THREE-DIMENSIONAL SEISMIC DEMONSTRATION

THE NORTHWOODS PROJECT

4207-ERTER-ER-96

FINAL REPORT

by

David L. Copley
and
Oliver N. Mohar

Ardent Resources, Inc.
Cathedral Park Tower
37 Franklin Street, Suite 210
Buffalo, New York 14202

October, 1997

NOTICE

Abstract

This report analyzes the use of three-dimensional (3D) seismic for hydrocarbon exploration in the Cambro-Ordovician section of New York State. Conducted by Ardent Resources, Inc. with financial support from the New York State Energy Research and Development Authority (NYSERDA), the report focuses on the Town of Arcade in Wyoming County.

The work conducted was designed to compare and evaluate results and interpretations derived from conventional methods such as two-dimensional (2D) seismic and well-log interpretation, and to determine whether the use of 3D seismic in this area is feasible in terms of both the results derived and cost effectiveness.

The results of the 3D survey resulted in a complete revision of the initial interpretation, and the entire preconception of stratigraphy and structure in the area studied. The initial assumption proposed a northeast-southwest strike in the fabric of the deep section, which would be consistent with the analysis of the shallower section, and basin configuration in general. The 3D data, however, strongly indicates that features in the deep section are actually oblique to this.

3D seismic technology can provide beneficial results. If more surveys are conducted in New York State, optimization of 3D data acquisition and a better understanding of the complex geology in the area will evolve, with the net result being the discovery of substantial hydrocarbon reserves and a revitalization of New York State's oil and gas industry.

Table of Contents

List of Figures

Introduction

Oil and gas exploration in the Cambro-Ordovician section of the Appalachian basin is not new. More than 8 trillion cubic feet (Tcf) of gas and .7 billion barrels (BBO) of oil are attributable to Cambro-Ordovician reservoirs within the basin. Much of this production occurred early in the history of the basin's hydrocarbon development, but within the past decade, drilling the Cambro-Ordovician section, particularity in Ohio, has resulted in some exceptional oil and gas production. Southern Ontario also has prospered from increased activity in the Cambro-Ordovician although much of this has occurred along the Algonquin arch and into the Michigan basin. To a much lesser extent Pennsylvania and New York State have also seen an increase in drilling to Cambro-Ordovician objects, with a measure of success and the possibility of economic justification similar to that in Ohio and Ontario.

Advancements of new technologies and refinement of older techniques in oil and gas exploration have led to successful, cost-effective discovery and exploitation of hydrocarbon reserves worldwide. Although many of these technologies are being used with proven results, the trend has been slow to migrate to the Appalachian basin. There are many reasons for this, but the most compelling is the marginal reserve character of most Appalachian hydrocarbon reservoirs. Many operators in the basin believe that, overall, the volume of reserves to be recovered (regardless of drilling target) is marginal compared to capital costs (exploration, land, environmental compliance, drilling, completion, production, taxation, etc.) necessary to achieve those volumes. The net result is that operators are hesitant to try new technologies for fear they will not be cost-effective, or, worse, they may negatively affect their corporate bottom line: net cash flow.

The decreasing number of operators in New York State, and the basin as a whole have been surviving for the last 10 years literally by "guerilla warfare," wherein the effort is modest, but results are still maximized. This is accomplished by applying what has been learned in the past, both in terms of choosing the least risky targets and using the most inexpensive drilling and completion techniques to maximize return. It has, in fact, been a mantra for survival, but not a means for growth.

The increase in exploration and hydrocarbon production in the Cambro-Ordovician in Ohio and Ontario happened during the last 10 years not because Cambro-Ordovician targets were viewed as less risky or less expensive to drill, but because fortuitous circumstances. Operators in Ohio hold thousands of acres under lease near shallower Silurian or younger-age production, but the submarginal character of much of this production led some enterprising operators to look deeper for more reserves. The early success of several of these attempts made believers out of skeptics and was all that was needed to allow the play to take off (at least locally). That early success did not, however, translate into a large increase in deep drilling activity in New York or Pennsylvania, even though the geology and stratigraphy of the Cambro-Ordovician section is similar in both states, with the potential for comparable hydrocarbons.

Current Exploration Methods in the Appalachian Basin

2D seismic, accomplished by vibrator, dynamite, or air gun is the primary geophysical exploration tool used in the Appalachian Basin. Data from this technique is often combined with sub-surface well control (well logs, drillers records, completion reports/cards, etc.) to arrive at a unified geological-geophysical interpretation.

Although both methods, used individually or in combination, are Appalachian exploration mainstays, the need exists to interpolate between wells or seismic lines. This inherent interpolative process is not only subjective, but also clearly allows subtle features (i.e., faults, fractures) and small features (i.e., reefs) to slip through the interpretive net.

3D seismic offers 100% coverage of an area. All points in between receivers are seismically imaged within the survey's confines. Although these benefits are clearly documented, and results have been lucrative, 3D seismic's acceptance in the Appalachian Basin, and especially in New York, has been slow in coming.

Impetus for Conducting the 3D Seismic Survey

In 1994, Ardent Resources, Inc., et al., drilled a deep test well in the town of Arcade, Wyoming County, New York. The well was located based on existing 2D seismic data that showed an east-west, basement-related structural rollover, with inferred closure to the north-northwest. (See Figures 1 - 7 in Appendix.)

Figure 1 is a regional map of western New York showing the location of the well and seismic. Figure 2 highlights the extent of the 2D seismic lines used to locate the prospect. Figure 3 is a partial copy of the east-west line showing the prospective structural feature. Two- way transit time is indicated on the left, and formation names on the right. Figure 4 is a time- structure interpretation, at or near the Knox Unconformity, as prepared from available 2D seismic lines. Figure 5 is an isochron interpretation of the interval from the top of the Onondaga limestone to the Knox unconformity. Note the thinning of section over the deep structural feature indicating the basement high occurred prior to deposition of the overlying section. This thinning, as well as strong structural nosing, is apparent in the shallow section (Siluro-Devonian) from well logs in the area. Figures 6 and 7 show the structural nose, top of the packer shell, and the isopach thinning, Onondaga to Packer shell, respectively. Although the feature was not closed in the shallow section (as interpreted from shallow-well control), the 2D seismic was interpreted to show 5-10 milliseconds (ms) of closure at depth. This was enough to allow the prospect to be tested.

In October, 1994, J. Matusik #1 (API # 31-121-22520) was drilled to a total depth of 6,321 feet. Two strong flows of gas were encountered in the deep section, one at 5,997 feet in the Little Falls dolomite, and the other at 6,167 feet in the Theresa Sandstone immediately beneath the Knox Unconformity (Figure 8). Combined flow was more than one million cubic foot (mmcf) per day natural and the well was accordingly deemed a success. However, completion soon changed that consensus. The Theresa, after perforation (6,164' - 6,175'), brought back no gas naturally, nor was gas encountered after several matrix acid (15% HCL) attempts. Finally, as a last resort, hydraulic fracturing was tried, and resulted in a large flow of both gas and saltwater. The zone was plugged off (via bridge plug) and the uphole zone was perforated (5,996' - 6,000'). A natural flow of pipeline quality gas was encountered, estimated at 75 - 95 thousand cubic foot (mcf) per day with a shut-in pressure of 1,630 pounds per square inch (psi). The well was subsequently brought into production. Figure 9 shows production to date, and when viewed against the backdrop of the more than $300,000 spent on drilling and completion, the well must be viewed as sub-marginal. The best that can be said of the Matusik is that hydrocarbons were proven to occur in the Cambro-Ordovician section here, and that perhaps under more favorable trapping circumstances, economic volumes could be encountered.

Ardent and its joint venture partners elected to pursue a 2D anomaly located northwest of the Matusik feature. Figure 10 shows this anomaly, located at the northwest end of line MEC-88-2, while Figure 2 shows the regional location of the line. The joint venture partners agreed to run a 2D confirmation or extension line to look at this lead in detail and, hopefully, develop a worthwhile prospect.

Discussions began at this time with NYSERDA to run a 3D survey as opposed to the suggested 2D line in an attempt to better image not only the lead at the end of line MEC-88-2, but also the original Matusik feature. NYSERDA essentially provided Ardent, et al., with an opportunity to apply 3D technology in New York State at a price comparable to that of the proposed 2D seismic program. Accordingly, in September 1995, a 3D seismic survey was conducted in Wyoming County in the Town of Arcade (the first 3D survey in the State) to image a suspected deep feature, and to determine if 3D seismic could provide a cost-effective means of exploring the Cambro-Ordovician.

Layout and Acquisition of the 3D Seismic Data

Bids were solicited from several seismic acquisition companies, and the contract for the shooting was awarded to Duncan Exploration, Inc. of Newark, Ohio.

Acquisition of 2D seismic requires careful planning, adherence to procedures, and quality control to insure high-quality data. This holds equally true for 3D. Shot-hole location and spacing, size of charge, and geophone location and spacing must be done within a carefully designed framework. Moreover, logistics such as permitting, surveying, clearing for shot/receiver lines, and quality control on the job must be thoroughly thought out prior to shooting. These preliminary steps took more than a month to complete and included review of numerous possible arrays for the layout of geophones and shots. The aim was not only to collect the highest quality data, but also to maximize survey size while adhering to a tight budget. The goal was to cover as much area as possible (within budget constraints) without jeopardizing data quality (through reduction in seismic fold).

A brick pattern for the receiver/tielines was finally chosen, with 220 feet between shotpoints, and 110 feet between geophones. (Figure 11 shows the survey layout.) Total coverage was 2.6 square miles, with a maximum estimated fold of 40 within the survey center and an average overall fold of 30.

The process for acquiring the 3D data (permitting, surveying, laying lines etc.) began on September 5, 1995, and culminated with the actual survey shooting on September 28 - 29, 1995. The survey as shot consisted of 567 receiver stations in 110-foot bins and 240 total shotpoints at 220-foot intervals, each with two 10-foot holes loaded with c10 charges. The total cost was $72,691, which included several small damage claims.

Processing and interpretation of the 3D Seismic Data

Bids for processing the 3D data were solicited from several processing companies, with the contract awarded to Lauren Geophysical Processing Services of Denver, Colorado.

