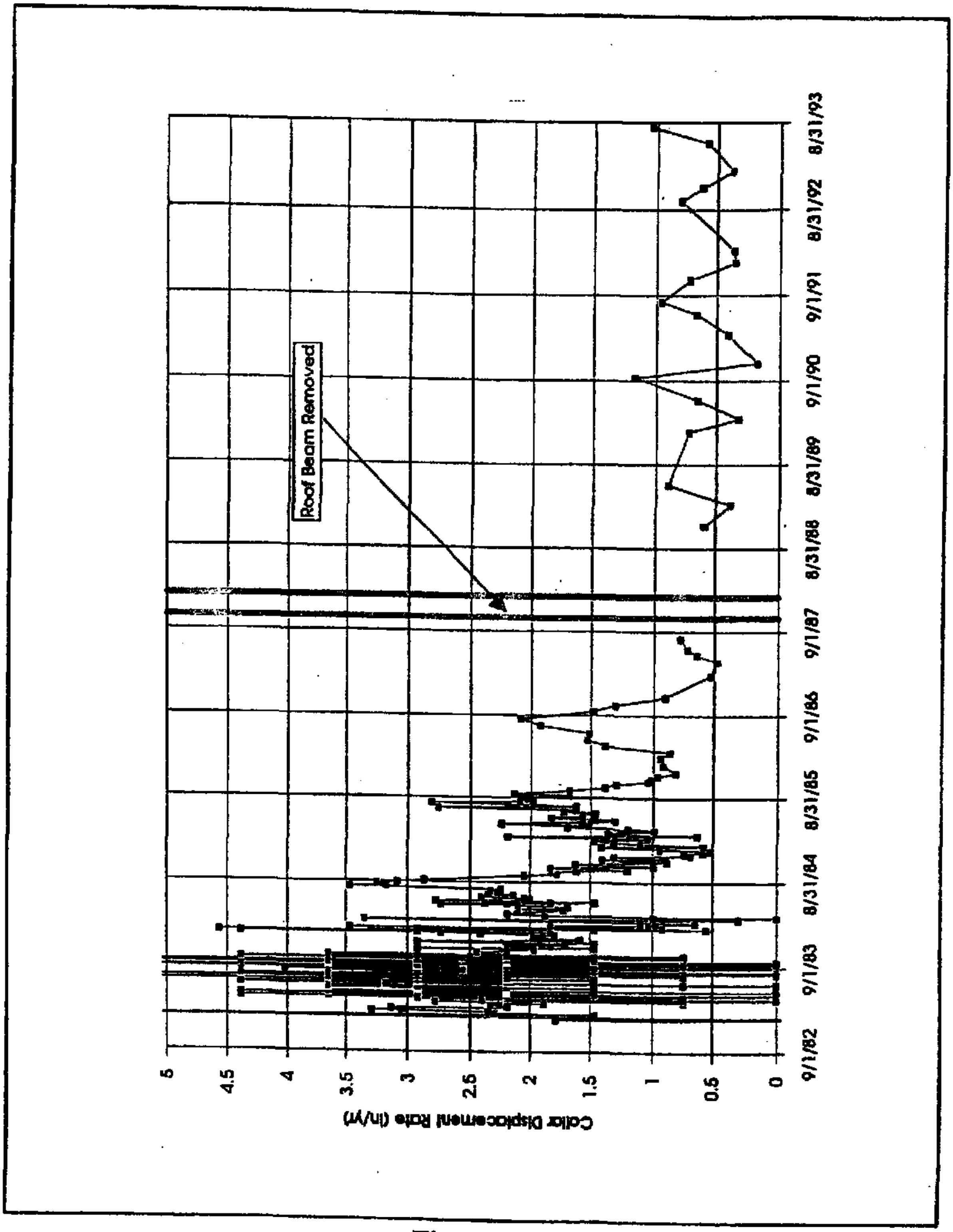


Figure 10
Salt Handling Shaft Station E0/S30 Roof Extensometer

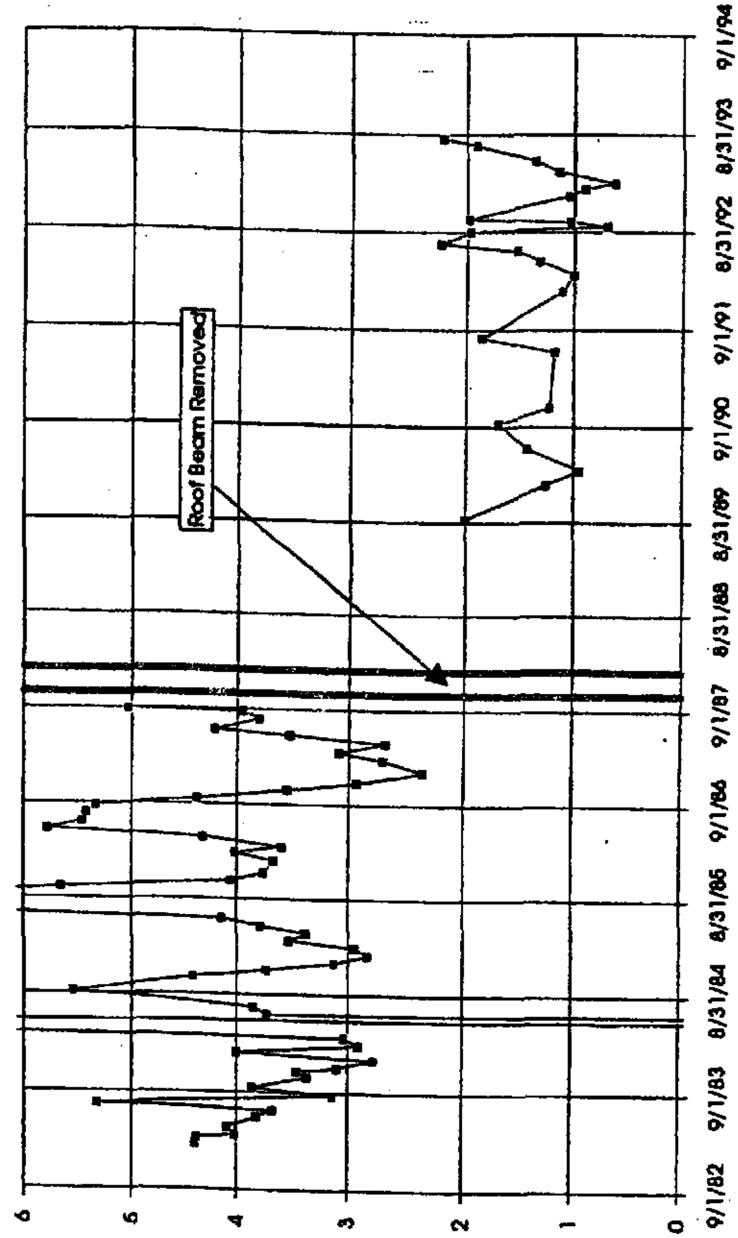


Figure 11
Salt Handling Shaft Station E0/S65 Vertical Convergence

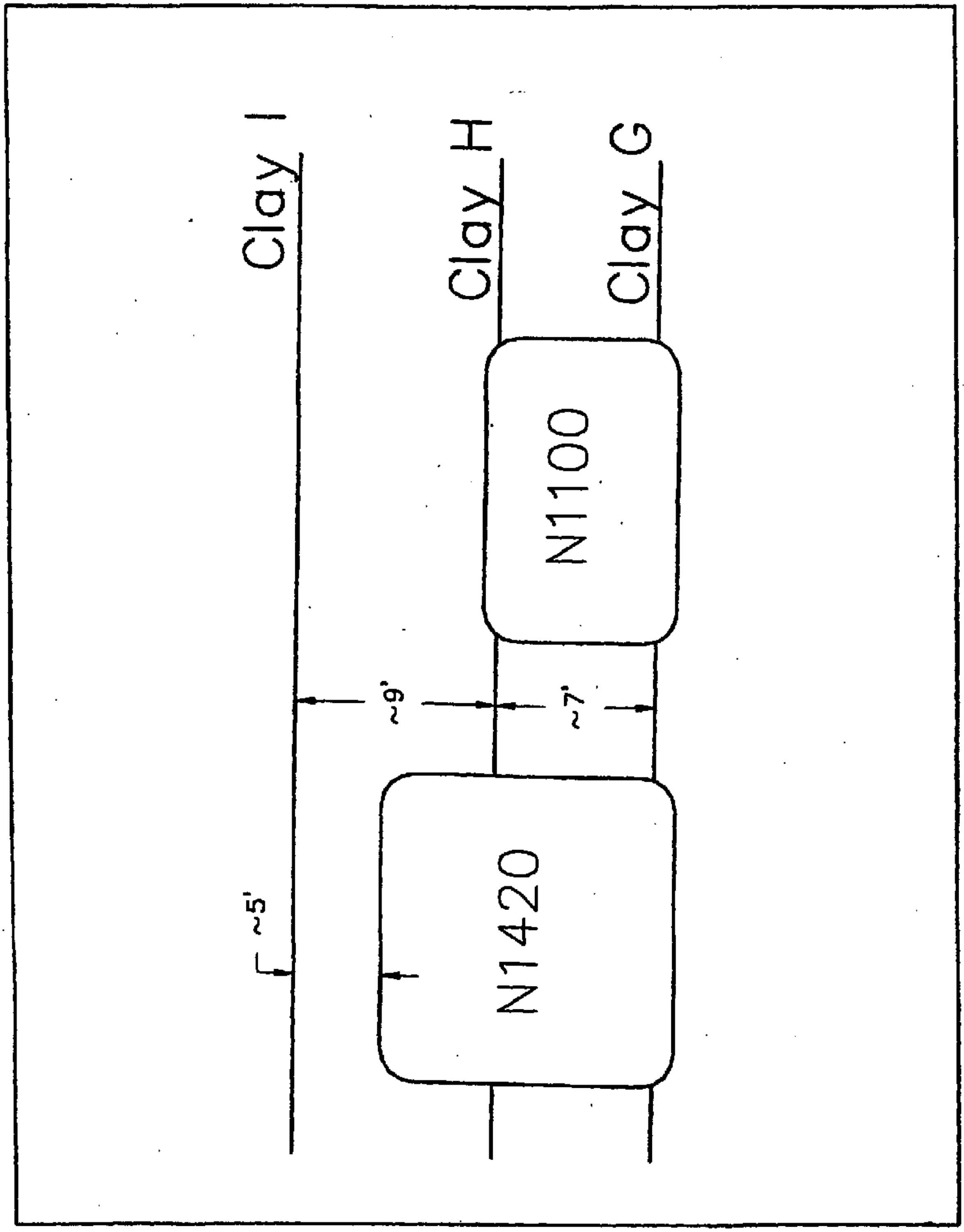


Figure 12
