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Data Processing and Preliminary Interpretation of the 2000 Southern Ontario Seismic (SOS) Project

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Abstract: In the summer of 2000, approximately 400 km of crustal seismic reflection data were acquired across parts of southern Ontario from the Ottawa Valley to north of Lake Erie. Nine profiles traversed parts of the exposed and covered Central Metasedimentary Belt of the Grenville Province to provide constraints on Grenville crustal structure and the interaction of the Paleozoic sedimentary section with the underlying Precambrian basement. The seismic work complements the higher resolution southern Ontario aeromagnetic survey data acquired in 1999.

Preliminary interpretation of the seismic data reveal structure of the Grenville and Appalachian orogens. Paleozoic strata are thin or absent from Toronto to Ottawa, whereas north of Lake Erie, Paleozoic strata are ~1200 m thick and are characterized by reflections associated with the Silurian-Ordovician transition (~425 m depth), the top of the Trenton Group (~950 m depth), the Trenton-Black River transition (~1075 m), and the Trenton-Cambrian transition (~1200 m depth). The Central Metasedimentary Belt boundary zone is imaged as a shallowly east-dipping zone extending from the near surface to ~8 s (24 km depth). Images of the Composite Arc Belt and the adjacent Composite Arc Belt boundary zone show shallow SE apparent dips from the near surface to ~4 s (12 km depth). Crustal thickness ranges across the area from a maximum of ~14 s (42 km) in the SW to ~12 s (36 km) in the NE.

Introduction

The Lithoprobe Abitibi/Grenville Transect aims to image and quantify the 3rd dimension of the Grenville orogen. Previous Lithoprobe seismic studies (Milkereit et al, 1992; Forsyth et al, 1994b, White et al, 1994, 2000) provided both a regional tectonic and structural framework for southeastern Ontario, identifying further questions which guided the new data acquisition. The data were collected by Kinetex Inc. of Calgary Alberta (Harrison, D., 2000).

The survey includes ~400 km of deep sounding seismic reflection data acquired along 9 profiles between the Ottawa valley and the Niagara peninsula (Fig.1). In addition to the Niagara Peninsula, the new data will enable the first look at structure of the Composite Arc Belt (Carr et al. 2000) boundary zone and the Frontenac Terrane underlying eastern Ontario. The new seismic profiles will address three main objectives.

1) ***Structure of the Grenville Orogen in Ontario***: A postulated Himalayan analogue (Wynne-Edwards, 1972), the Grenville Province provides one the best examples of an exhumed continental-collision zone and records a history of the Laurentian continental margin preceding the collision nearly 1 billion years ago.

The new data will 1) provide constraints on the 3-D regional architecture of the Grenville Province in southern Ontario, and 2) characterize geological domains and boundaries not covered in previous surveys. As shown in Figure 1, profiles 1 to 3 cross from the Composite Arc Belt to the Ontario part of Frontenac Terrane. These fundamental subdomains and the Composite Arc Belt boundary zone represent key missing pieces to our knowledge of the subsurface geological framework of the Central

Metasedimentary Belt. Secondly, profile 4 crosses the projected sub-sedimentary location of the Central Metasedimentary Belt boundary zone, a first-order collisional boundary between parauthochthonous rocks of the Laurentian margin and allochthonous Terranes of the Central Metasedimentary Belt (Carr et al, 2000). This boundary zone was not completely crossed in the original Lithoprobe surveys. The new data will provide a test of the hypothesized southward extension of the Central Metasedimentary Belt boundary tectonic zone and will define along-strike variations in the nature of the boundary. Finally, profiles 5 to 9 provide a second crossing of the postulated sub-Phanerozoic extension of the Central Metasedimentary Belt boundary zone and additional coverage of the previously poorly imaged Central Gneiss Belt (parauthochthonous rocks of the Laurentian margin).

2) *Sedimentary/Precambrian basement interaction*: The basement cover in southwestern Ontario consists of northerly thinning Paleozoic strata of the Appalachian orogen and unconsolidated glacial till. The basal cover section may also include pre-Paleozoic material with local accumulations of several hundred meters. The economically important sedimentary cover hosts oil and gas deposits, potable groundwater and industrial construction stone. Fluid pathways within the sedimentary rocks and porous basement rocks form conduits for potential groundwater contamination. Our knowledge of the interaction of these sedimentary rocks with the underlying Precambrian basement has seriously lagged behind the accelerated pace of infrastructure development in southern Ontario. Profiles 4 to 9 image a significant section of the Quaternary cover and Appalachian orogen to provide new information on the Precambrian basement-cover interaction. Profile 4 provides a 75 km-long section of the Oak Ridges Moraine and underlying structure. Glacial till deposits such as the Oak Ridges Moraine are important components of aquifer systems, but the role of the underlying basement in contributing to regional subsurface fluid flow is not well documented. In the area of the Oak Ridges Moraine, detailed shallow seismic models from the Oak Ridges NATMAP Project can be integrated with the new seismic images of the cover and underlying basement to improve our understanding of this major aquifer.

The exploration model for oil and gas (e.g., Sanford et al., 1985) includes basement trends and reactivated structures as primary influences on the formation and retention of hydrocarbon deposits. Profiles 5 to 9 will provide a regional benchmark for petroleum-related studies in southwestern Ontario. Faults that can be identified within the Precambrian basement rocks and followed into the overlying sediments may constrain the ages and amount of possible post-sedimentary fault activity.

3) *Earthquakes in an intracontinental setting:* Although moderate and small earthquakes have been recorded (e.g., a magnitude 5.5 earthquake in upstate New York in April 2002, a magnitude 5.2 event near Toronto in November of 1996 and events with magnitudes 1-3 occur at a rate of ~10 per year), large earthquakes are unknown in the historical record of southern Ontario. However, the seismic risk is amplified by an increasingly dense population and critical infrastructure in the area. A high resolution aeromagnetic survey was flown in 1999 (Fig.1) to improve the database that is the subject of an ongoing debate concerning the structural and seismogenic significance of gravity and magnetic anomalies in the Lake Ontario area (Wallach et al, 1998). The new seismic data will aid the search for displacements of well-defined stratigraphic markers that may imply reactivation of the Precambrian basement structures.