Processing took about one month for final sections, but preliminary sections were turned around in less than three weeks. Processing required geological input to achieve a geophysical interpretation consistent with the geological understanding. This led to some early disagreement between geologist and geophysicist as to regional structural fabric and the corresponding implications for exploration.

After the final processing was completed, the survey data were incorporated into the existing geologic framework to verify the validity of the initial geologic interpretation. The total cost for processing the 3D seismic data was $3,615, which included sizable discounts given by Lauren Geophysical for the opportunity to process the first 3D seismic survey in New York State.

Interpretation of the Results

3D seismic modelling software (VEST) was used to model the data and compare it with our previous 2D interpretation. (Figure 12 is a time-structure map at or near the Knox Unconformity; the contour interval is 2 ms. The map clearly shows a northwest-southeast trending ridge through the survey area, separating two low areas to the northeast and southwest. The ridge has two high points, one in the southeast corner corresponding to the Matusik anomaly, and the other in the northwest corner of the survey. Compare this to Figure 4, our original interpretation of time structure at the Knox Unconformity based solely on 2D data. The difference in interpretation is startling.)

In the original interpretation, a northeast-southwest structural fabric for deep-seated features was assumed. Based on an understanding of shallower structural fabric (in the Siluro-Devonian) as demonstrated by shallow-well control. This shallow structural fabric was controlled in large part by decollment in the Silurian salt with a primary transport to the northwest. While the section below the salt need not necessarily reflect this shallow fabric, the regional strike of beds into the basin is reasonably consistent throughout the sedimentary section. Logically, it seemed to follow that shallow structures were ultimately tied to older, parallel or sub-parallel basement features that provided a locus for later structural events. The new 3D interpretation forced rethinking of this theory.

The anomaly on the end of line MEC-88-2 had originally been interpreted as a separate feature, and it was that interpretation that led to the 3D survey. The new interpretation now incorporated that anomaly into a northwest-southeast trending ridge. Moreover, the ridge continued to build to the northwest, so that the end-of-line anomaly on line MEC-88-2 was not nearly the highest point in the survey. The new interpretation was compelling, and it became quite evident that the first interpretation, indicating a NE-SW structural fabric in the deep section below the salt, was incorrect, and that the predominant fabric is nearly perpendicular to this.

A combined total of more than 450 (primarily shallow) well logs from Erie, Livingston, Cattaraugus, Allegany, and Wyoming counties were collected and assimilated into a geologic framework as an adjunct to the 3D survey. The intent was to provide a more regional view of geology based on sub-surface well control, which could then be incorporated into our geophysical interpretation. The ultimate goal was to be able to present a uniform and logical interpretation, using all the geological and geophysical information available, focused on the area within and immediately adjacent to the 3D study area.

In the area surrounding the Matusik well (the western portion of the Town of Arcade, Wyoming County, and the eastern portion of the Town of Sardinia, Erie County), shallow wells had been previously field-checked for location and elevation, so structure and isopach maps derived from this information were thought to be reasonably accurate. Only wells with electric logs were used in preparing the maps, as drillers tops can be unreliable and all log picks were done by one interpreter. (Figures 6 and 7 show the structural nose apparent on the packer shell, and the isopach thinning between the Onondaga to Packer Shell, respectively. These two shallow structural indicators both imply the presence of a deep-seated feature that probably predates the overlying section. Differential thinning or "draping" is the result, and shallow structure is not necessarily indicative of either structural elevation or relative position at depth. This same thinning is also observed in Figure 13, an isochron map of the Onondaga to Knox Unconformity.)

Prospects Derived from the 3D Seismic Survey

As noted previously, the Matusik feature is high, superimposed on a northwest trending structural ridge. The Matusik feature plunges to the northwest, but another feature builds along the ridge moving to the northwest (in the vicinity of line MEC-88-2). This feature culminates in the northwest corner of the 3D survey. Closure for either feature cannot be demonstrated from the 3D survey, but the northwestern feature is about 30 ms higher than that in the southeast (Matusik). At an average transit time of seven feet/millisecond, the northwestern feature is at least 210 feet higher than the Matusik, and even subtracting regional dip (approximately 70 feet/mile SE) the feature is still at least 60 feet structurally higher than the Matusik, based on seismic interpretation. (Figure 14 is a representative line (from NW to SE) along the ridge. Figure 15 is a cross line (NE-SW) showing the northwest feature [compare this to the Matusik feature in Figure 3]).

Closure remained an interpretative problem. The survey was simply not large enough to demonstrate closure for either feature, because, quite literally, the features turned out to be much larger and broader than anticipated. Based on the earlier interpretation, the survey was positioned to center it on the end of line MEC-88-2, never anticipating that the anomaly as seen was only the beginning of a much larger feature to the northwest. Closure could be inferred from a regional vibroseis line that extended north of the survey and showed north dip on the deeper section. However, it wasn't clear how important closure really is in trapping hydrocarbons here. In Ohio, the deep traps are stratigraphic, structural, or a combination, and the drilling of any prospect depends more on attribute processing (secondary seismic attributes) than on demonstrated closure. To this end a seismic amplitude map of the survey area was prepared (Figure 16). While amplitude anomalies are present across the entire structural ridge, they are clearly more pronounced in the northwest corner.

Dr. Bruce Hart of the New Mexico Bureau of Mines and Mineral Resources did a companion study of the 3D data under a Cooperative Research and Development Agreement (CRADA) with Ardent Resources, Inc. and the Los Alamos National Laboratory. His interpretation which was similar to the one in this study, was later published in the Oil & Gas Journal (10/14/96). The net result was a joint venture decision to drill the Stahl #1 (API # 31-121-22655) and test the feature at the northwestern extremity of the 3D survey.

On September 28, 1996, the Stahl #1 was spud and in 10 days a total depth of 5,920 feet was reached. A show of gas was encountered in the Little Falls. There was also evidence of water, as indicated by the increase in observed air-drilling pressure, in the underlying Theresa (Figure 17). The well was perforated (5,962' - 5,972') only in the Little Falls using a new technique known as "extreme overbalanced perforating". Open flow was reported at 143 mcf/day with a shut-in pressure of 1850 psi.

Side wall cores taken through the Little Falls with one core recovered from the Theresa will be the subject of a separate report from NYSERDA and U.S. Energy Development Corp. The well is currently shut in awaiting pipeline connection.

The Stahl #1 may be no better (in terms of deliverability) than the Matusik (and at similar cost). Based on that assumption and put only in those rigid terms, the project can be viewed as a failure. While all involved clearly wanted economic success from drilling the Stahl, there is nothing to suggest that is not achievable. More importantly, much was learned from this study that can be applied not only to the next 3D survey run in New York, but also to deep hydrocarbon exploration as a whole.

Conclusions

What has been learned? What benefits can be derived from this study? More to the point, how can those benefits be applied to further deep exploration in New York State? The following observations may be helpful.

- The Stahl feature is probably not closed; the (indicated) occurrence of saltwater in this section suggests that. Had the survey been larger in the first instance, this lack of closure may have been determined prior to drilling. Whether advance knowledge of failure to close would have prevented the well from being drilled is an entirely different matter. Certainly the next 3D survey needs to cover a larger area, but not necessarily with a corresponding increase in expense. The data quality achieved using the designated brick pattern was far better than anticipated, to the point where survey size could easily have been increased (perhaps doubled) without increasing the number of shot points. This would have increased survey size (with only a modest increase in acquisition cost) at the expense of seismic fold, which in retrospect was expendable to a degree.

- The structural fabric of the deep section in western New York appears to be oblique to that of the shallower section above the Silurian Salt. Some geologists have pointed out that one need only look at the surface expression of the (still active) Clarendon-Linden fault system in west central New York to recognize this, but it is preferable to have observed it in the deep section miles from the Clarendon-Linden system. However, the implication is clear. There may be a regional trend for features in the deep section that will allow for better planning of future exploration programs.

- The cost of 3D seismic is not prohibitive in the Appalachian Basin (at least not in the gently rolling terrain in which this survey was run). Costs in terms of layout, shooting, reclamation, and damage settlements are comparable to other areas in the Southwest.

- Coverage within a 3D survey is much more inclusive, thereby eliminating subjective interpolation between data points (2D seismic lines, well control, etc.). The fact that the initial 2D interpretation was completely revised upon reinterpretation with the 3D data is evidence of this.

- Interpretation of the 3D data can be more intuitive than 2D seismic alone. Both offer sections that are comparable, but based on the previously outlined point (inclusive coverage), actual structures and anomalies not so readily apparent in a 2D section are brought out in the 3D data.

Summary

This first 3D seismic study in New York State was aimed at:

- Demonstrating an emerging technology in New York State;
- Determining feasibility and applicability of that technology to deep hydrocarbon targets in New York State;
- Comparing this technology to conventional methods, in terms of both cost-effectiveness and benefits derived; and
- Promoting deep drilling in New York State.

The results obtained from this 3D seismic survey clearly indicate the technology has reached a level of maturity that makes it feasible for Appalachian Basin operators. If the technology is incorporated into more exploration efforts in New York State, a clearer geologic picture is sure to develop, and this undoubtedly will lead to more proven hydrocarbon reserves. In the final analysis, the goals of the Northwoods 3D Demonstration Project were met. The future for deep hydrocarbon exploration in New York State, and the basin as a whole, remains bright.