Stratigraphic Location of N1100 and N1420 Drifts

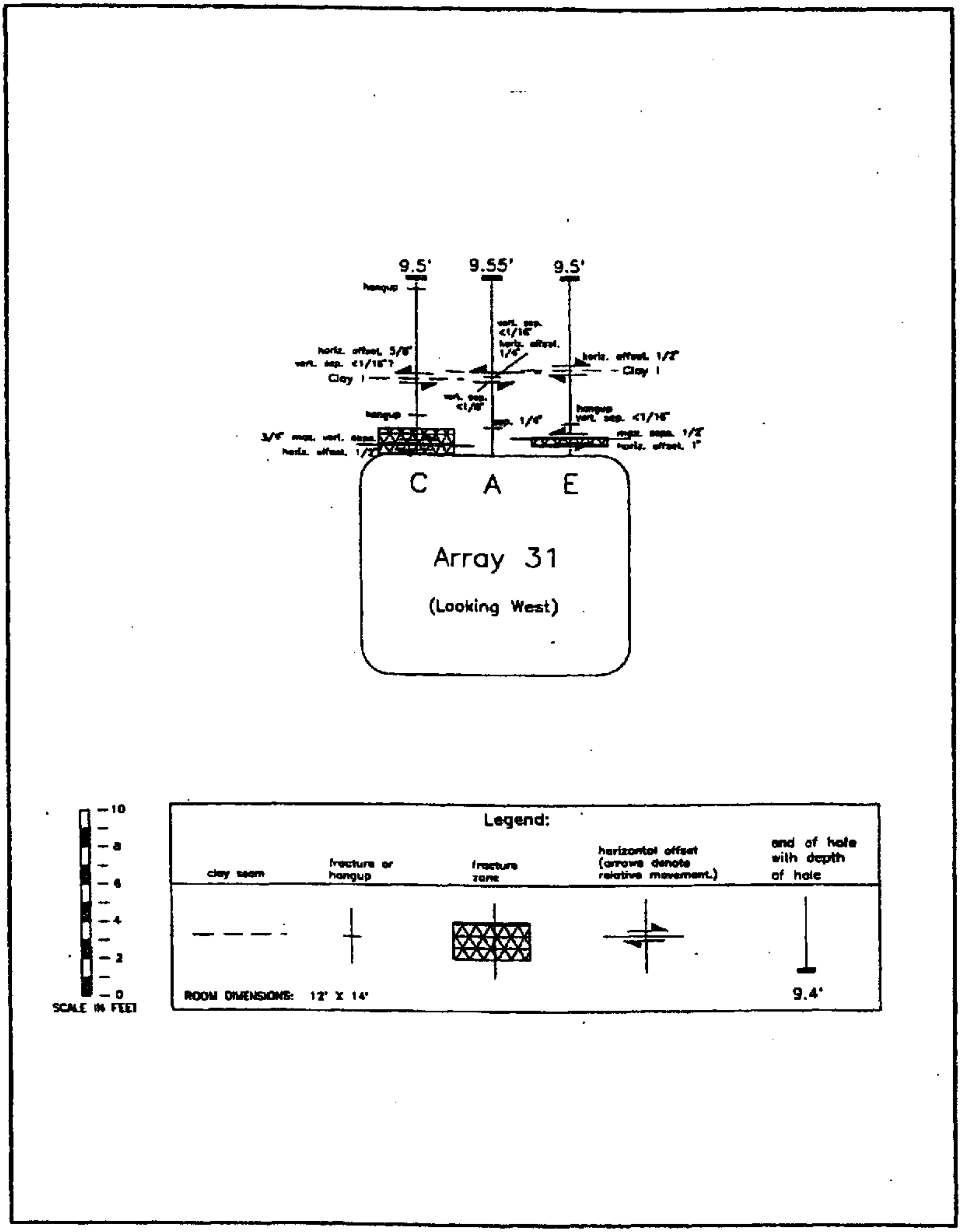


Figure 13
Fracture Data - N1420/E1375

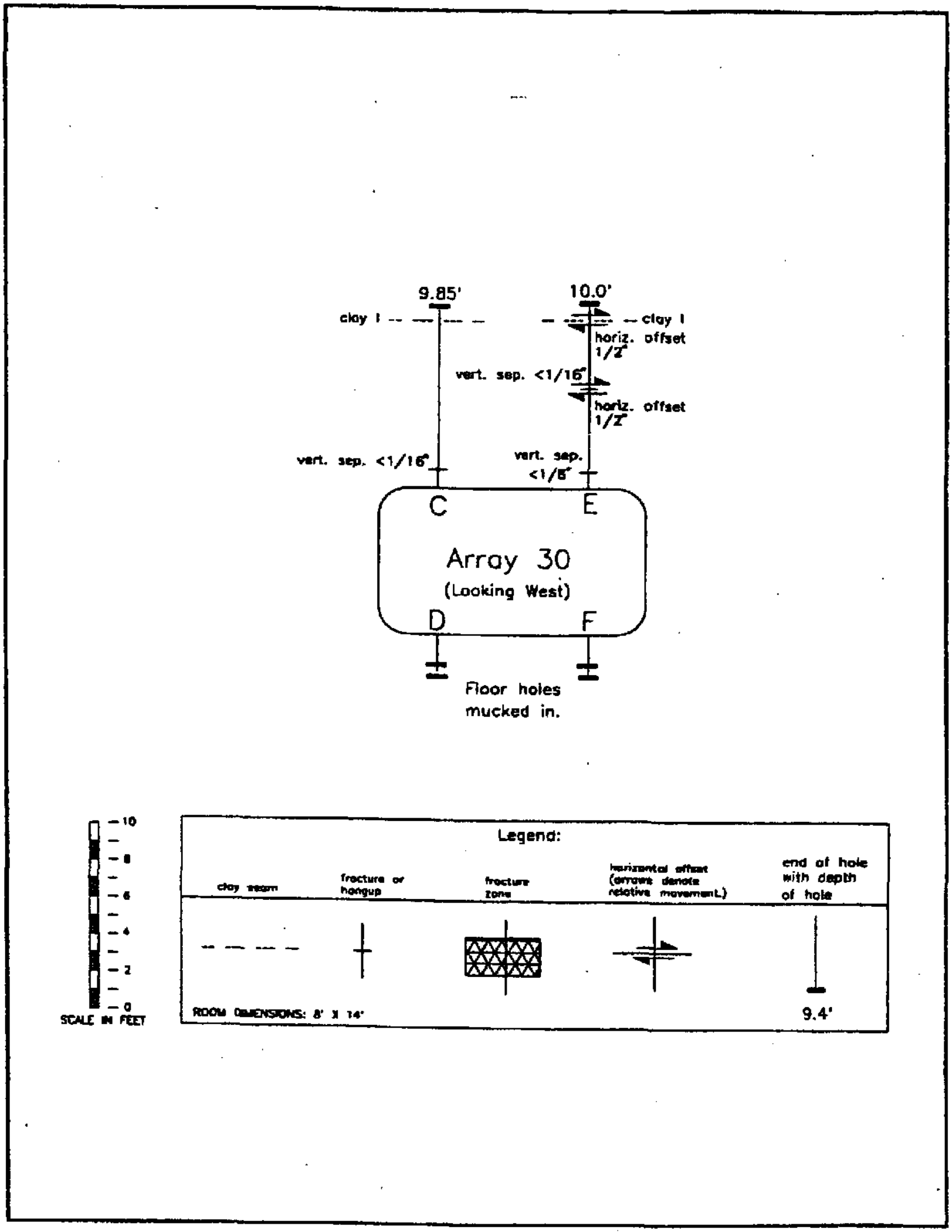


Figure 14
Fracture Data - N1100/E1303

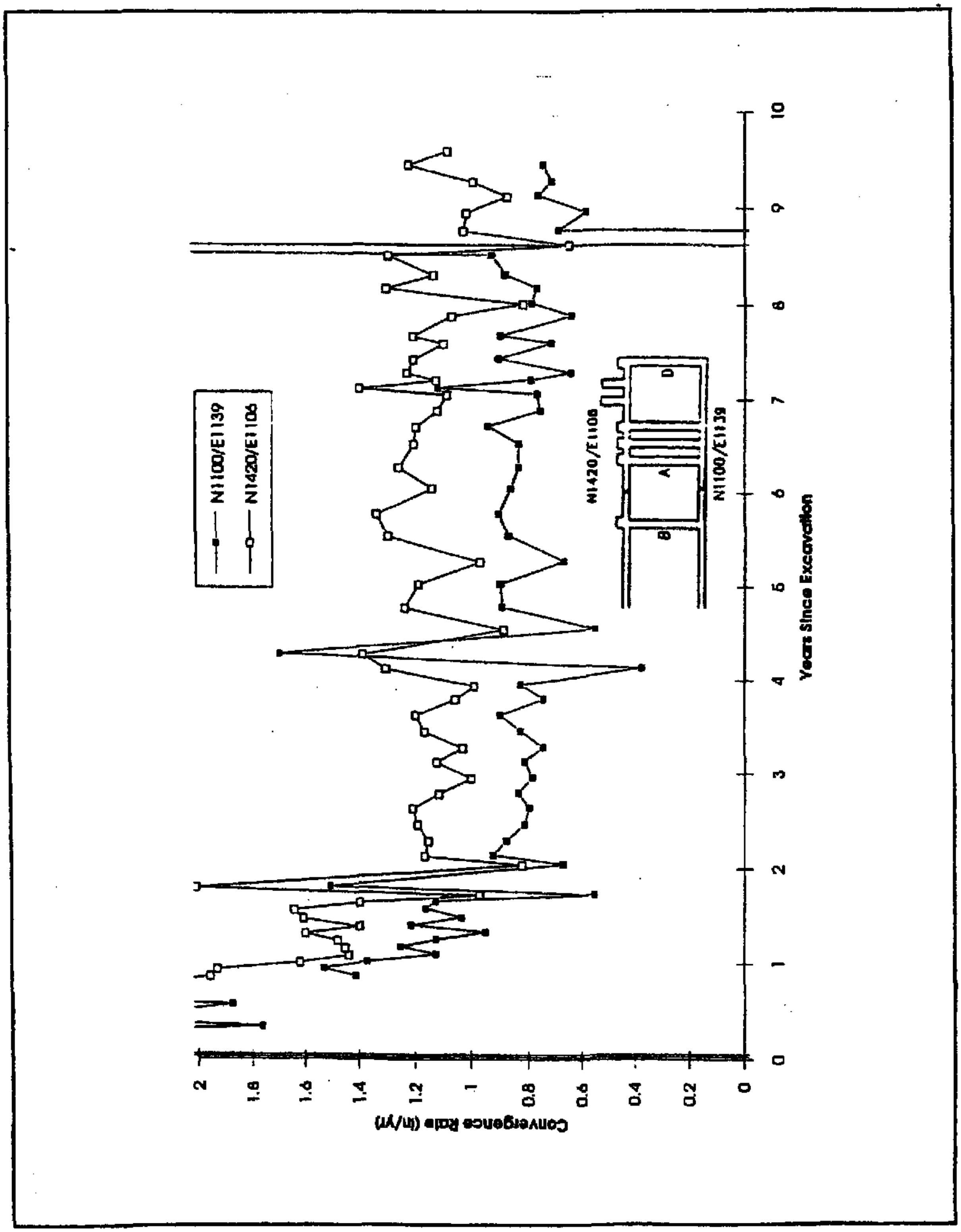


Figure 15