Ultimately, with the increased earthquake monitoring capabilities of the POLARIS network (Fig.1), an attempt can be made at clarifying a possible link between imaged subsurface structures and earthquake activity.

Recording Parameters

Municipal permission was obtained for the survey routes that followed a network of secondary roads. These roads were selected to optimize coverage of the target structures, minimize disruption of adjacent infrastructure (buildings, pipelines etc.) and simplify survey geometry. Recording station spacing decreased from 25m for profiles 1-4 and 8-9 to 12.5m for profiles 5, 6 and 7 in an attempt to obtain a higher resolution seismic image of the shallow structure in an area of both special tectonic and hydrocarbon interest near eastern Lake Erie. The recording parameters are outlined in Table 1.

Data Processing

Seismic data transcription from IBM 3590 tapes to hard disk was initially delayed by 6 months due to the unavailability of a tape drive capable of reading the IBM 3590 data cartridges used by the commercial contractor Kinetex.

Data processing was done from October 2001 to December 2003 at the Geological Survey of Canada (Ottawa) by K. Ouassaa on a Sparc Ultra (Enterprise 450) workstation using Promax (v7.0) and Insight (V5.1) software from ITA/LandMark. The processing sequences described in Table 2 were accomplished with special attention paid to refraction statics corrections and velocity analysis. The results presented are stacked and time migrated seismic sections obtained using a Kirchhoff based algorithm. Figures 2a to 10a show the slalom line used for cdp-binning along the crooked line compared with the real data acquisition path. Figures 2b to 10b and 2c to 10c show respectively the stacked and migrated images of crustal seismic sections for all SOS lines. Figures 2d to 10d present enlarged portions of the Paleozoic-Precambrian part of the sections with preliminary lithology identification. Horizons on the seismic section are identified by correlation with lithology depth from well logs. The approximate depth is obtained from depth migrated seismic sections (not presented in this report) where stacking velocities have been used for migration.

The Niagara Peninsula Profiles

Paleozoic rocks underlying the Niagara Peninsula and adjacent lakes Erie and Ontario form part of the northerly thinning edge of the Appalachian orogen. The mainly Paleozoic cover sequence thickens southward from near 900-1000 m beneath the Niagara Peninsula to about 1500 m beneath eastern Lake Erie (Forsyth et al, 1994). Beneath the Niagara Peninsula, well cuttings indicate a variation in the thickness of basal Cambro-Ordovician material from tens to hundreds of meters suggesting deposition on an eroded Precambrian surface with considerable local relief.

Sanford et al. (1985) have proposed a fracture framework for southern Ontario based on results from several thousand boreholes drilled in exploration for oil and gas. The Sanford et al. (1985) work also suggested that periodic fracturing coincided with plate tectonic events related to Appalachian mountain building processes some 450-350 million years ago.

Linear magnetic anomalies and drill cuttings have been interpreted as evidence of ductile deformation domains extending from the exposed Central Metasedimentary Belt and Central Gneiss Belt to beneath the eastern Lake Erie area (Easton and Carter, 1995). Magnetic anomalies associated with the northeast trending Central Metasedimentary Belt Boundary zone suggest related structure may extend beneath the area of western Lake Ontario, the Niagara Peninsula and eastern Lake Erie.

As indicated in Table 1, profiles 5, 6 and 7 beginning just west of the Welland Canal, were recorded with a reduced station spacing of 12.5 m in an attempt to improve the resolution of the Paleozoic section and provide constraints for the hydrocarbon exploration model for the eastern Lake Erie area. Figures 2d to 6d show the enlarged portion of Paleozoic-Precambrian strata for profiles 5 to 9, from the eastern Niagara peninsula. The generally horizontal reflectors of the Appalachian strata are succeeded at a depth of about 0.5 s by shallow dipping events associated with the Precambrian basement.

The Paleozoic strata maintain a generally constant thickness of ~1180 m along line 5 and thicken slightly to ~1250 m at the end of line 6. A well located about 200 m north of shot point 1205 from line 5 indicates a Paleozoic section thickness of 992 m. The Paleozoic strata dip slightly to the south on line 7. The Paleozoic section thickness is 1150 m at the end of line 7 and 1200 m at the intersection with line 6.

The Paleozoic strata are characterized by strong and continuous reflectors. We distinguish four reflectors (A to D, Fig. 2d-6d) characterizing the Paleozoic strata, based on correlation with formation depths in a nearby well to the north of line 5 and well 24T ~20km south of line 5 and 6. The reflector-formation character is very similar to that observed on seismic line 1 of the NYSGS-V9 experiment located in western New York state (Ouassaa and Forsyth, 2002).

Reflector A is discontinuous along lines 6 and 7 and occurs at a two-way time of 0.18 s (425 m). It is correlated with the Silurian-Ordovician transition. The Bottom of the Queenston shale may be represented by a segmented reflector along the eastern part of line 5 (station #510 to 650) located at a two-way time 0.33 s (800 m). This reflector is unclear on the east part of line 6. Reflectors B, C, and D are all strong and continuous. They occur at 0.40 s (950 m), 0.45 s (1075 m) and 0.48 s (1200 m), and correlate with the Trenton Group, the Trenton-Black River transition, and the Trenton-Cambrian transition, respectively.

The formations cited above vary little in thickness along the lines. For example, the Black River strata is ~50 m thicker on line 6 and 7 than on line 5. The generally horizontal stratification is interrupted locally where the Trenton and Black River strata indicate small vertical undulations of ~50 m over a distance of 2.5 km and larger undulations of 125 m over a distance of ~1 km as shown in figures 2d to 4d. Possible fractures or faults with an apparent maximum offset of ~50 m and apparent dips of 50^o to 80^o both to the east and to the west, appear to be associated with the undulations in the Trenton and Black River strata. The transition from Potsdam-Theresa (Cambrian) to Precambrian is located at a two-way time of ~0.52 s (1275 m). The Cambrian thickness may vary locally from 25 m to 250 m.