Appendix

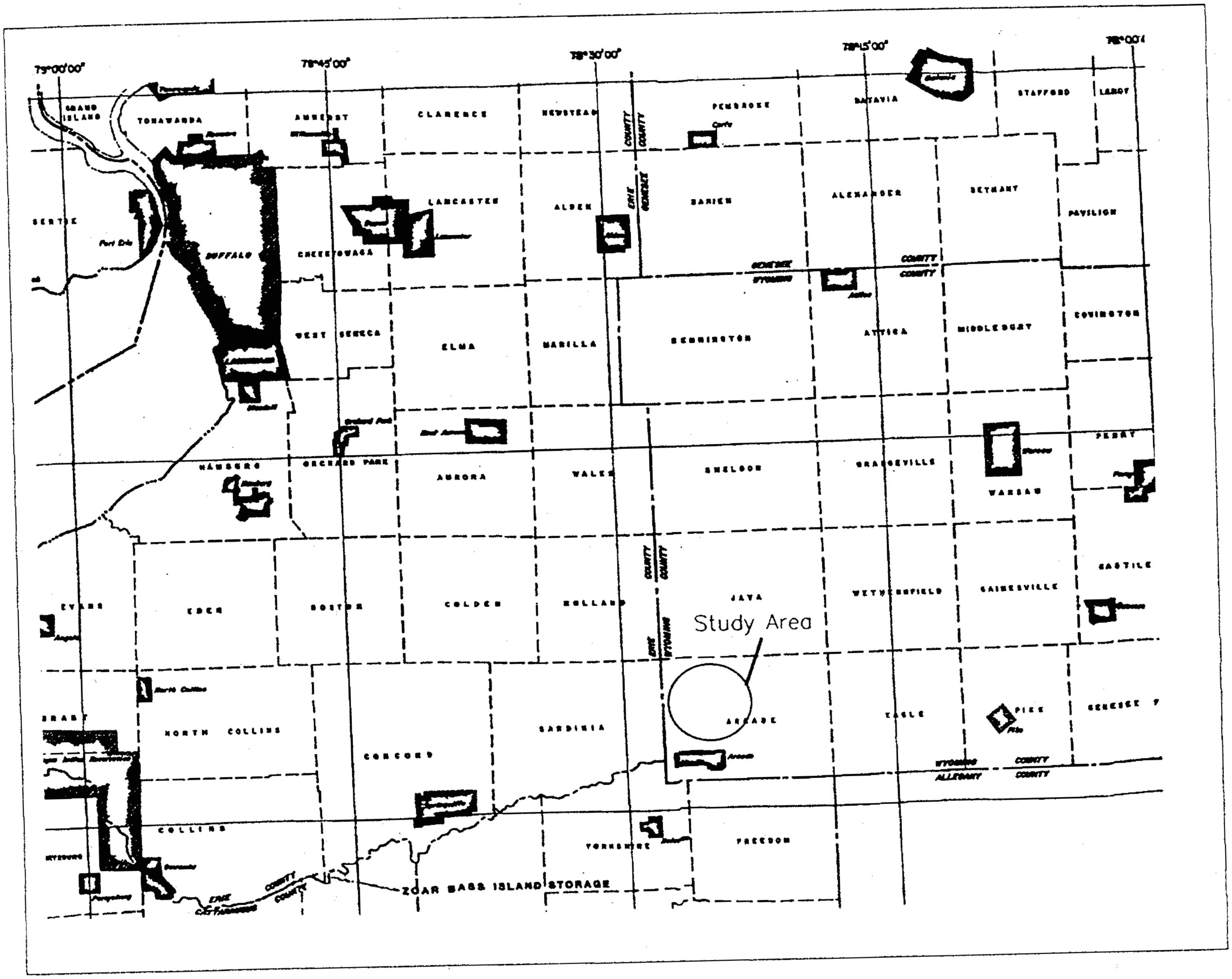

Figure 1 - Regional map of Western New York showing location of Northwoods study area

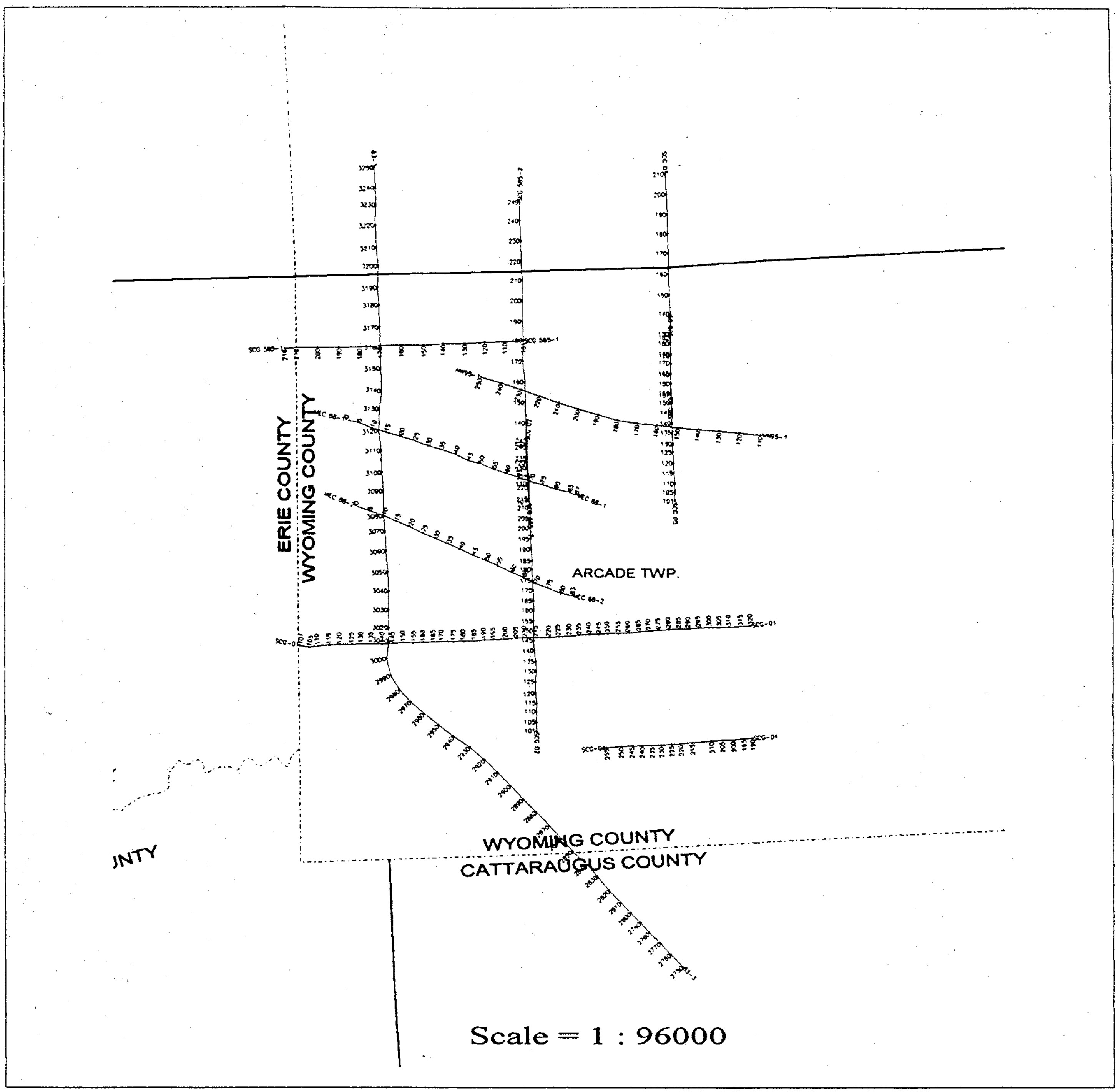

Figure 2 - Map of study area highlighting location of 2D seismic lines used in study

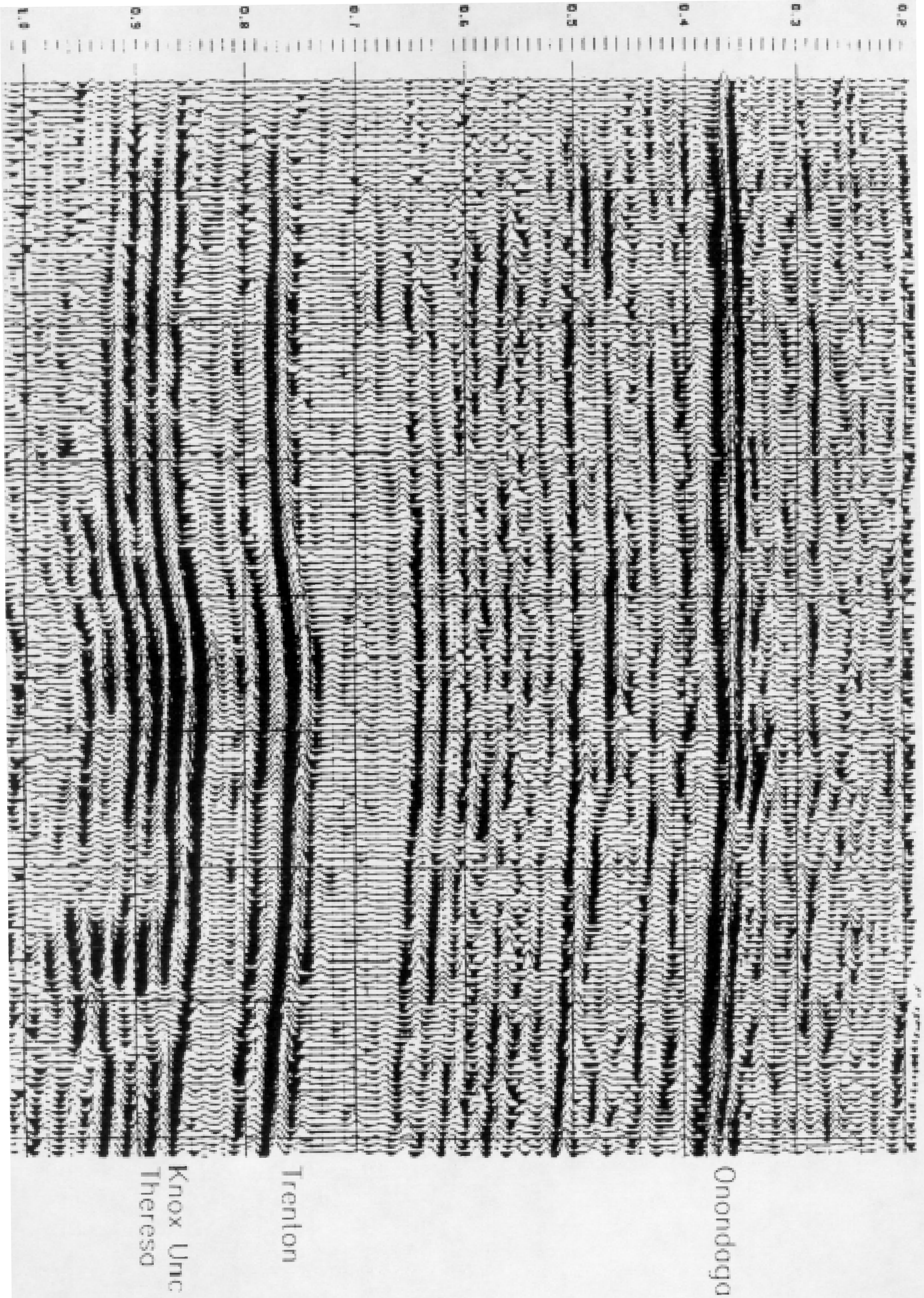

Figure 3 - Partial copy of east-west seismic section showing initial prospective anomaly