N1100 and N1420 Drifts Comparison Vertical Convergence

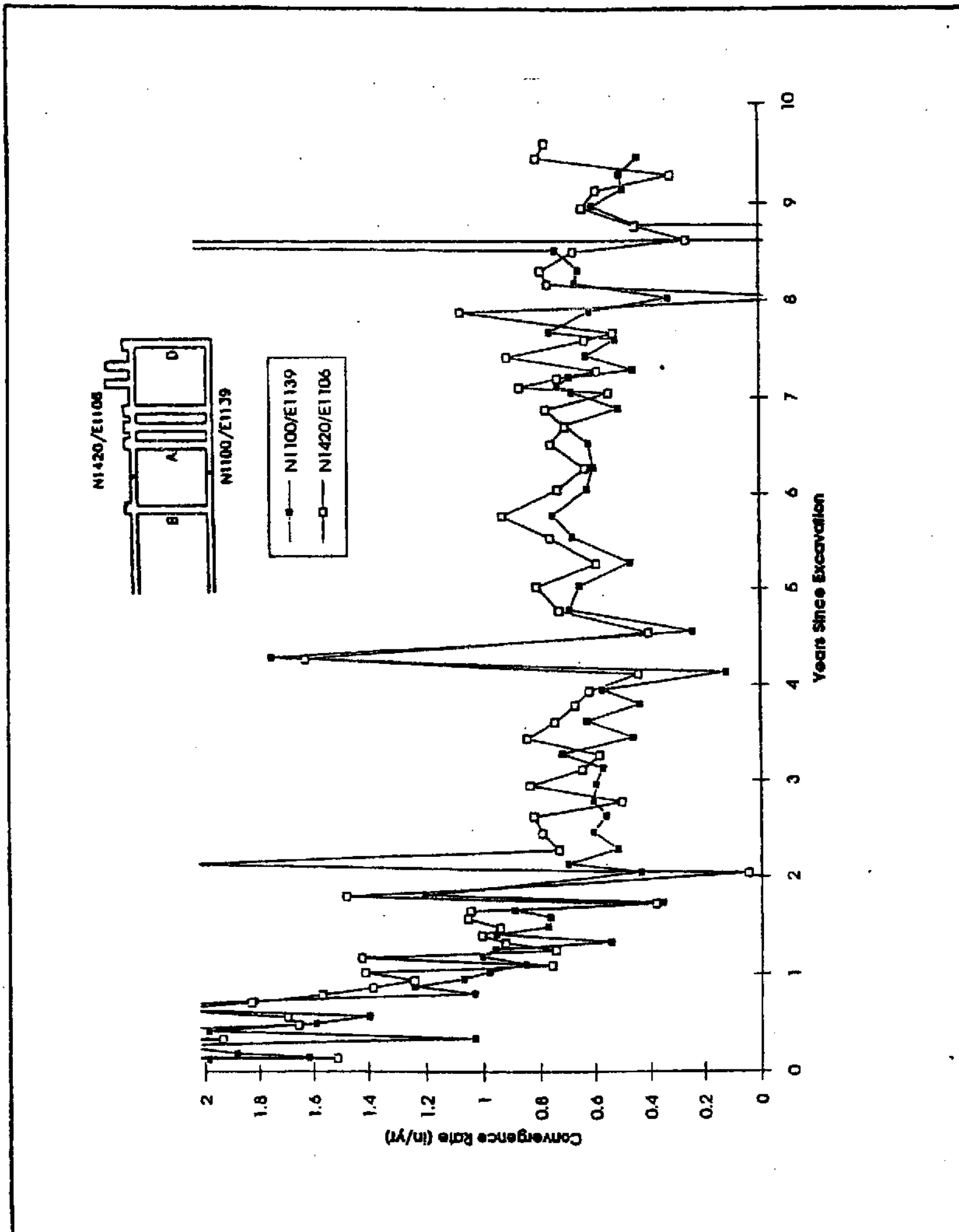


Figure 16
N1100 and N1420 Drifts Comparison Horizontal Convergence

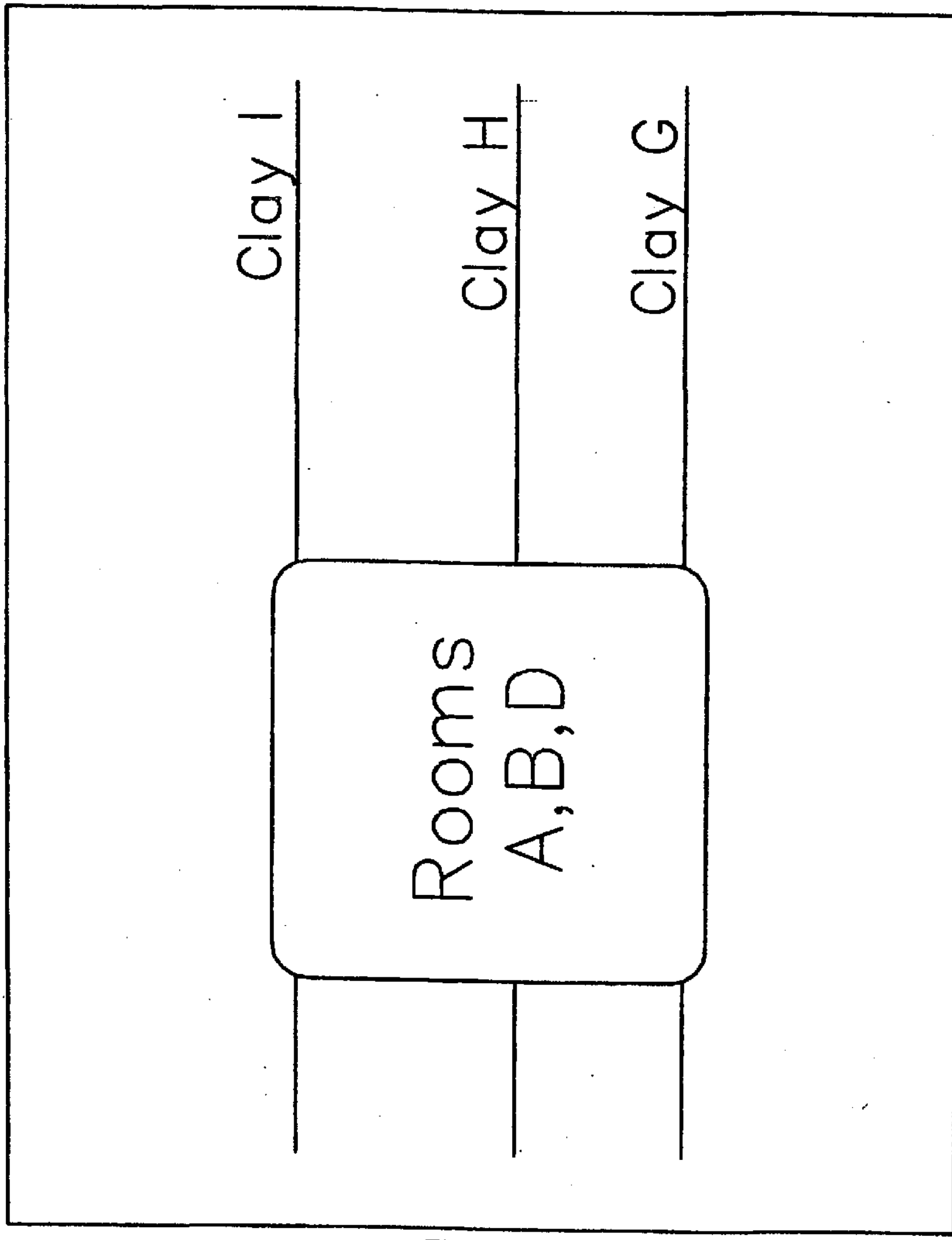


Figure 17
Stratigraphic Location of Rooms A, B, and D