Beneath the Paleozoic strata, the seismic sections (Figures 2b to 7b and 2c to 7c) show strong linear and arcuate reflector geometries interpreted as Precambrian basement that require further detailed comparison with those observed on Lithoprobe lines to the north (White et al, 1994, 2000) and beneath Lake Ontario (Forsyth et al, 1994). A change from easterly to westerly or northwesterly dips is indicated immediately below the Paleozoic strata near the centre of line 6 (Fig.3b,c). Four zones of reflectivity may be distinguished (Figures 2b to 7b and 2c to 7c). The first, extending from just below the Paleozoic to about 4.5 s, is characterized by strong linear and arcuate reflections, with both easterly and westerly apparent dips of 15–25^o. The second zone, from ~4.5 s to 9.2 s, is dominated by linear reflections with apparent easterly dips varying from 15 to 30^o. A third zone, from ~9.2 s to 18s, features mainly short linear horizontal reflections. The Moho transition at ~12-14 s beneath this part of the Niagara Peninsula defines the top of a zone of faint reflectivity interpreted as the mantle.

The Oak Ridges Moraine Profile

Line 4 forms a 75 km east-west transect near the crest of the Oak Ridges Moraine northeast of Toronto. The near surface section above about 0.3 seconds contains information from the moraine structure and the immediately underlying Paleozoic strata. This structure may only be outlined by further processing of the shallow data and integration with high-resolution local sections from other studies (Barnett et al., 1998, Pugin et al., 1999).

Beneath the Paleozoic strata, strong easterly dipping linear reflections, possibly related to the Central Metasedimentary Belt boundary zone, are succeeded and overlain to the east by more arcuate elements. This reflection geometry resembles the Grenville structure observed on Lithoprobe line 32 (White et al, 2000) and beneath Lake Ontario (Forsyth et al., 1994). In contrast to the increase in reflection strength observed at mid-crustal depths near 7 seconds on SOS lines 1 and 3 to the northwest (Figs 9b, 9c, 10b, 10c) an anomalous zone of much reduced reflectivity characterizes the western part of the section below about 6 seconds. Both dipping and subhorizontal reflections characterize the lower crust to near 13 seconds. Near the western edge of the section, local reflections with westerly apparent dips should be compared with analogous reflections seen on Lithoprobe line 32 to the northwest (White et al, 1994). The Moho transition may lie at ~13 seconds.

The Eastern Ontario Profiles

Lines 1 through 3 (Figs 8 through 10) traverse a part of the Central Metasedimentary Belt previously unmapped by seismic reflection surveys. Further detailed integration of the SOS lines with Lithoprobe profiles to the west (White et al., 1994, 2000) and beneath Lake Ontario (Forsyth et al, 1994) is required to construct a new crustal model for the Ontario part of the Central Metasedimentary Belt.

Lines 1 to 3 cross the northern flank of the Frontenac Axis and form a composite crustal transect from the Composite Arc Belt in the northwest to the Frontenac Terrane in the southeast. Exposures of Grenville rocks from beneath Quaternary cover occur regularly along line 1, whereas lines 2 and 3 are covered by an intermittent thin veneer of lowermost Paleozoic strata. Special processing of portions of the near surface sections may help characterize the Paleozoic-Precambrian unconformity and the location of Terrane boundaries. There are presently no well log data along the profile to provide an effective calibration of the sedimentary section.

Structurally, lines 1 to 3 cross both boundaries of the Composite Arc Belt boundary zone between the Composite Arc Belt and the Frontenac Terrane (Easton, 1999; Ouassaa and Forsyth, 2002) as well as several local faults identified from geological maps of the survey route.

Linear magnetic anomalies and bedrock mapping (Easton, 2001abc) indicate profiles 1 through 3 provide a key central structural calibration for the various Central Metasedimentary Belt domains extending from lakes Ontario and Erie to western Quebec.

Line 1: The seismic section (Fig. 8b, 8c) shows strong linear and arcuate Precambrian basement reflectors that dip generally southeast. This reflectivity patterns marks the transition from Composite Arc Belt to Composite Arc Belt boundary zone and indicate finer deformational features within the regional domains. On the northern part of the section, the linear and arcuate structures with apparent dips of 15-20^{o} extend from the surface to about 7 seconds or near 20 km depth. These are succeeded to the southeast by strong linear and arcuate reflections with steeper dips characterizing the Composite Arc boundary zone. Truncations of arcuate structures are suggested. Beginning at about 7 seconds, the crust is characterized by stronger, more horizontal reflections extending to the reflection Moho at ~12 seconds or 40 km depth.

Line 2: Fig. 9b and 9c maps the transition from the linear elements of the eastern edge of the Composite Arc Belt boundary zone to the more gently dipping but complex geometry of the Frontenac Terrane. The mid-crustal change to increased reflectivity near 7 seconds as observed on line 1 is not as evident. The decreased reflectivity at a Moho depth travel time of ~12 seconds resembles line 01.

Line 3: The complex pattern of easterly dipping reflections representing the upper crust of Frontenac Terrane continues on line 3 (Fig. 10b, 10c). The mid-crust between about 7 and 9 seconds features an increase to stronger sub-horizontal reflections analogous to profile 1. Similar reflection attitudes characterize weaker reflections from the lower crust that extend to ~15 seconds.

The southeast apparent dips on lines 1 to 3 that strike northwest combined with easterly apparent dips on earlier Lithoprobe lines indicate the true regional dip of eastern Ontario Central Metasedimentary Belt structure is southeast. The above patterns of reflections require further study and integration with those observed both on adjacent lines and earlier Lithoprobe lines from the Central Metasedimentary Belt, as well as geological and tectonic information.