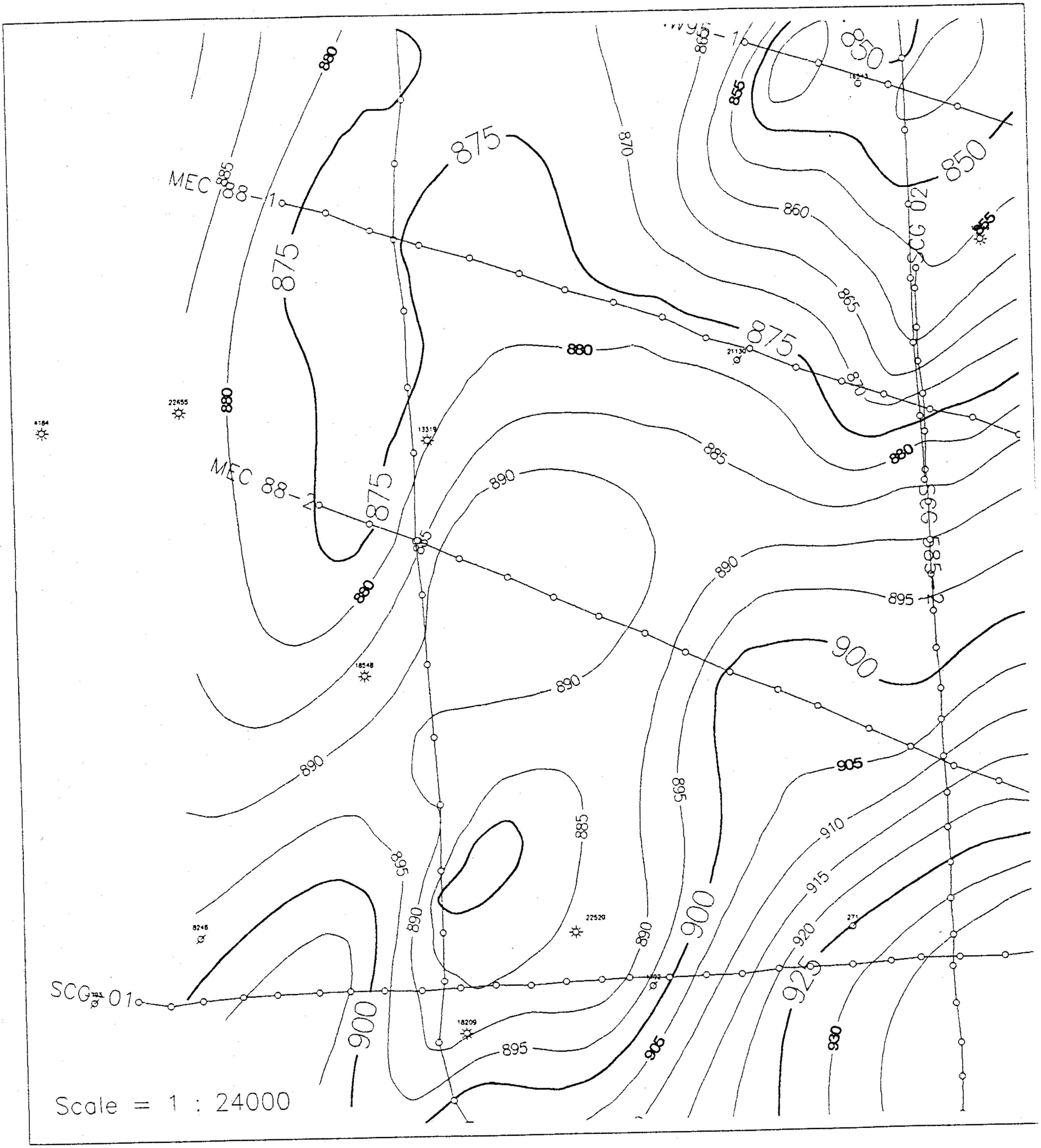

Figure 4 - Time structure at or near Knox Unconformity (2D seismic data)

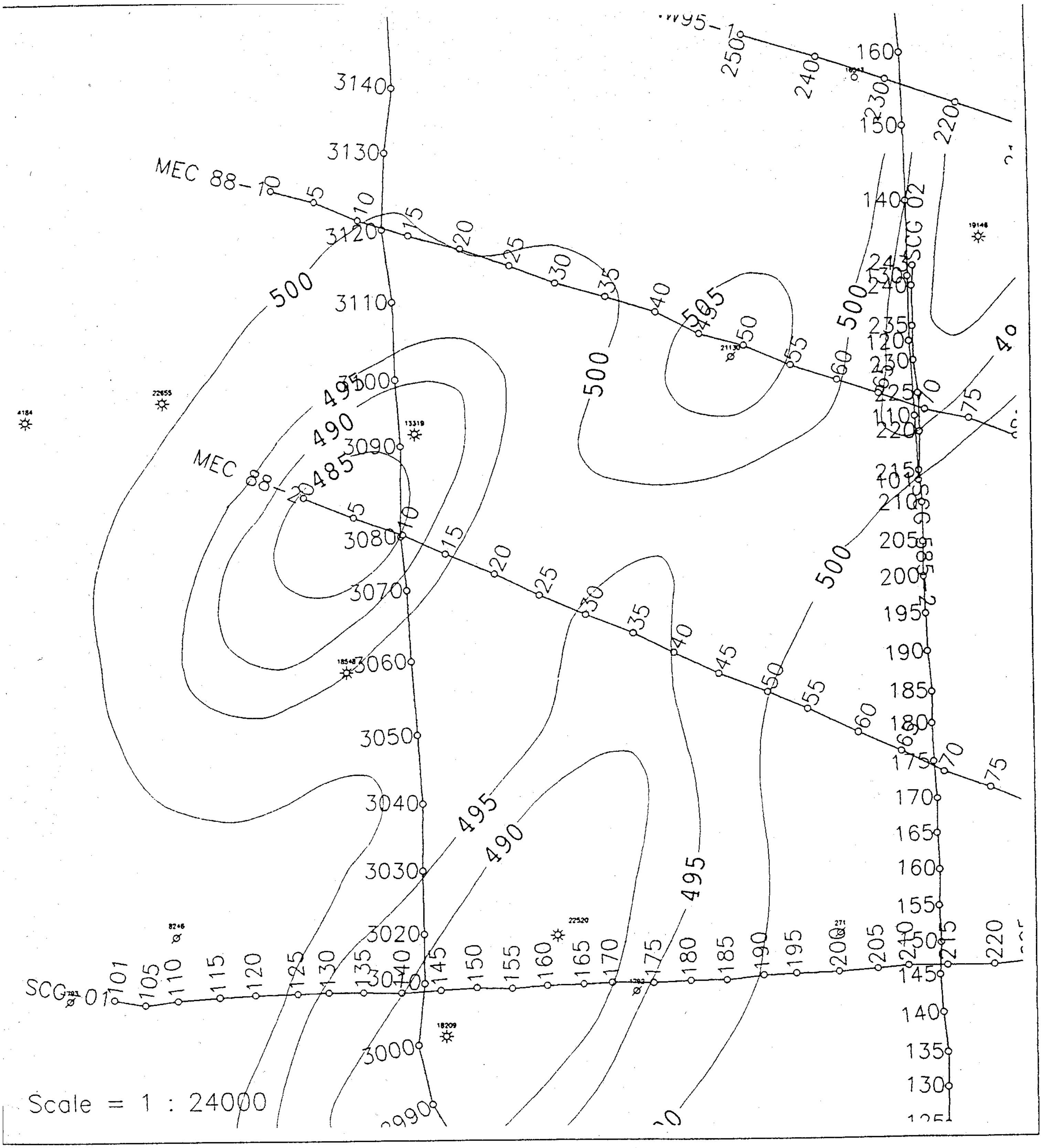

Figure 5 - Isochron from top of Onondaga to Knox Unconformity (2D seismic data)