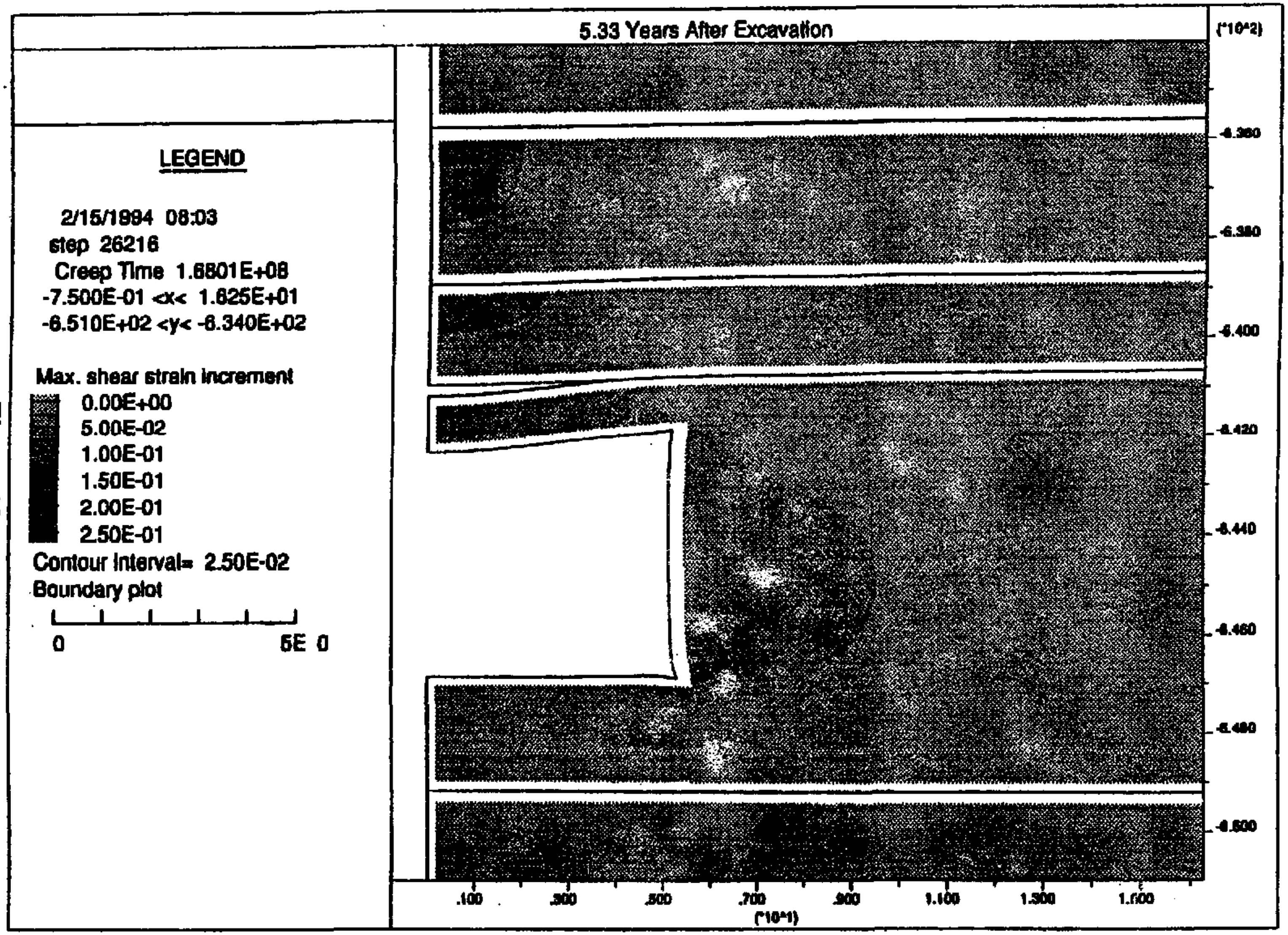


Figure 18
Model Results for Salt Shaft Station Before Roof Beam Removal

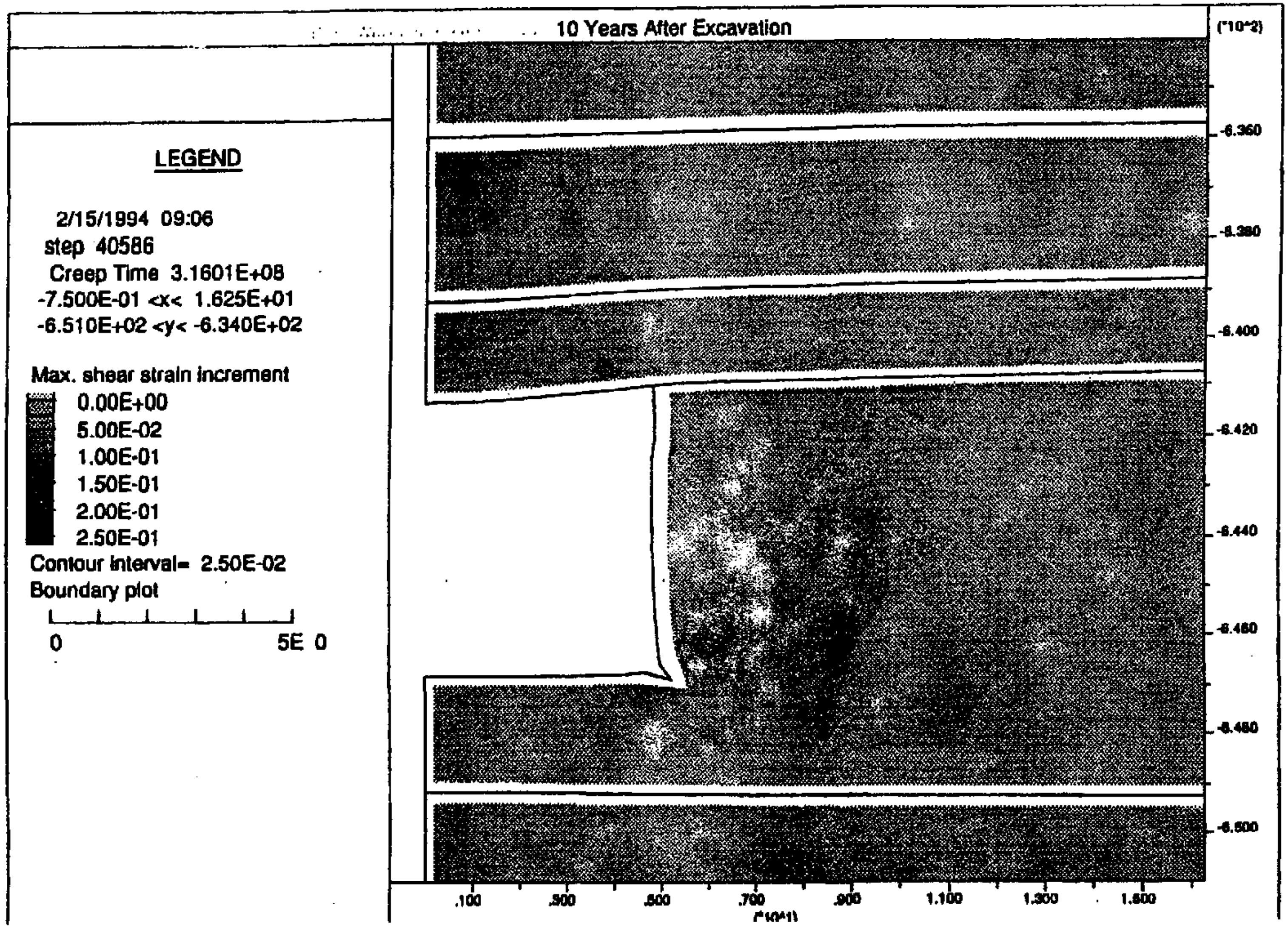


Figure 19
Model Results for Salt Shaft Station After Roof Beam Removal

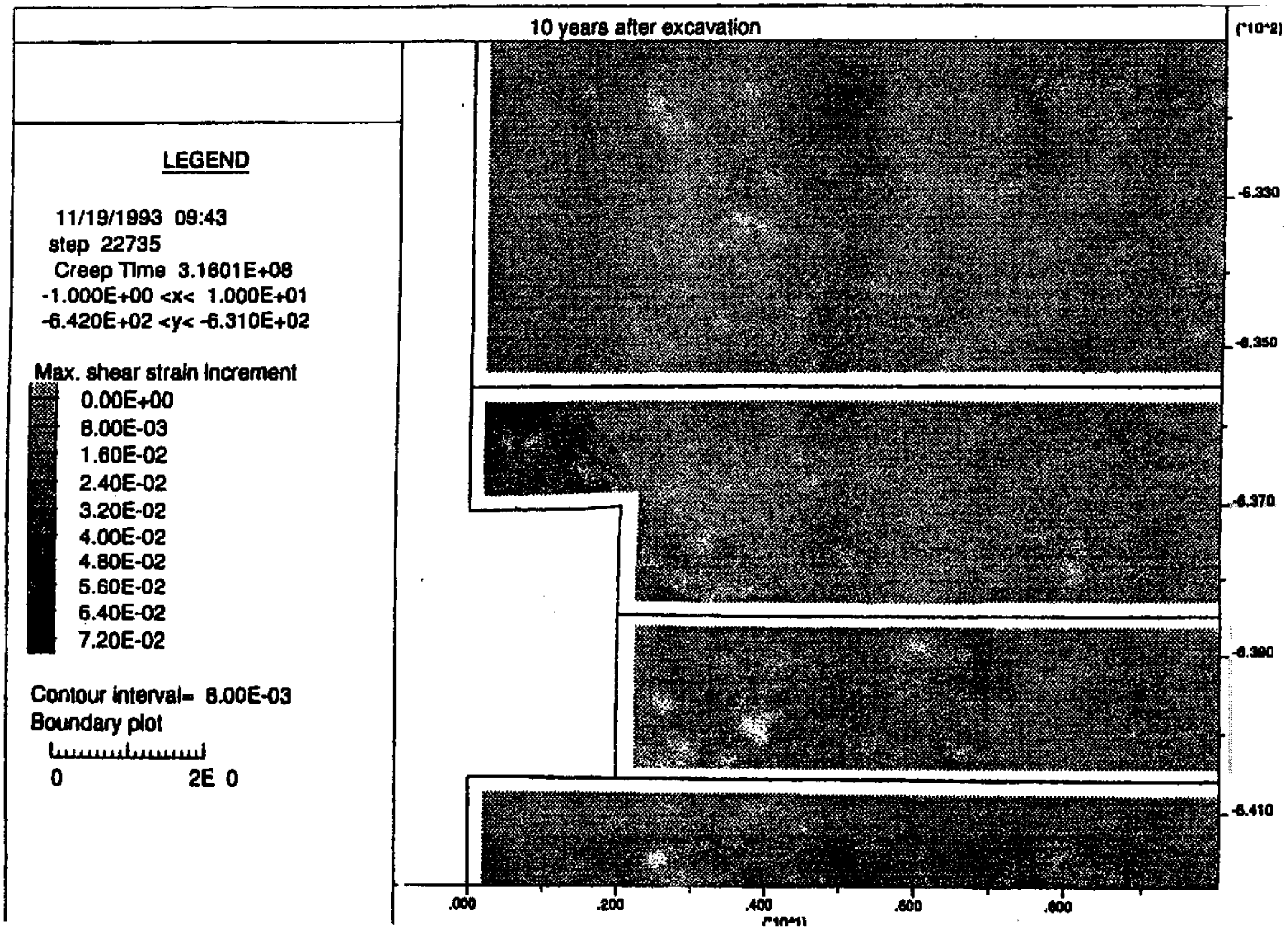


Figure 20