Summary and Conclusions

This report presents an outline of the 2000 SOS survey and a preliminary look at the first crustal seismic images from eastern Ontario and the Niagara Peninsula. The seismic sections document Paleozoic thickness, structural features and Precambrian basement elements that form new contributions to the structural framework beneath southern Ontario. The clear reflective geometry of the basement elements on profiles 1 to 3 provide the basis for a new tectonic interpretation from a comparative analysis with existing Lithoprobe seismic sections, mapped geology and magnetic data. The apparent deformational feature observed east of the intersection of lines 6 and 7 (Fig. 3d, Station Number 1750) appears to be a rare seismic example of a structural change in the relatively undisturbed Paleozoic strata of southern Ontario. Additional aspects of this feature, its relationship to the underlying Precambrian basement and its association with the west side of the Niagara escarpment are all topics for future study.

The interesting change from easterly to west or northwesterly dips near the center of line 6 may indicate a change from the predominantly easterly dipping fabric of the Central Metasedimentary Belt to a domain associated more with the Central Gneiss Belt exposed to the north.

The interpretation of all the SOS data will be integrated with previous Lithoprobe seismic results and available geological and geophysical information to form a new structural framework for the crust underlying southern Ontario.

Acknowledgements

Administration of the survey was conducted by LITHOPROBE to augment and extend the Lithoprobe Abitibi-Grenville transect. 35 southern Ontario municipalities and the gas distribution industry provided cooperative support for the survey and funding provided by Ontario Power Generation and Talisman Resources. Scientific supervision of the survey was provided by the Geological Survey of Canada and the University of Western Ontario. The field program only succeeded as a result of the very positive collaboration of all the following individuals and organizations. Harold Asmis and Clive Alexander (Ontario Power Generation), Ron Clowes, Andrew Nikiforuk (Lithoprobe Secretariat), Timo Von Rudloff, Lynne Davies (Talisman Energy), Dave Eaton, Dave Markus, Charley Murphy, Melissa Burdan (University of Western Ontario), Jean-Claude Paradis, Gervais Perron, Brian Roberts (Natural Resources Canada), Dale Harrison, Darryl Armstrong and field crew (Kinetex Inc.), Matai Surveys, Ontario Ministry of Transport, Enbridge Consumers Gas, Union Gas and countless gracious landowners along the route.

Profiles 1, 2, 3	***Profiles 5, 6, 7, 8, 9***
- Township of Admaston / Bromley - Township of Bagot, Blythfield & Brougham - County of Renfrew - Canadian Pacific Railway - Municipal Office of Lanark Highlands - County of Lanark - City of Ottawa - Kitley Township Roads Department - United Counties of Leeds and Grenville - Township of Elizabethtown	-Six Nations Public Works -Six Nations Natural Gas -Region of Haldimand Norfolk -City of Nanticoke -Town of Haldimand -Delhi Public Works -CGC Inc., Hagersville -Township of Wainfleet -Port Colborne Public Works -Regional Municipality of Niagara -Fort Erie Public Works -Town of Dunnville

Profile 4
- Township of Scugog - Uxbridge Township - Whitby Engineering Services - Pickering Municipal Property and Engineering - Town of Oshawa - Region of Durham Works Department - Regional Municipality of York - Town of Whitchurch Stouffville - County of Peterborough - Municipality of Clarington - Township of Cavan, Millbrook, North Monaghan - Township of Otonabee-South Monaghan - Township of Manvers

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Table 1: SOS Data acquisition parameters

Field Crew	Kinetex Inc.
Date	May-June 2000
Client	Geological Survey of Canada
Instrument type	I/O System 2000
Trace/Record	963
Record Length	46 seconds
Sample rate	4 milliseconds
Filter	¾ Nyquist
Fold (% CDP)	6000%
Nominal Vibroseis Source Parameters	
Source array	4 Vibrators in-line
Pattern length	120 meters
VP interval	100 meters
Sweep length	28 seconds
Sweep type	Linear
Sweep frequency	~ 8-87 Hz
Nominal Receiver Array Parameters	
Group. Interval	12.5 meters (lines 5-7) 25.0 meters (lines 1-4, 8 and 9)
Geophone/Group.	9 geophones

Table 2: Processing Sequences

A-Prestack Processing :

Brute Stack and Parameter tests

- Demultiplex: IEEE SEG D 86360 bpi produced by Kintex Inc. to Promax format.
- Crooked line Geometry application, first break picking and trace editing.
- Elevation static correction: final datum elevation 200 m, 2000 m/s replacement velocity.
- Select deconvolution, filtering and scaling.
- Velocity Analysis: Semblance and constant velocity stack.
- Stack.
- Migration Parameters Tests: Phase Shift time migration, Kirchhoff time and depth Migration.

Signal Enhancement (SOS 5 to 9):

- Minimum Phase Spiking Deconvolution (operator length : 80 ms, white noise: 1%, window: (Offset: 0 m : 100-800 ms, Offset: 1200 m :300-800 ms).
- Ormsby Band Pass Filter 15-20-70-80 Hz, with NOTCH Filter Frequency at 60 Hz.
- 2D Weighted Median Filter (1,1,1; 1,2,1; 1,1,1), with linear Move out Velocity of 1800 m/s).
- Time-Invariant Spectral Balancing (15-20-70-80 Hz , 4 panels).

- 2D Weighted Median Filter (1,1,1; 1,2,1; 1,1,1), with linear Move out Velocity of 1800 m/s).
- Automatic Gain Control (AGC), with 250 ms operator length.

Signal Enhancement (SOS 1 to 4):

- Minimum Phase Spiking Deconvolution (operator length : 80 ms, white noise: 1%, window: (Offset: 0 m : 100-800 msecondes, Offset: 1200 m :300-800 ms).
- Ormsby Band Pass Filter 15-20-70-80 Hz, with NOTCH Filter Frequency at 60 Hz.
- Time-Invariant Spectral Balancing (15-20-70-80 Hz , 4 panels).
- Automatic Gain Control (AGC), with 250 ms operator length.