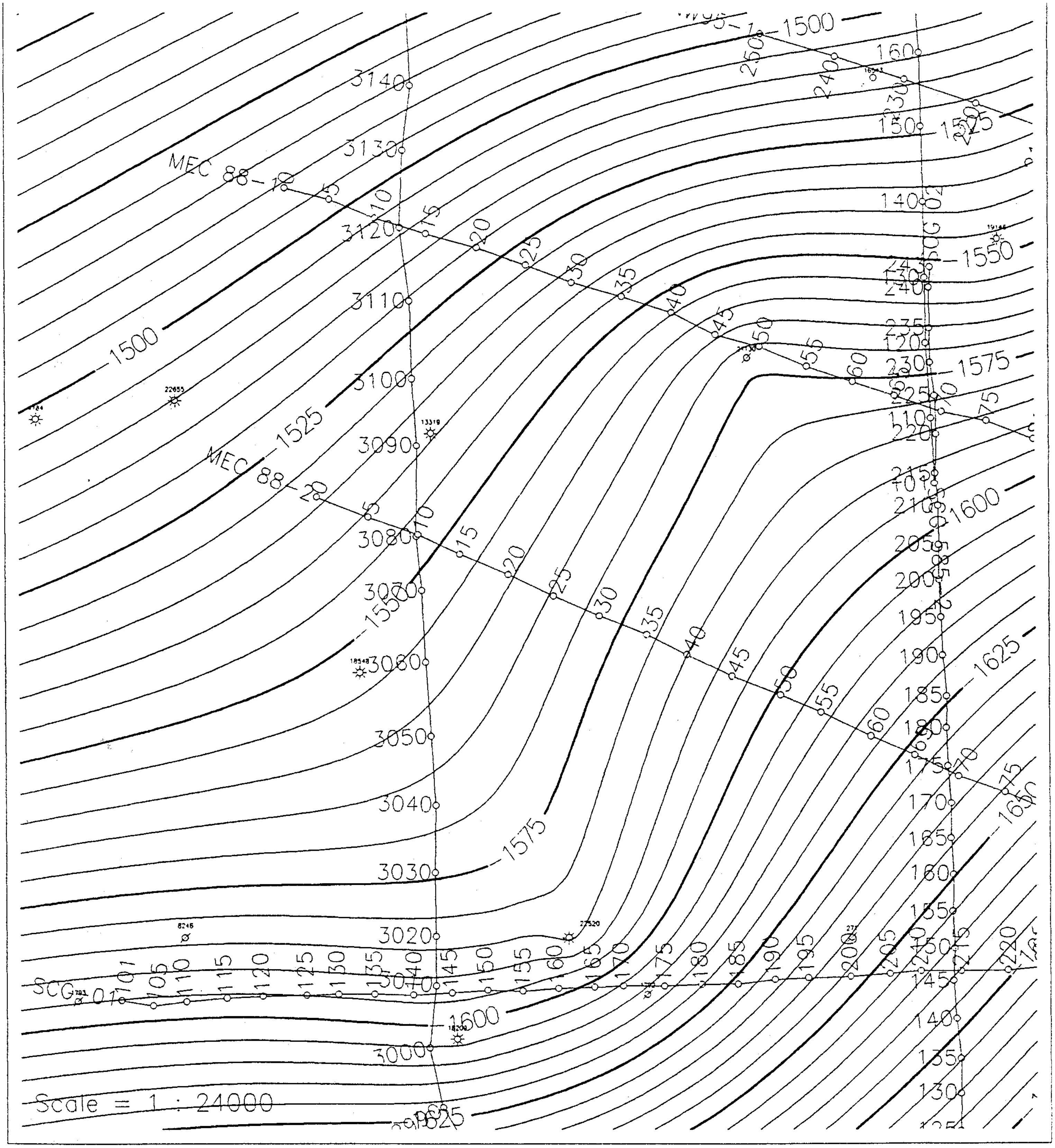

Figure 6 - Structure top of Packer Shell

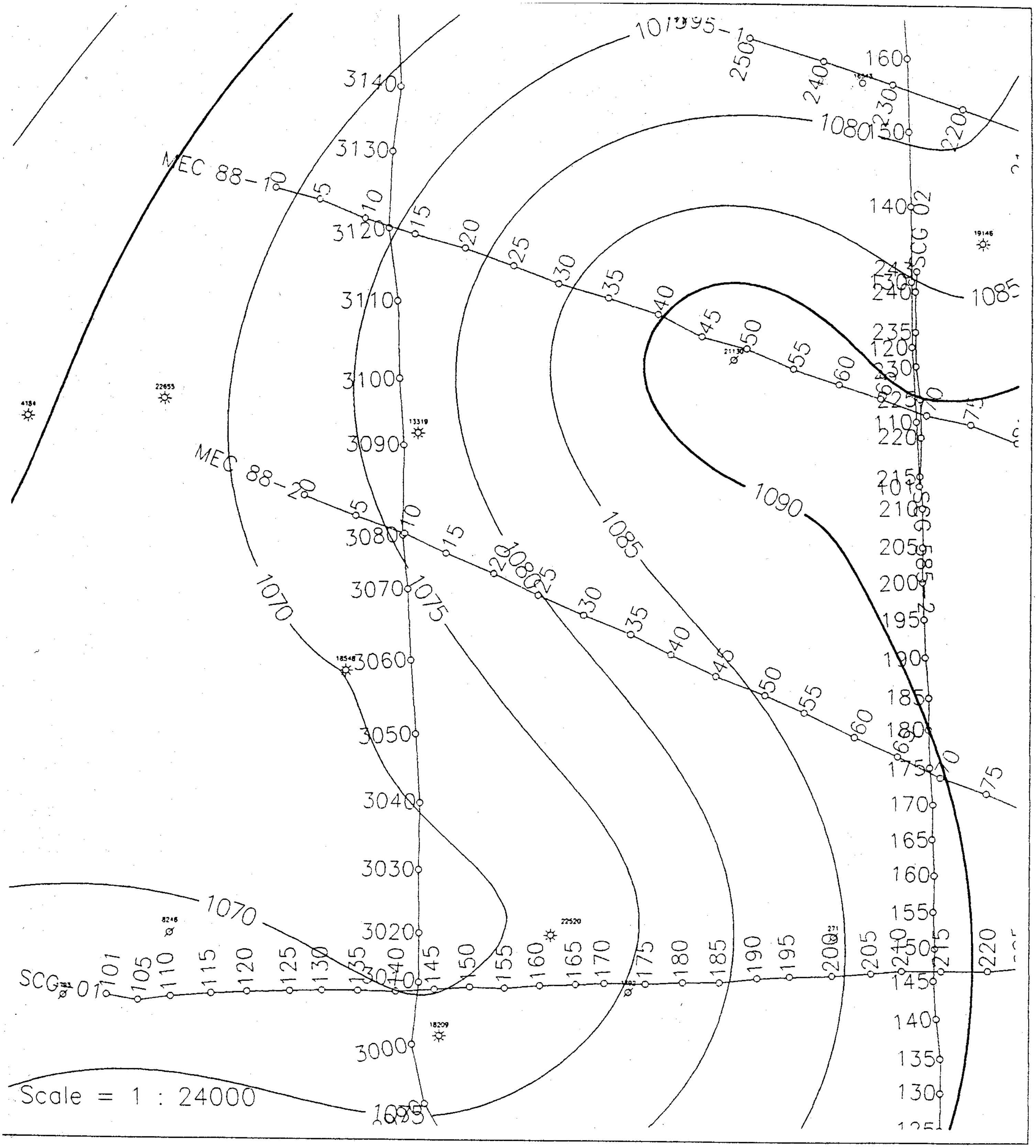

Figure 7 - Isopach top of Onondaga to top of Packer Shell.

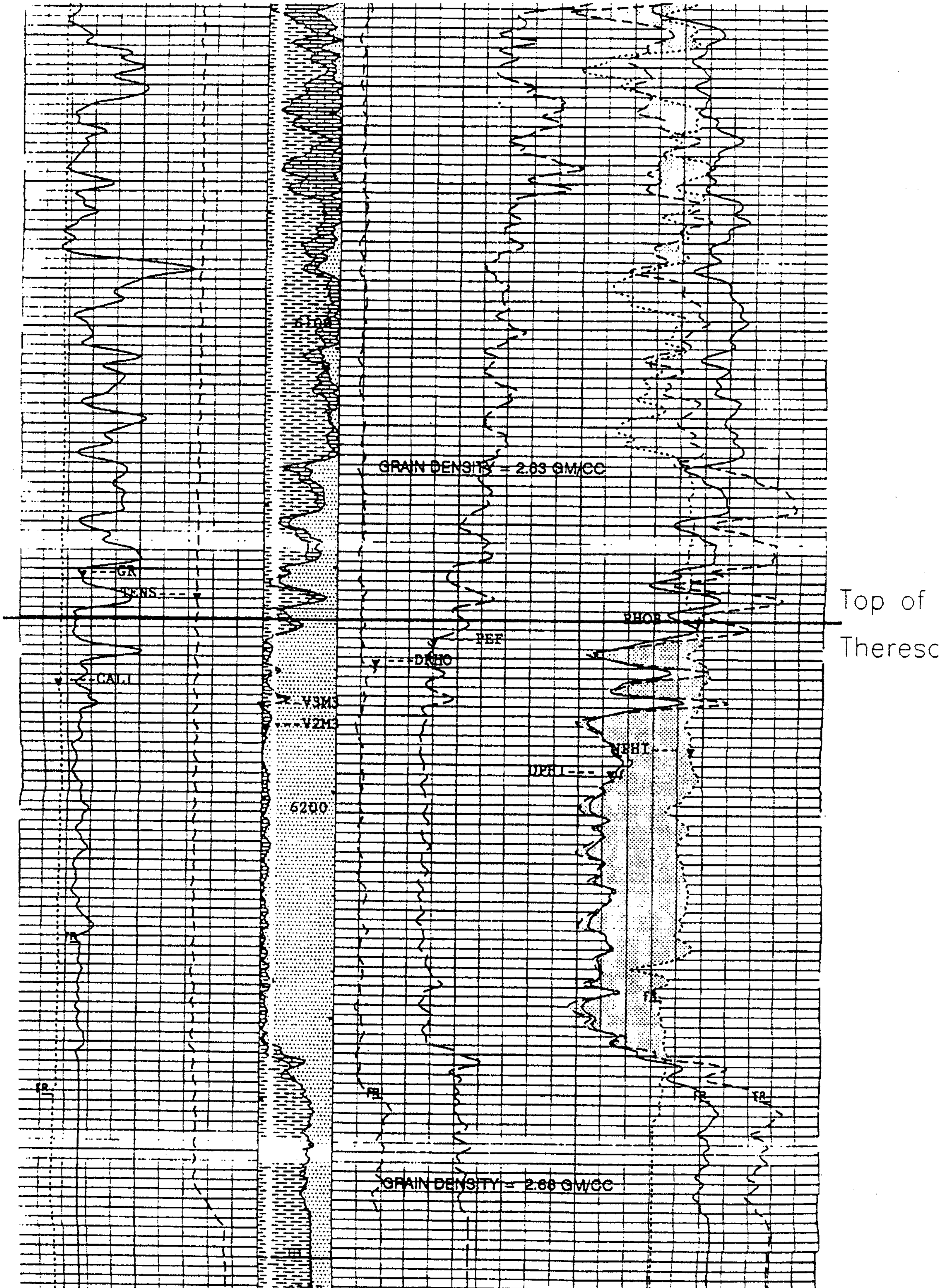

Figure 8 - Partial log section of J. Matusik #1

MONTH	MCFD
03/95	1587
04/95	2590
05/95	2348
06/95	2029
07/95	2083
08/95	0
09/95	2031
10/95	0
11/95	1369
12/95	993
01/96	929
02/96	814
03/96	1917
04/96	1520
05/96	1533
06/96	1302
07/96	1320
08/96	1370
09/96	864
10/96	1203
11/96	1077
12/96	927
01/97	724
02/97	862
Cumulative Production	**31392**