Model Results for N1420 Before Roof Beam Removal

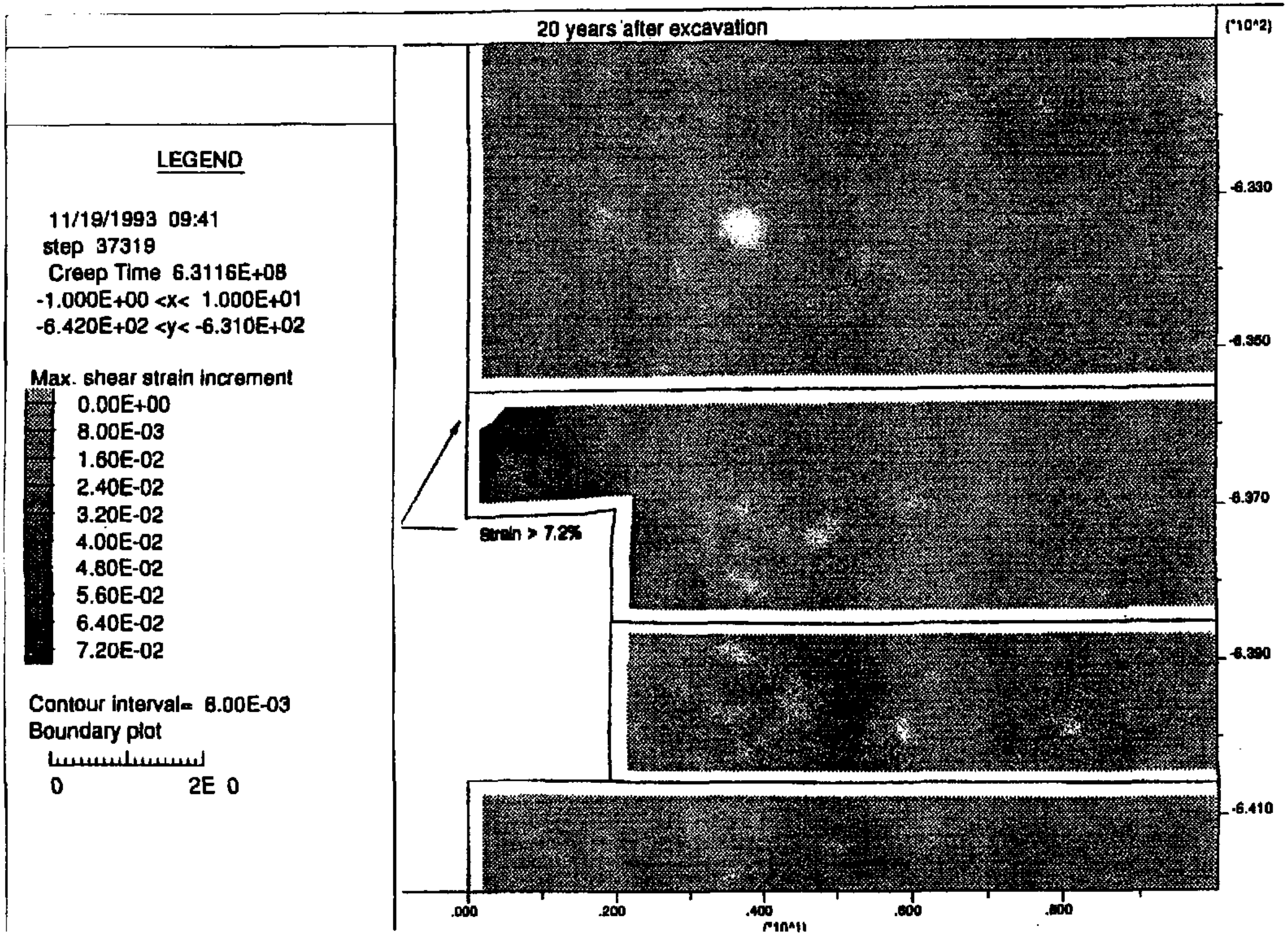


Figure 21
Model Results for N1420 Drift Without Roof Beam Removed

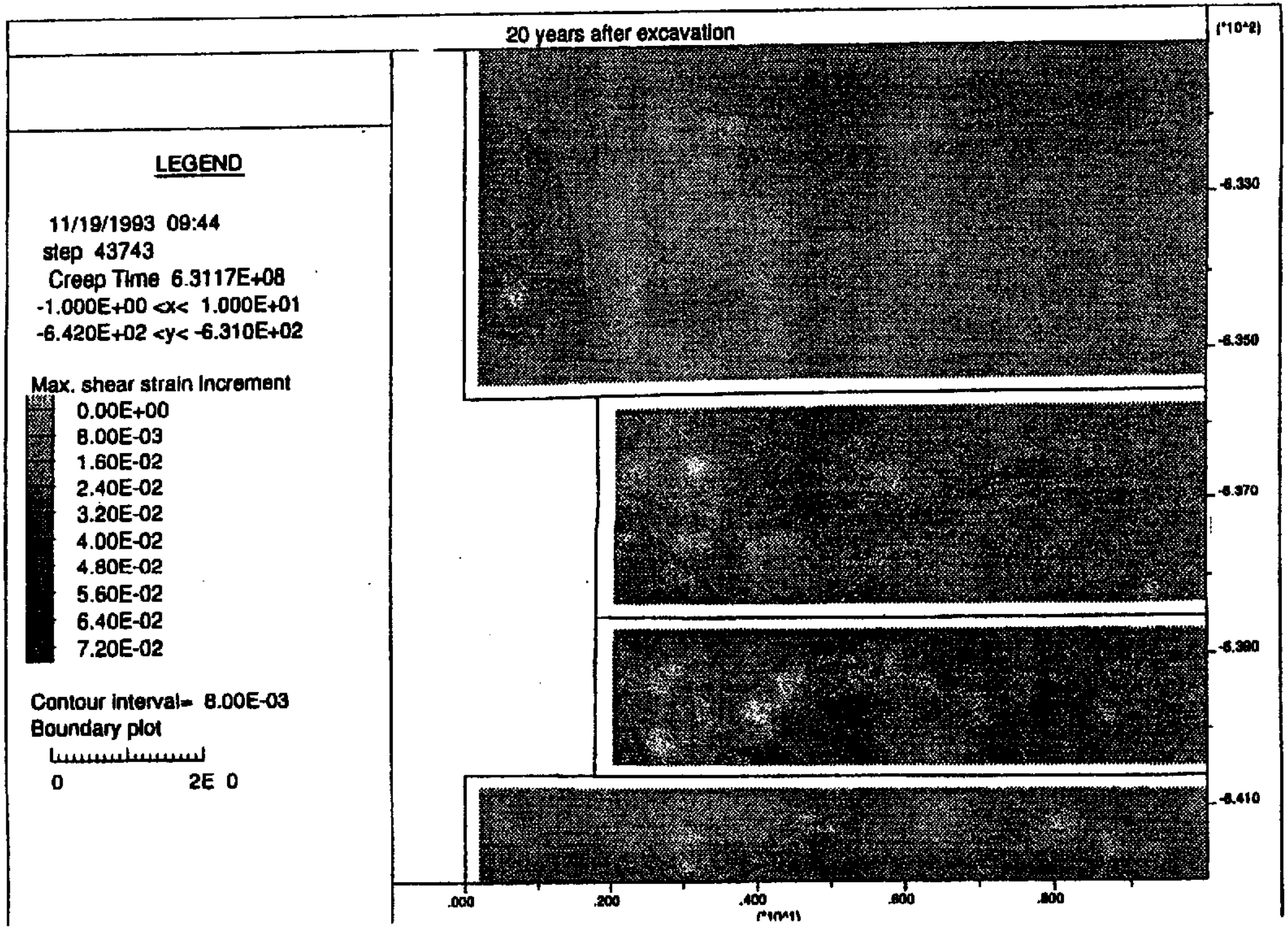


Figure 22
Model Results for N1420 Drift With Roof Beam Removed