Final stack:

- Signal Enhancement data input.
- Normal Move out Correction, with stretched mute tolerance of 30%.
- Weighted Stack
- Automatic Gain Control (AGC), with 250 ms operator length.

B-Poststack Processing

Time Migrated Seismic Section:

- Kirchhoff time migration with the same RMS velocity used for the Stack.
- Automatic Gain Control (AGC) with 800 ms operator length.

Depth Migrated Seismic Section:

- Convert RMS Velocity to smoothed velocity interval
- Kirchhoff depth migration (75 Hz maximum frequency).
- Automatic Gain Control (AGC) with 250 ms operator length.

Crustal Scale Seismic plots:

- Stacked or Migrated seismic section
- Coherency Filter (semblance smooth (59, 59)).
- 5 trace mixing (1,1,1,1,1) for lines 5 to 7.
- 3 trace mixing (1,1, 1) for lines 1 – 4, 8 and 9.
- Plot threshold; data values below 1.5 RMS are set to zero print plotting

Figures Captions:

Figure 1: Regional tectonic setting and locations of seismic profiles (SOS survey, Lithoprobe, NYSGS-V9 and Great Lakes Surveys). The symbols show the location of earthquake monitoring networks (POLARIS and University of Western Ontario).

Figure 2a: Survey line and slalom line used for crooked line processing of SOS Line 5. The shot station ID is increasing from blue to red color.

Figure 2b: Stack seismic section (distance, Two-Way time) for SOS line 5.

Figure 2c: Time migrated seismic section (distance, Two-Way time) for SOS line 5.

Figure 2d: Enlarged portion of Time migrated seismic section (distance, Two-way time) for the Paleozoic-Precambrian part of SOS Line 5.

Figure 3a: Survey line and slalom line used for crooked line processing of SOS Line 6. The shot station ID is increasing from blue to red color.

Figure 3b: Stack seismic section (distance, Two-Way time) for SOS line 6.

Figure 3c: Time migrated seismic section (distance, Two-Way time) for SOS line 6.

Figure 3d: Enlarged portion of Time migrated seismic section (distance, Two-way time) for the Paleozoic-Precambrian part of SOS Line 6.

Figure 4a: Survey line and slalom line used for crooked line processing of SOS Line 7. The shot station ID is increasing from blue to red color.

Figure 4b: Stack seismic section (distance, Two-Way time) for SOS line 7.

Figure 4c: Time migrated seismic section (distance, Two-Way time) for SOS line 7.

Figure 4d: Enlarged portion of Time migrated seismic section (distance, Two-way time) for the Paleozoic-Precambrian part of SOS Line 7.

Figure 5a: Survey line and slalom line used for crooked line processing of SOS Line 8. The shot station ID is increasing from blue to red color.

Figure 5b: Stack seismic section (distance, Two-Way time) for SOS line 8.

Figure 5c: Time migrated seismic section (distance, Two-Way time) for SOS line 8.

Figure 5d: Enlarged portion of Time migrated seismic section (distance, Two-way time) for the Paleozoic-Precambrian part of SOS Line 8.

Figure 6a: Survey line and slalom line used for crooked line processing of SOS Line 9. The shot station ID is increasing from blue to red color.

Figure 6b: Stack seismic section (distance, Two-Way time) for SOS line 9.

Figure 6c: Time migrated seismic section (distance, Two-Way time) for SOS line 9.

Figure 6d: Enlarged portion of Time migrated seismic section (distance, Two-way time) for the Paleozoic-Precambrian part of SOS Line 9.

Figure 7a: Survey line and slalom line used for crooked line processing of SOS Line 4. The shot station ID is increasing from blue to red color.

Figure 7b: Stack seismic section (distance, Two-Way time) for SOS line 4.

Figure 7c: Time migrated seismic section (distance, Two-Way time) for SOS line 4.

Figure 7d: Enlarged portion of Time migrated seismic section (distance, Two-way time) for the Paleozoic-Precambrian part of SOS Line 4.

Figure 8a: Survey line and slalom line used for crooked line processing of SOS Line 1. The shot station ID is increasing from blue to red color.

Figure 8b: Stack seismic section (distance, Two-Way time) for SOS line 1.

Figure 8c: Time migrated seismic section (distance, Two-Way time) for SOS line 1.

Figure 8d: Enlarged portion of Time migrated seismic section (distance, Two-way time) for the Paleozoic-Precambrian part of SOS Line 1.

Figure 9a: Survey line and slalom line used for crooked line processing of SOS Line 2. The shot station ID is increasing from blue to red color.

Figure 9b: Stack seismic section (distance, Two-Way time) for SOS line 2.

Figure 9c: Time migrated seismic section (distance, Two-Way time) for SOS line 2.

Figure 9d: Enlarged portion of Time migrated seismic section (distance, Two-way time) for the Paleozoic-Precambrian part of SOS Line 2.

Figure 10a: Survey line and slalom line used for crooked line processing of SOS Line 3. The shot station ID is increasing from blue to red color.

Figure 10b: Stack seismic section (distance, Two-Way time) for SOS line 3.

Figure 10c: Time migrated seismic section (distance, Two-Way time) for SOS line 3.

Figure 10d: Enlarged portion of Time migrated seismic section (distance, Two-way time) for the Paleozoic-Precambrian part of SOS Line 3.