Figure 9 - Monthly production history from J. Matusik #1

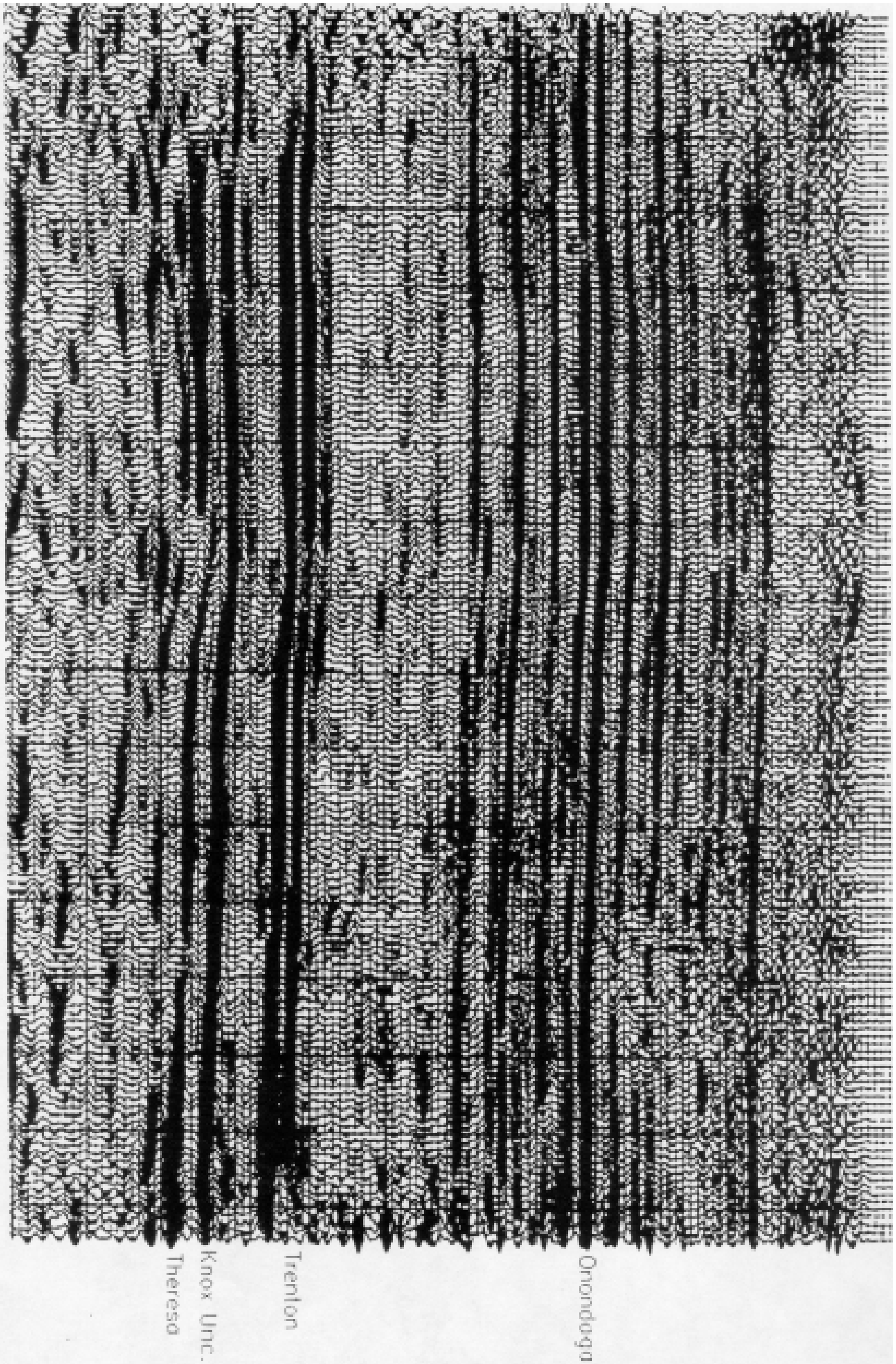

Figure 10 - Northwest anomaly at end of line MEC-88-2

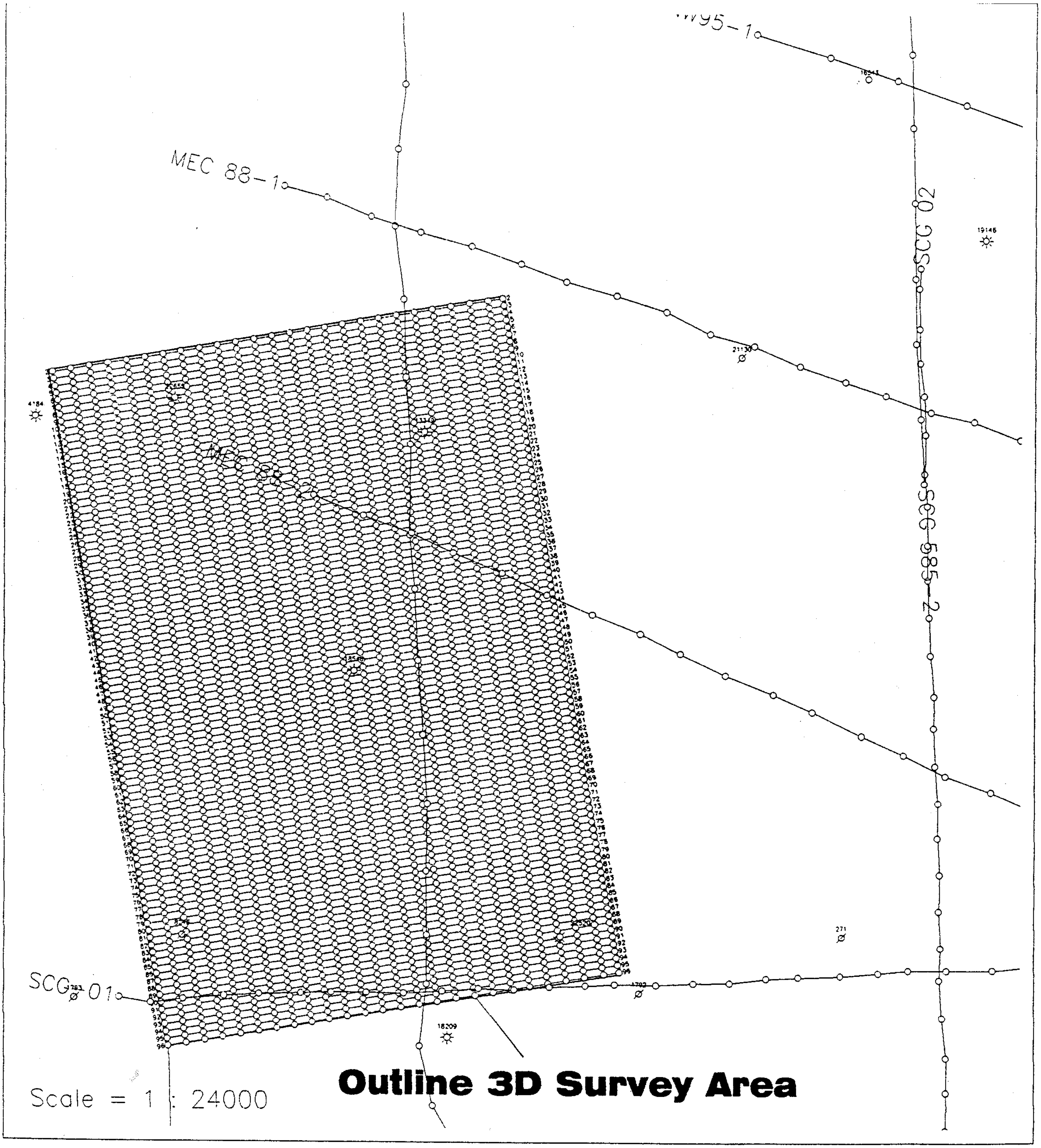

Figure 11 - Layout of Northwoods 3D seismic survey

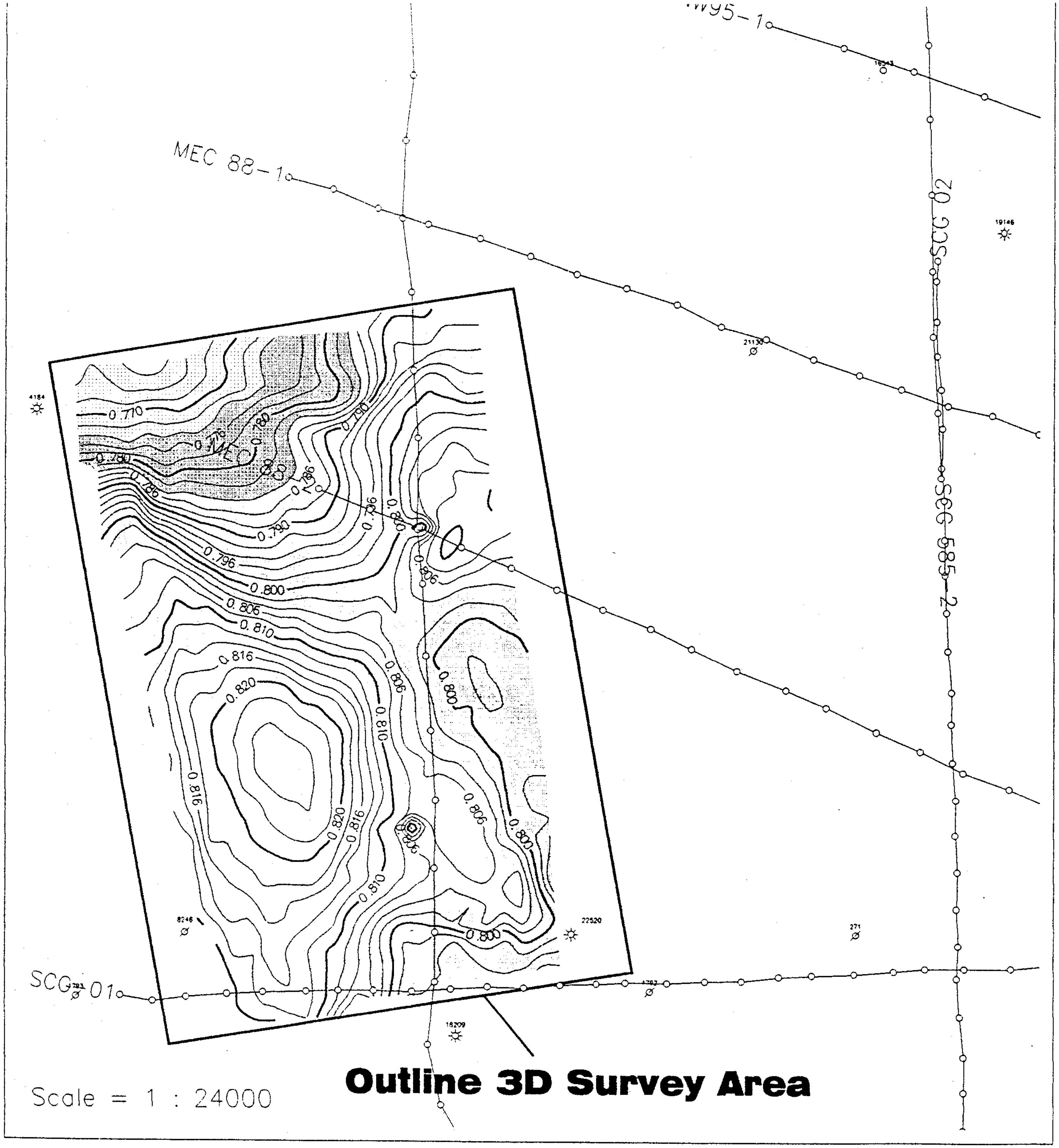

Figure 12 - Time structure at Knox Unconformity (3D data)