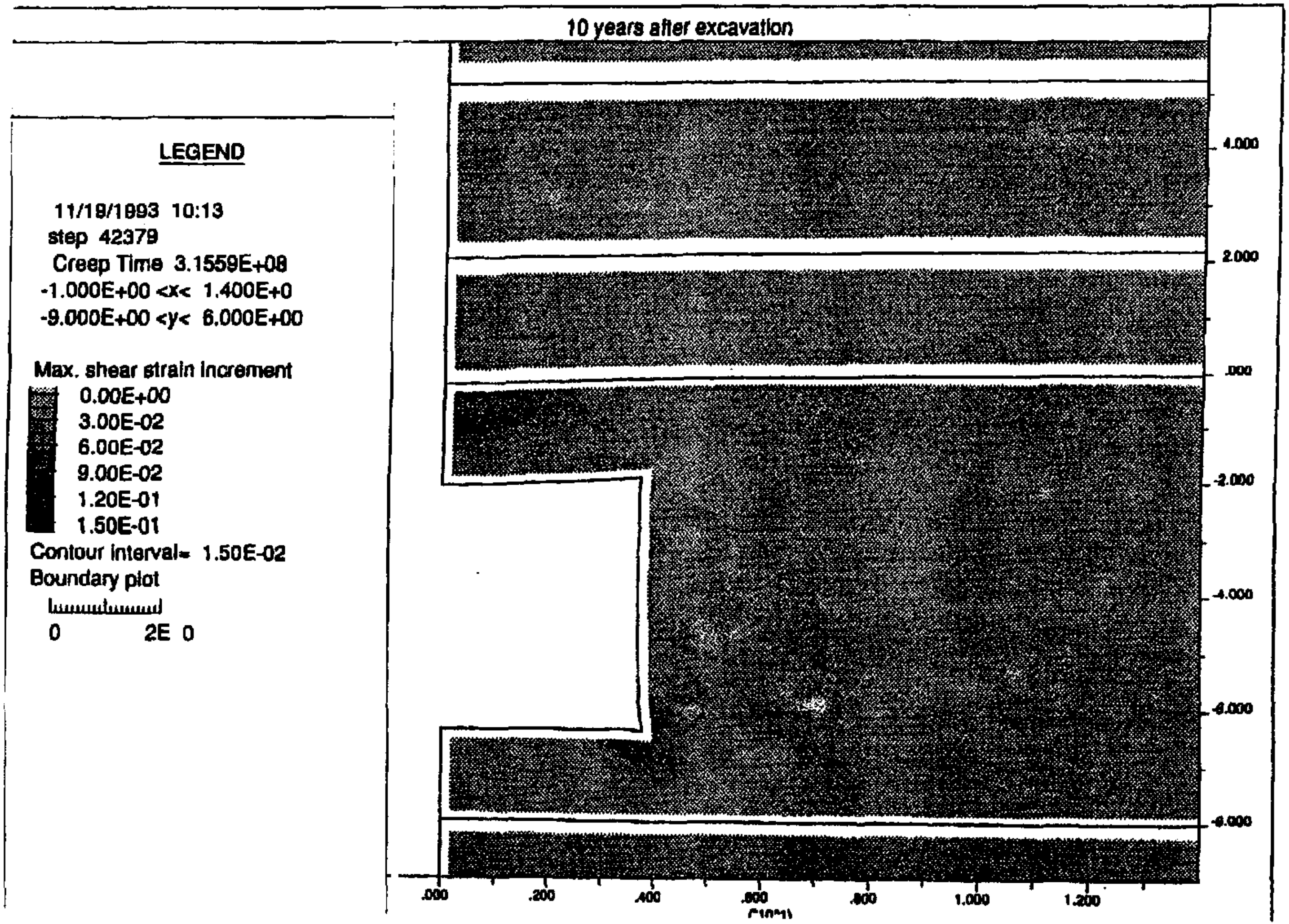


Figure 23
Model Results for E140 Drift Before Roof Beam Removal

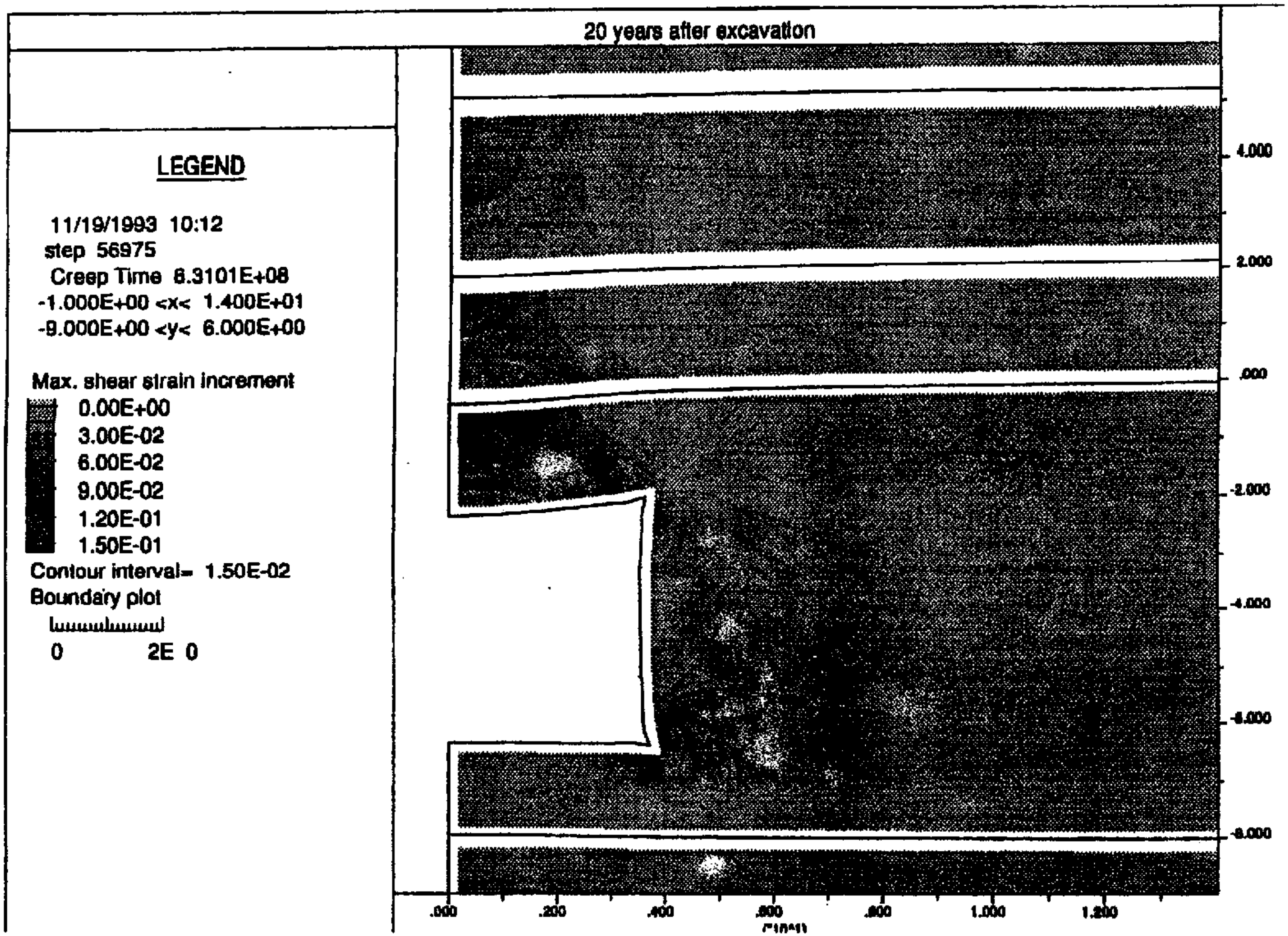


Figure 24
Model Results for E140 Drift Without Roof Beam Removed

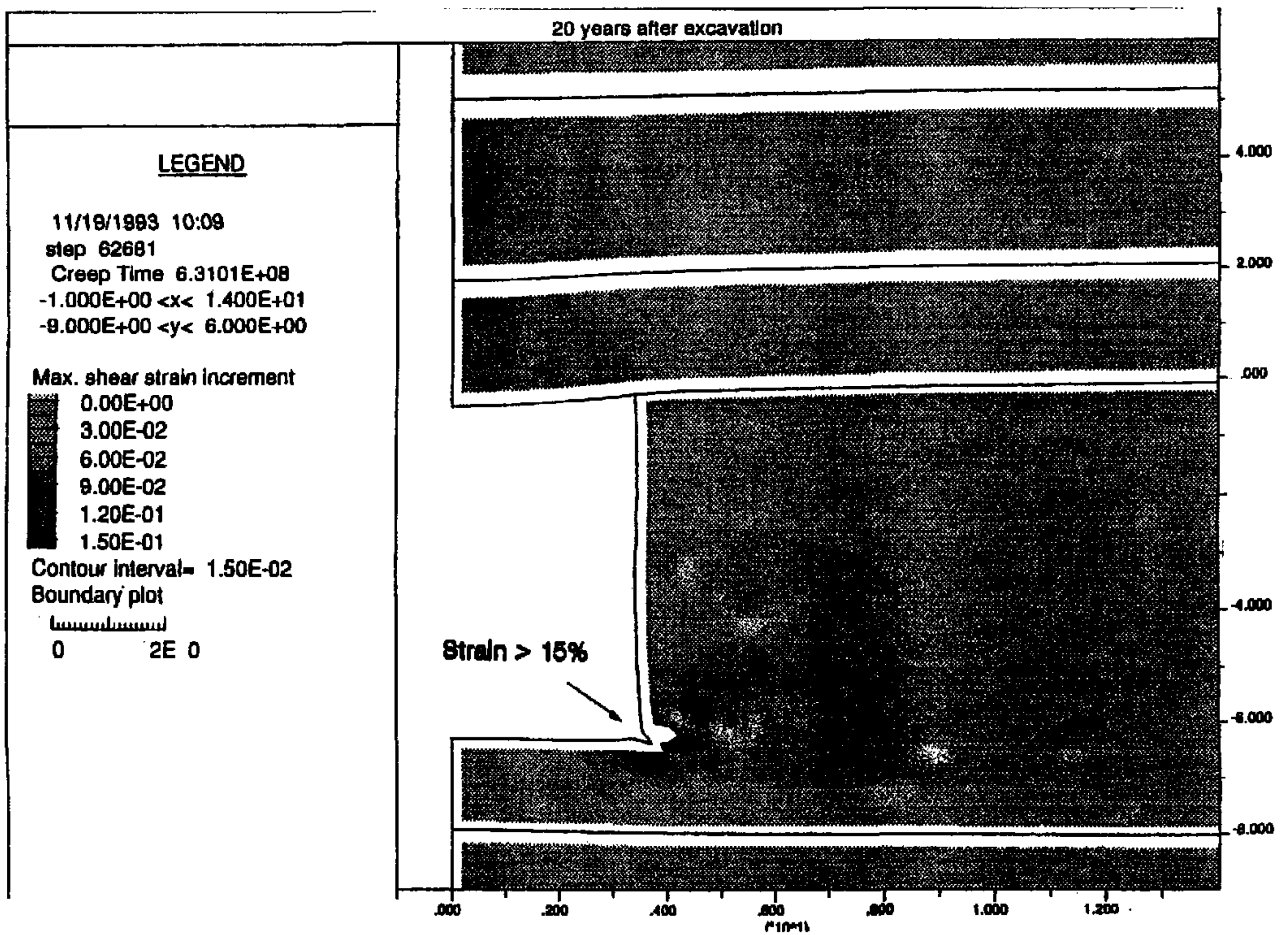


Figure 25