Reflection seismic surveys in the southern Ontario area

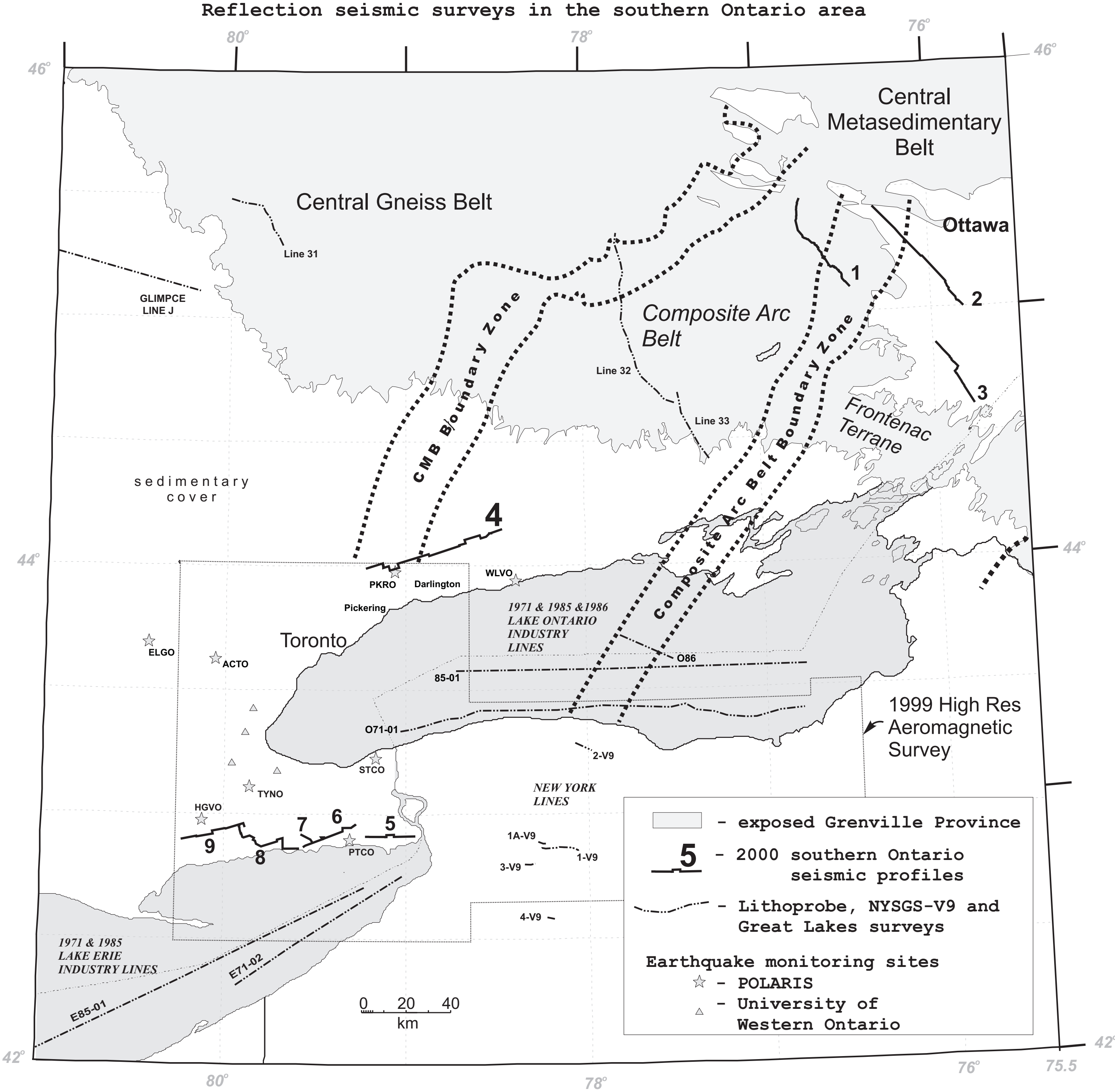


Figure 1.: Regional tectonic setting and locations of seismic profiles (SOS survey, Lithoprobe, NYSGS-V9 and Great Lakes Surveys). The symbols show the location of earthquake monitoring networks (POLARIS and University of Western Ontario).

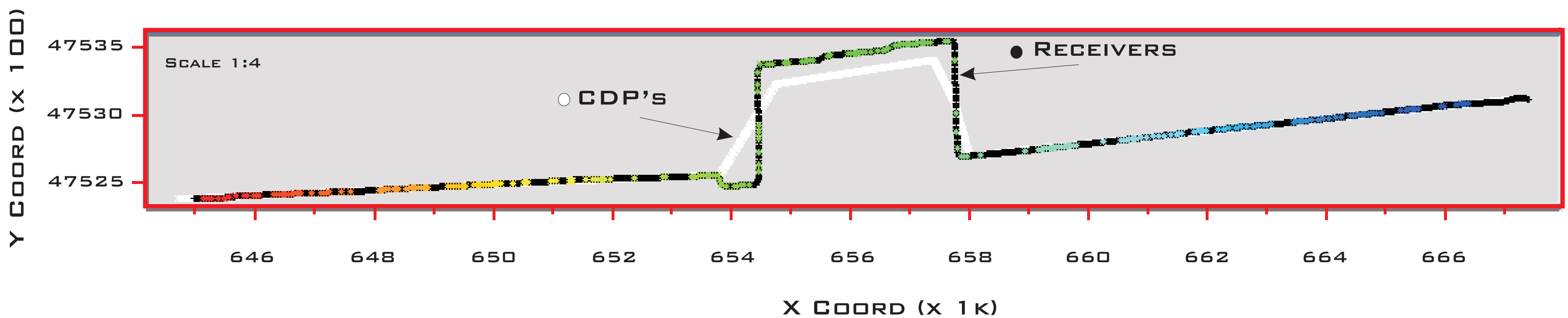


Figure 2a: Survey line and slalom line used for crooked line processing of SOS Line 5. The shot station ID is increasing from blue to red color.