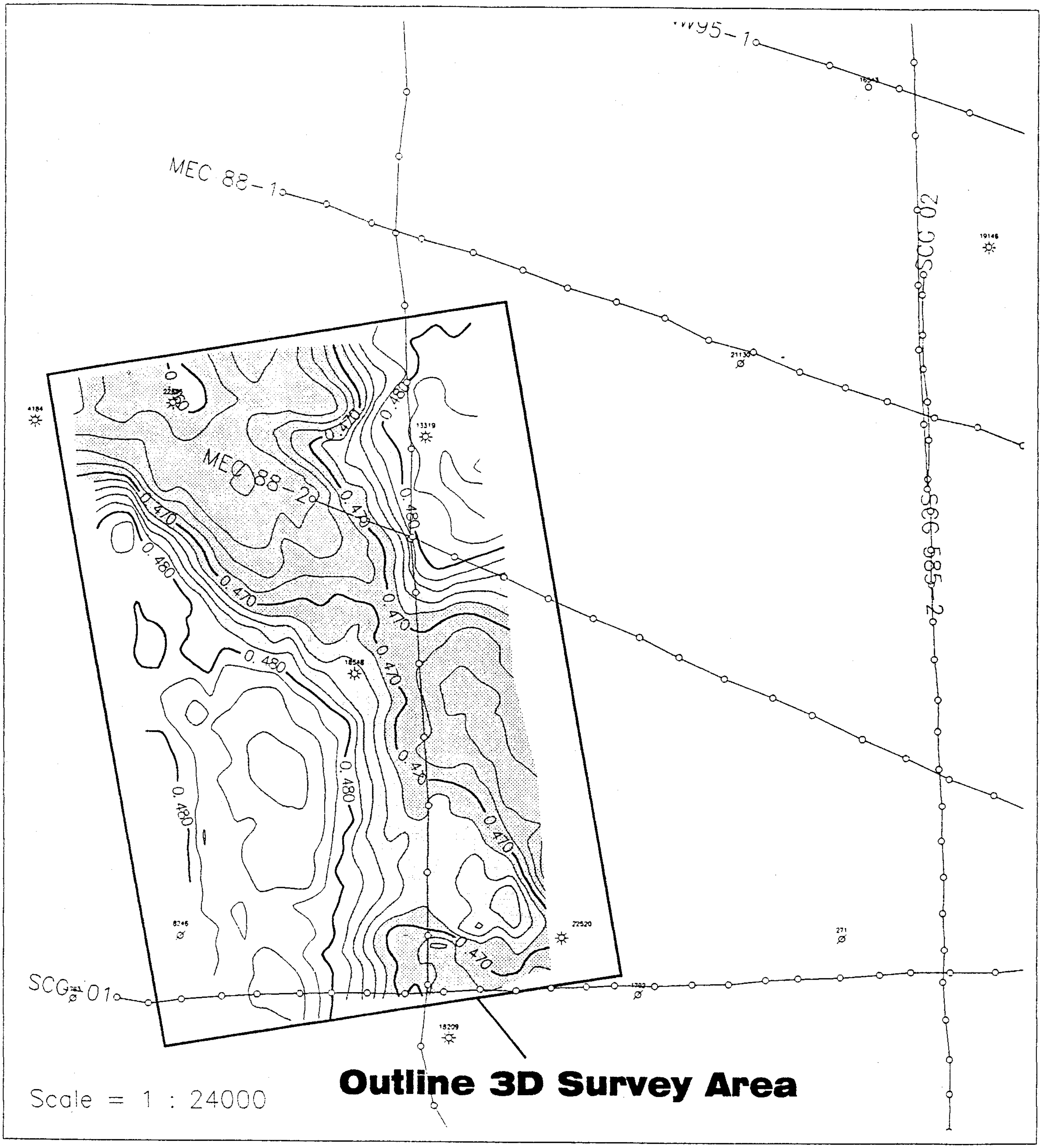

Figure 13 - Isochron top of Onondaga to Knox Unconformity

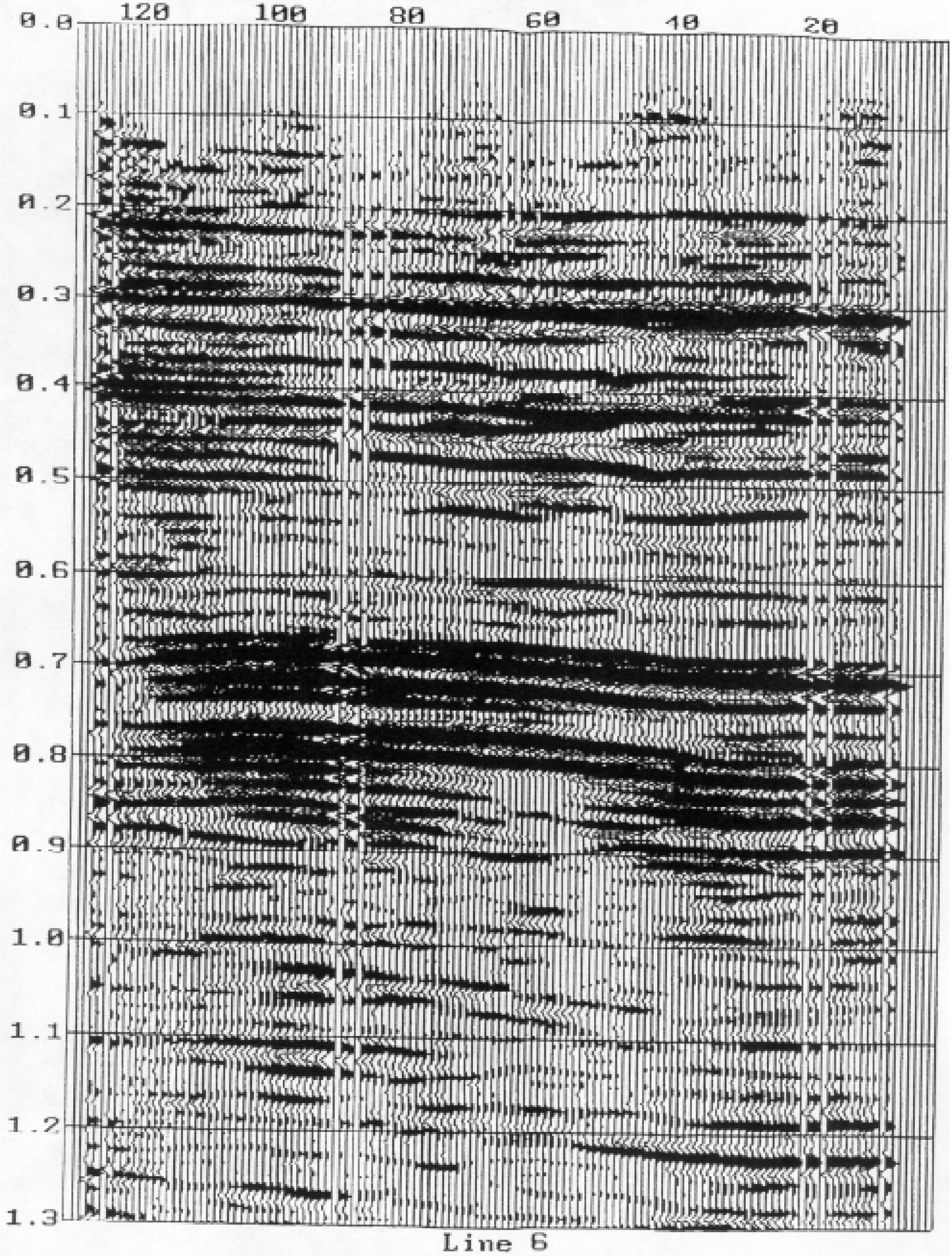

Figure 14 - Representative line along structural ridge (northwest-southeast)