Model Results for E140 Drift With Roof Beam Removed

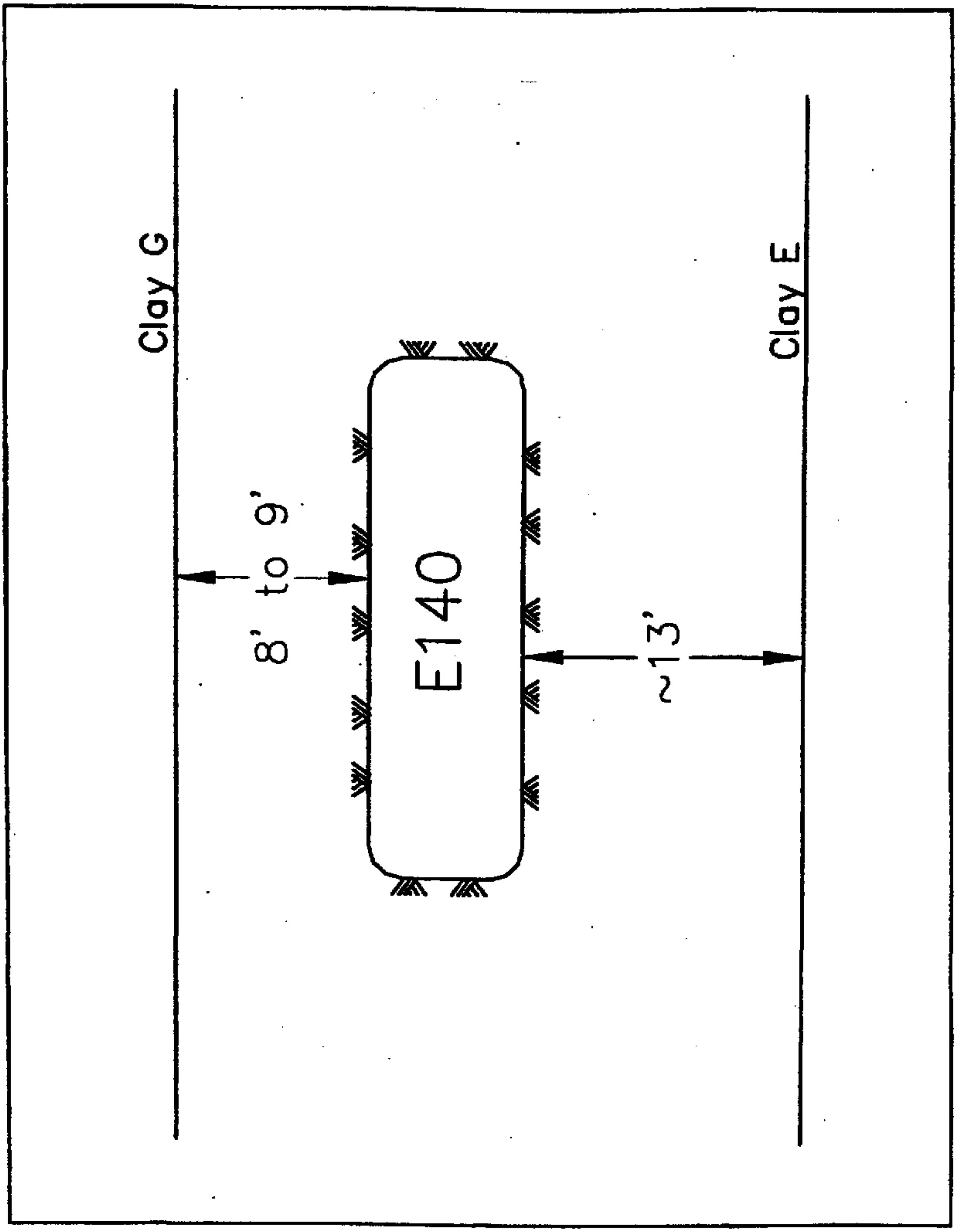


Figure 26
Stratigraphic Location of E140 Drift South of S2180

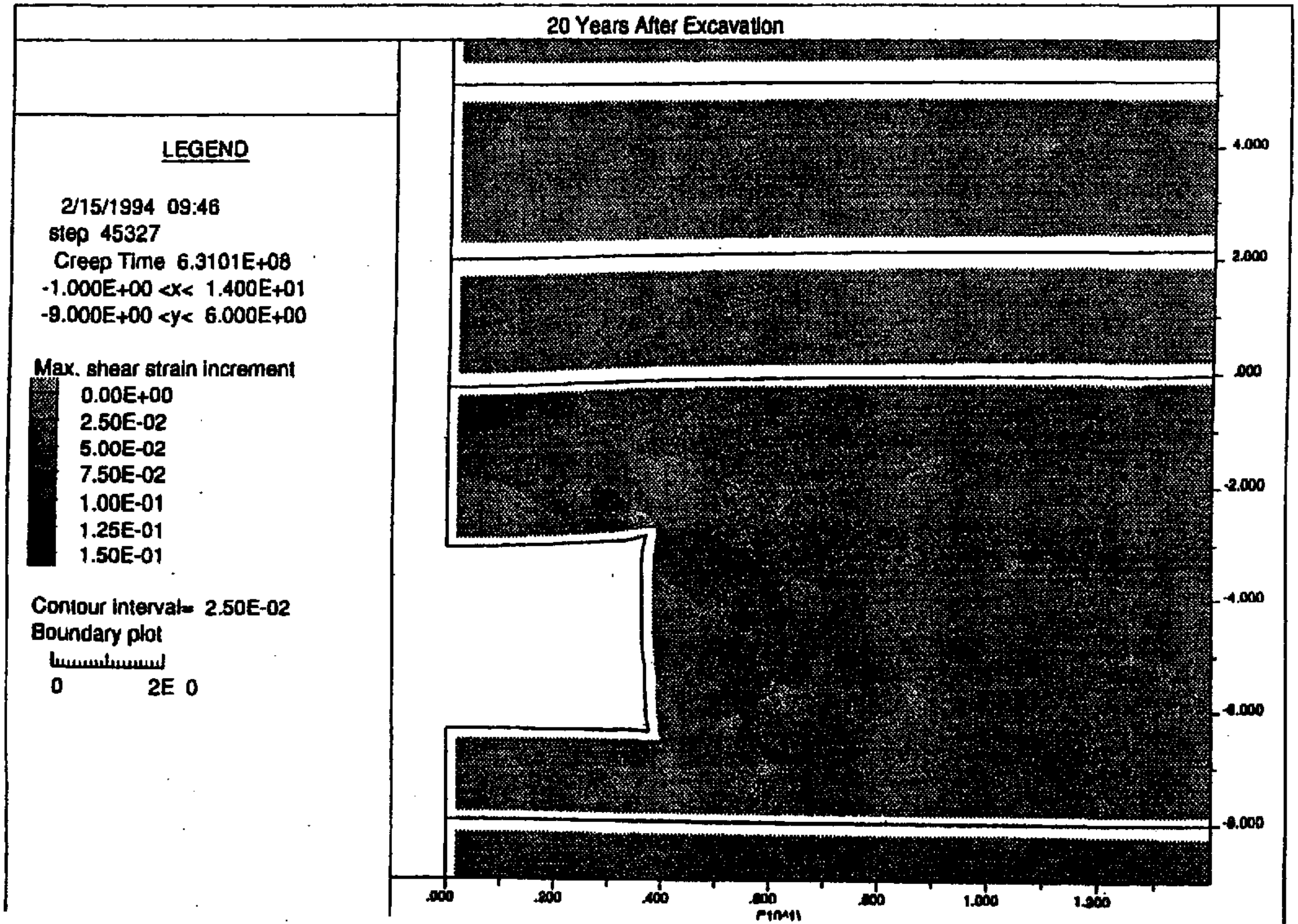


Figure 27
Model Results for South E140 Drift With Floor Lowered