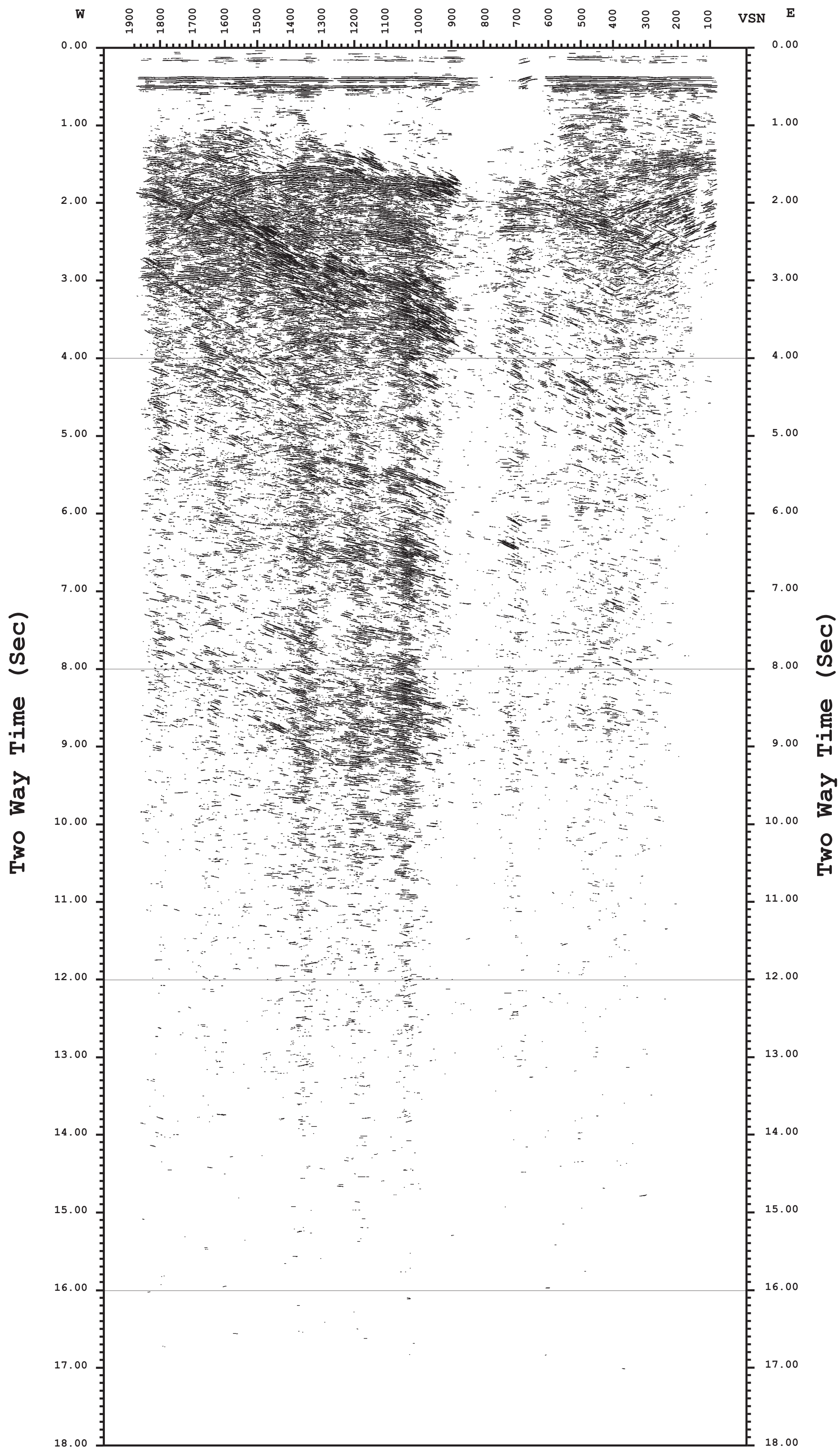


Figure 2b: Stack seismic section (distance, Two-way time) for SOS line 5.