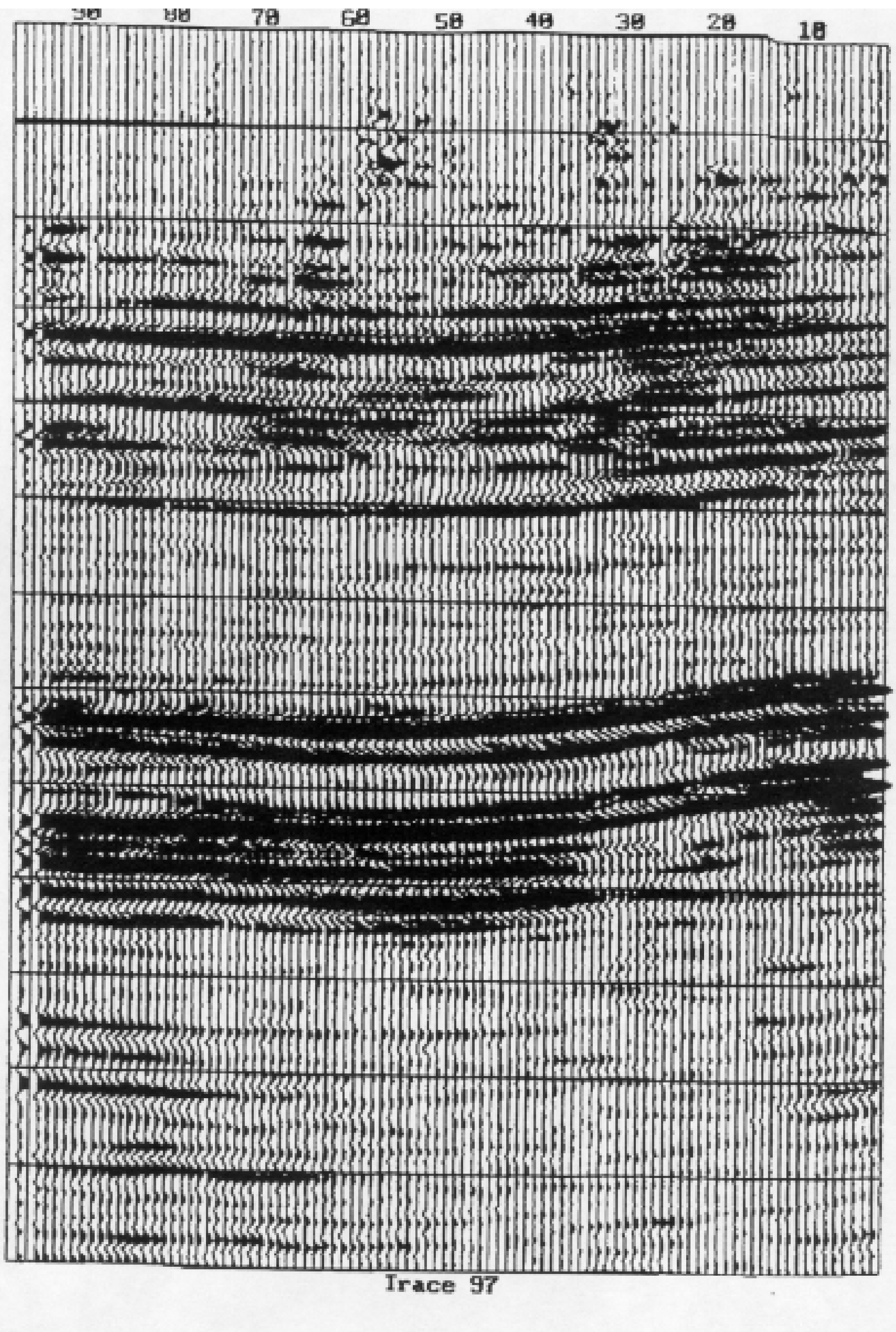

Figure 15 - Crossline (northeast-southwest) showing northwest feature

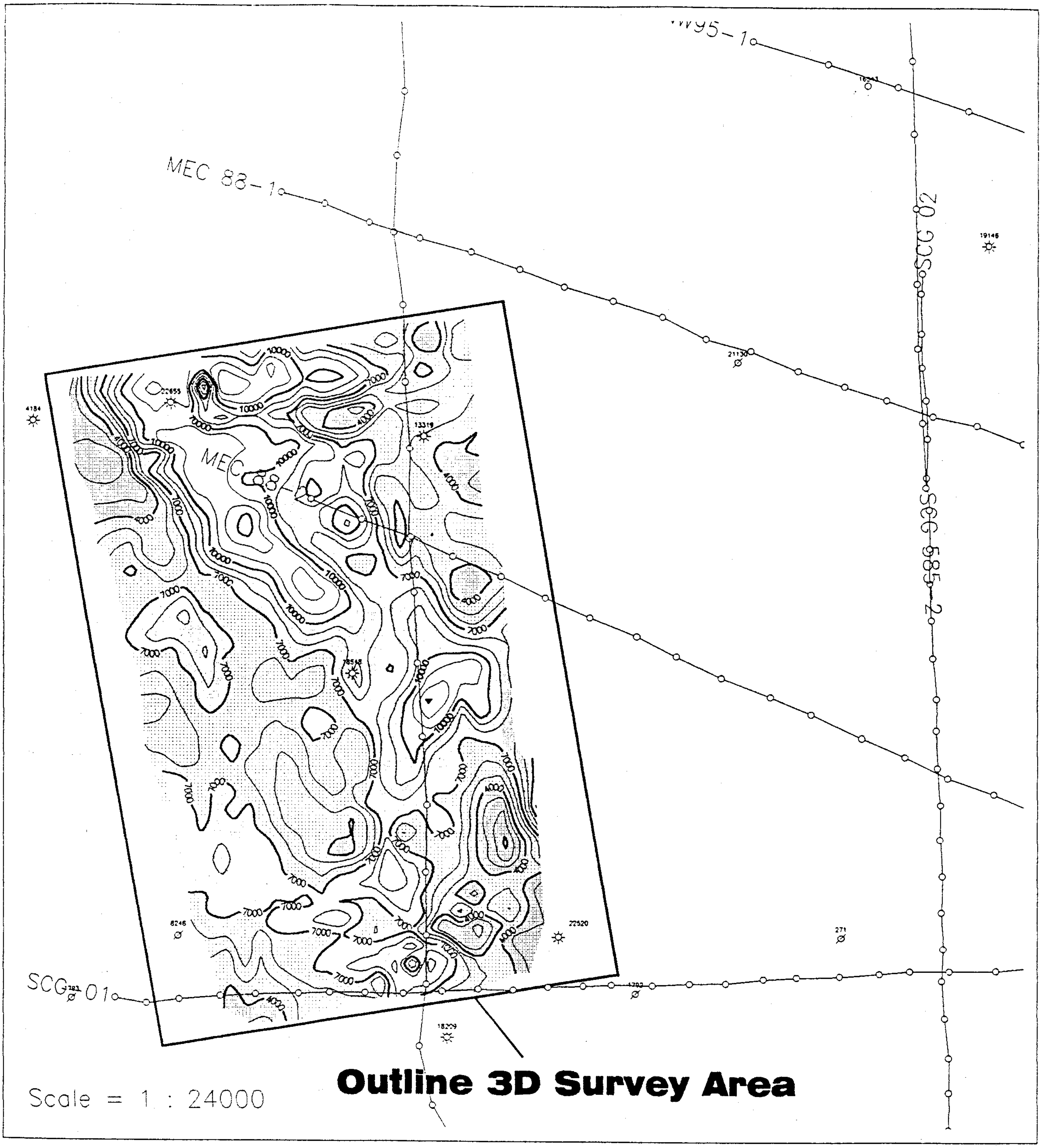

Figure 16 - Seismic amplitude map

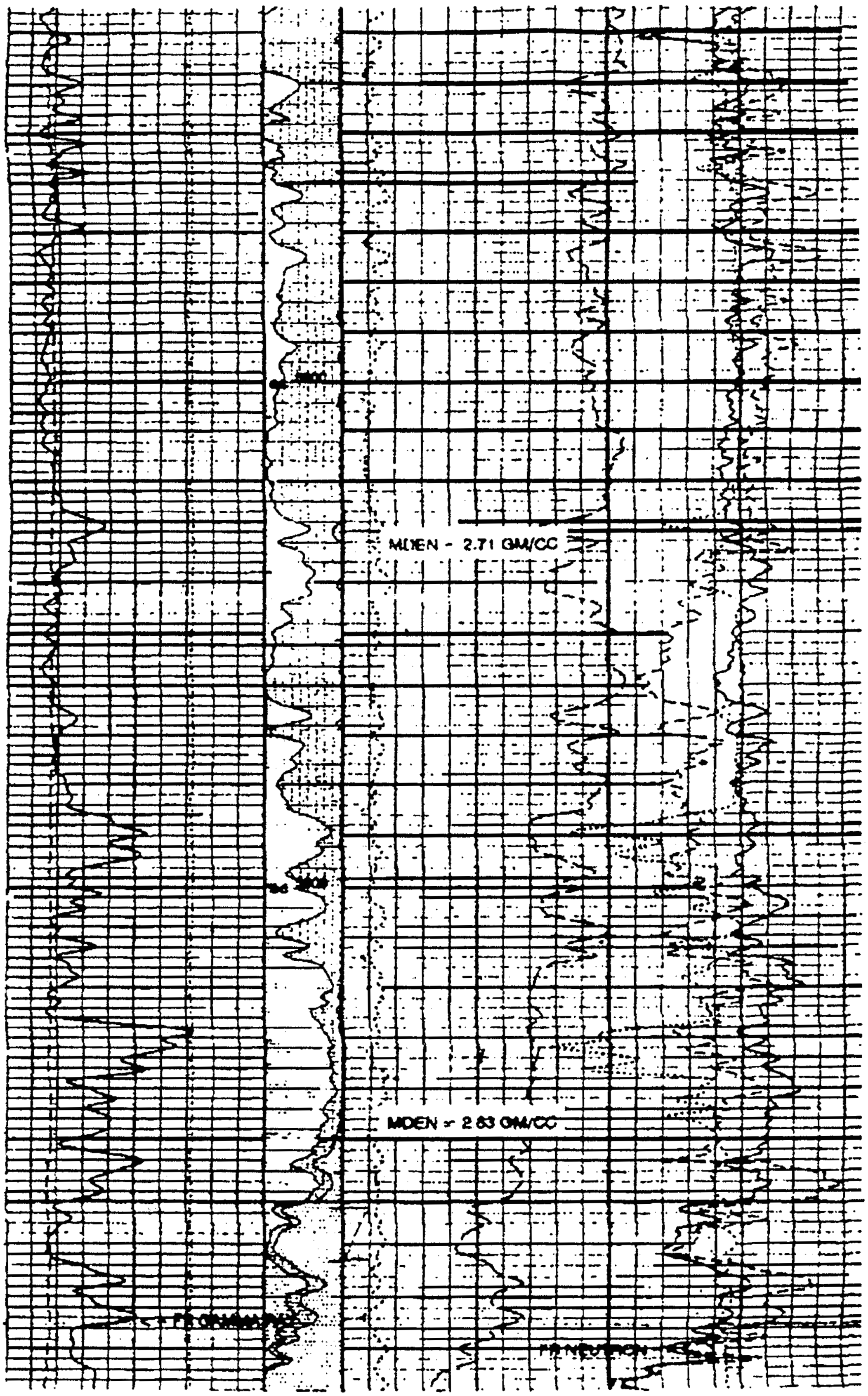

Figure 17 - Partial log section Stahl #1