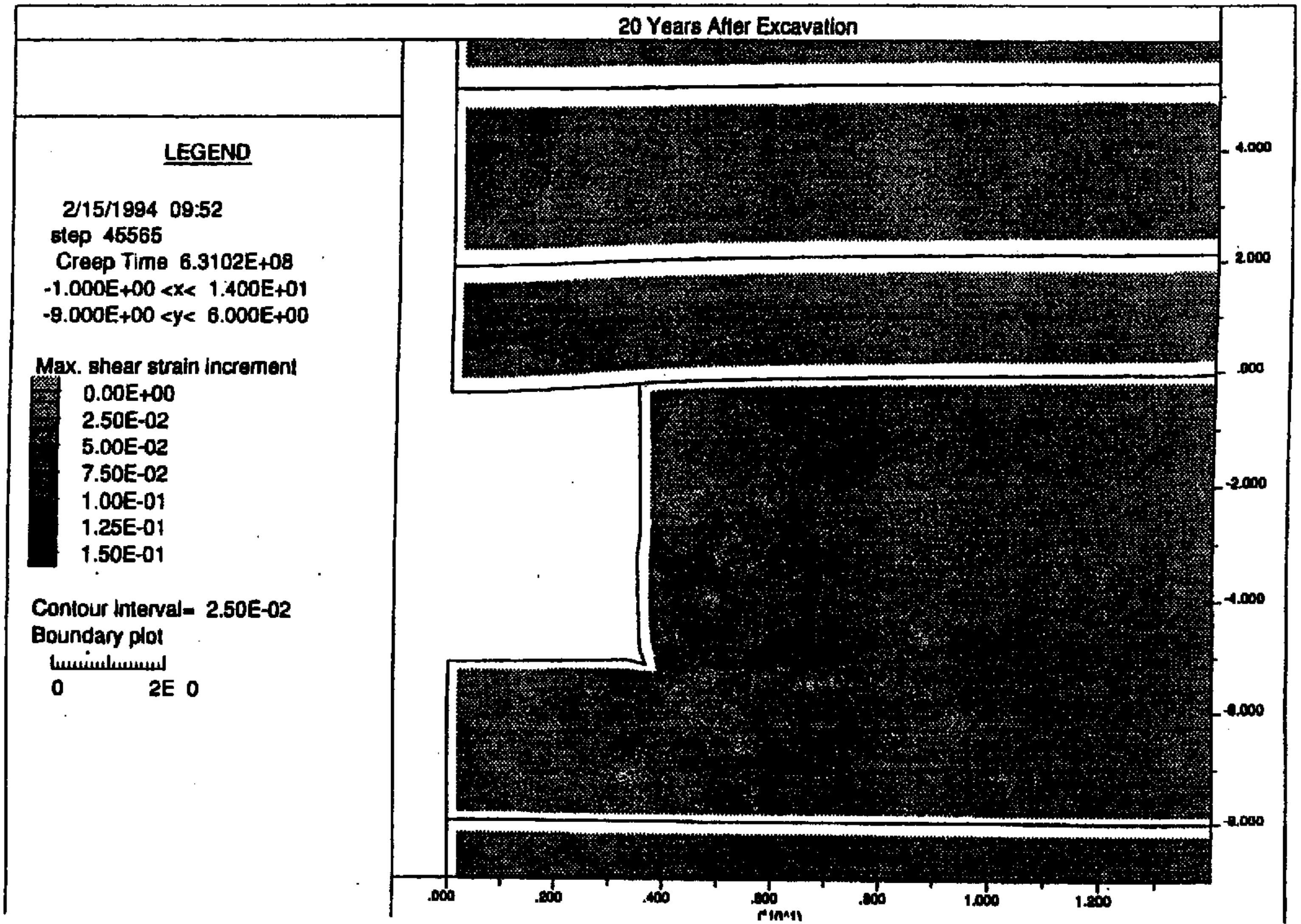


Figure 28
Model Results for South E140 Drift With Roof Beam Removed

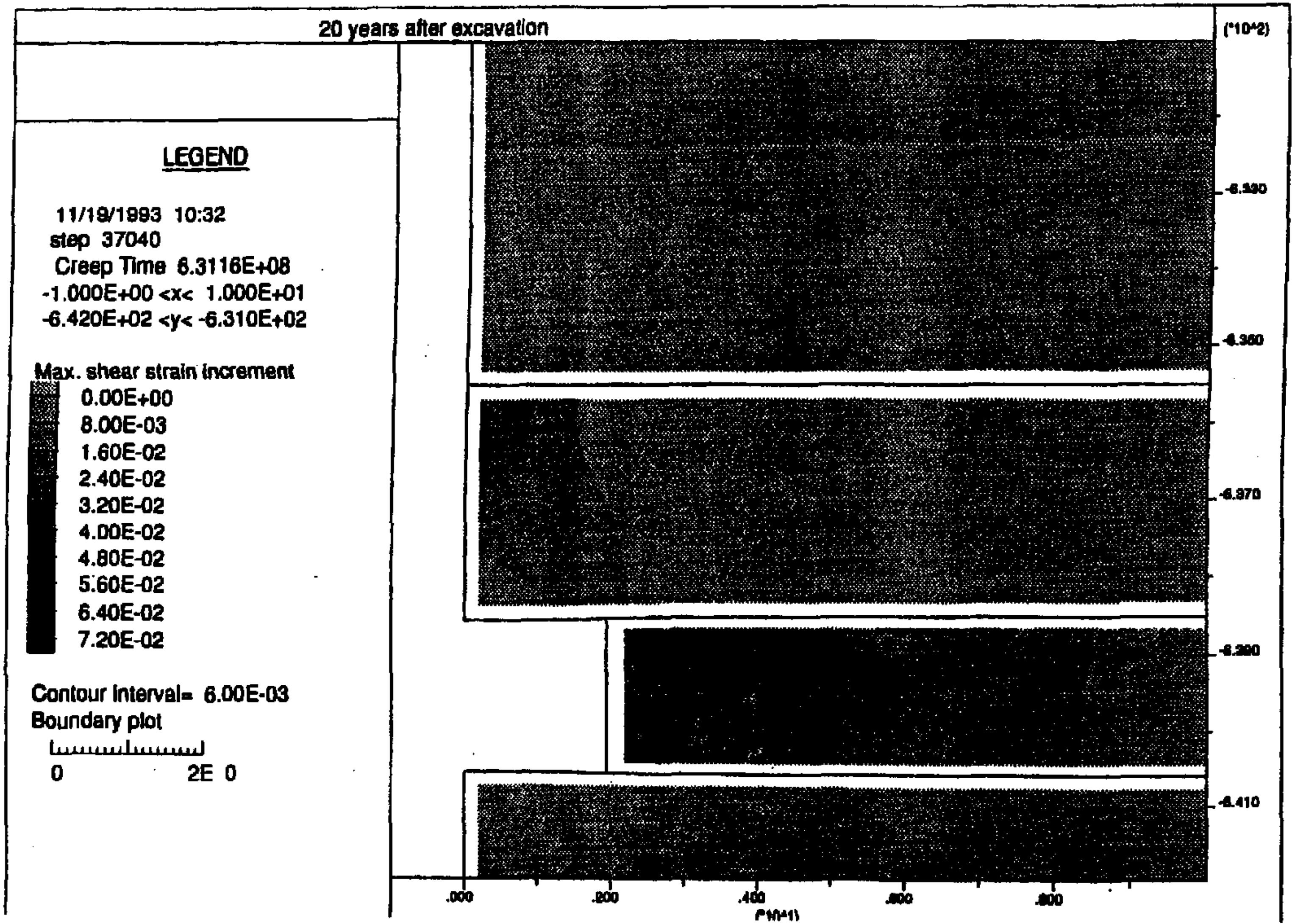


Figure 29
Model Results for N1100 Drift

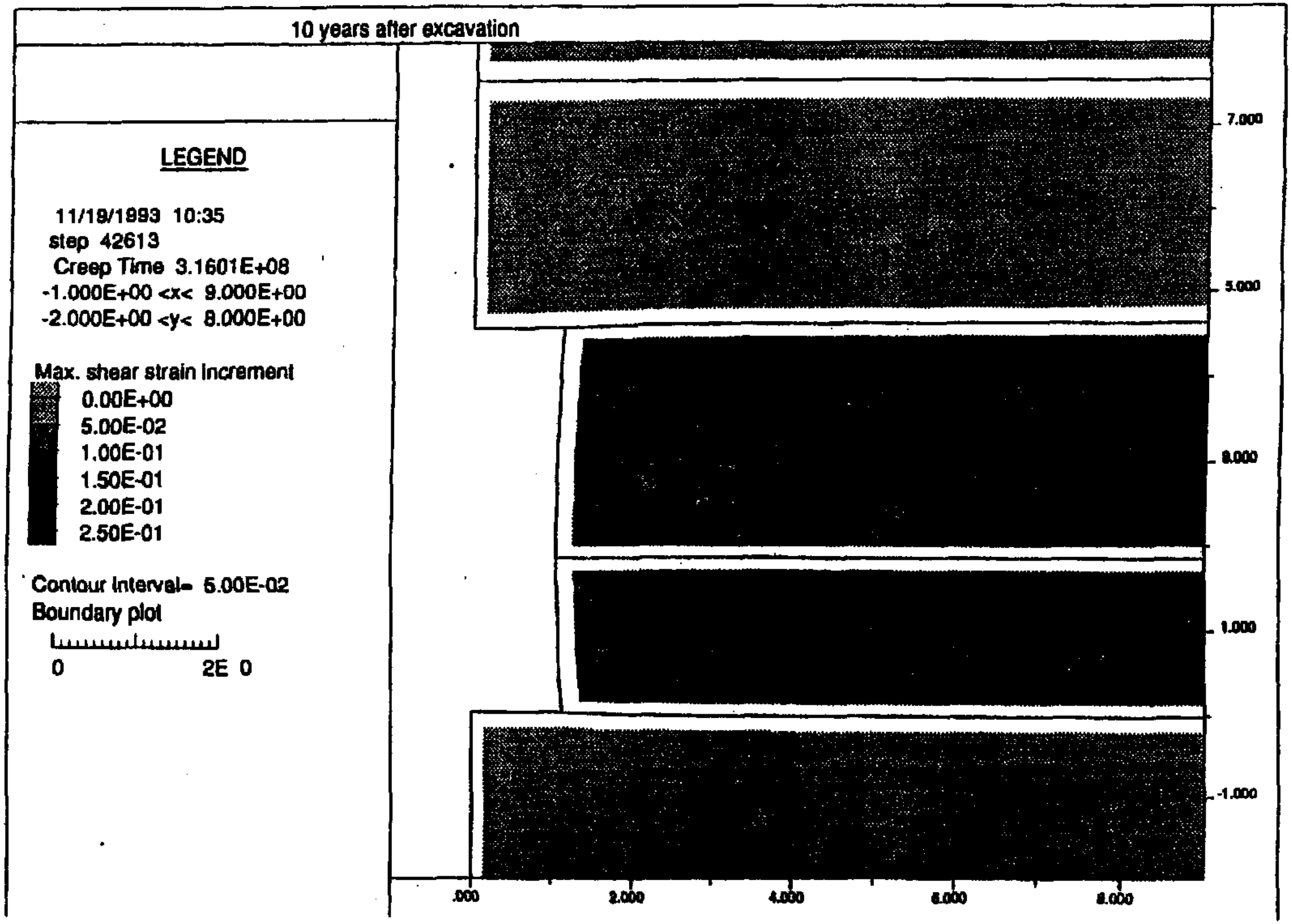


Figure 30
Model Results for Room D