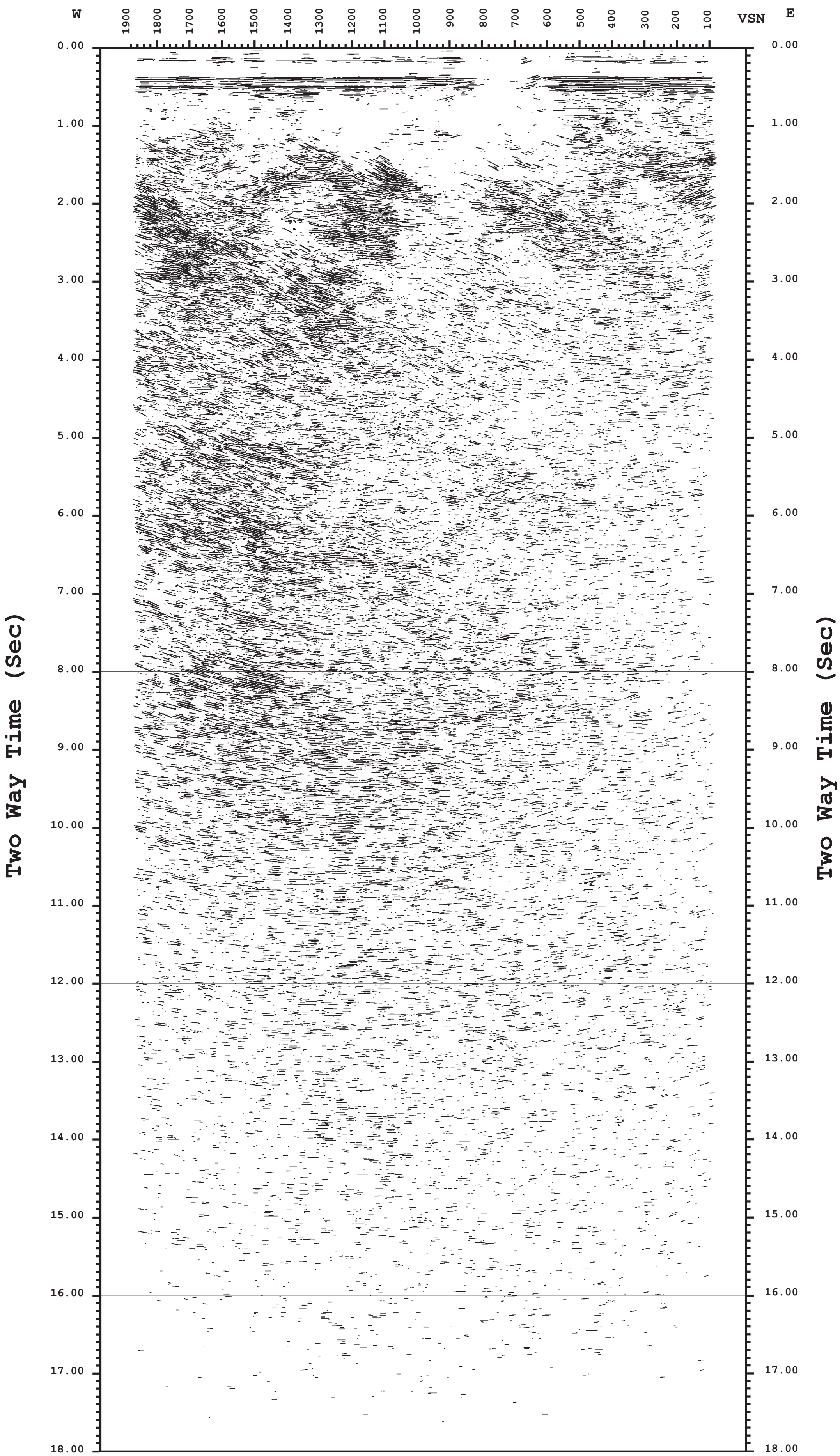


Figure 2c: Time migrated seismic section (distance, Two-way time) for SOS line 5.

Figure 2d: SOS 5

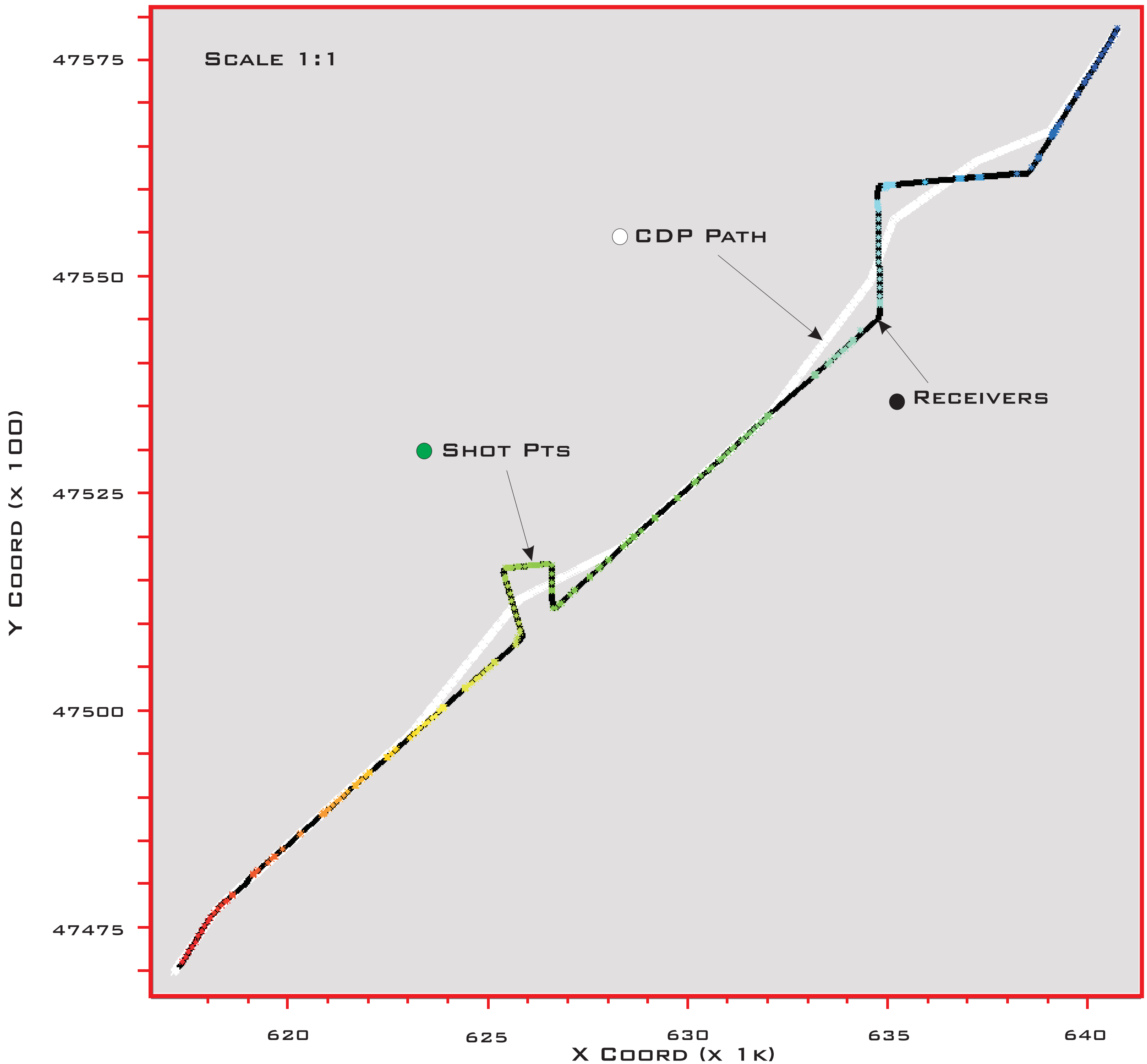


Figure 3a: Survey line and slalom line used for crooked line processing of SOS Line 6. The shot station ID is increasing from blue to red color.

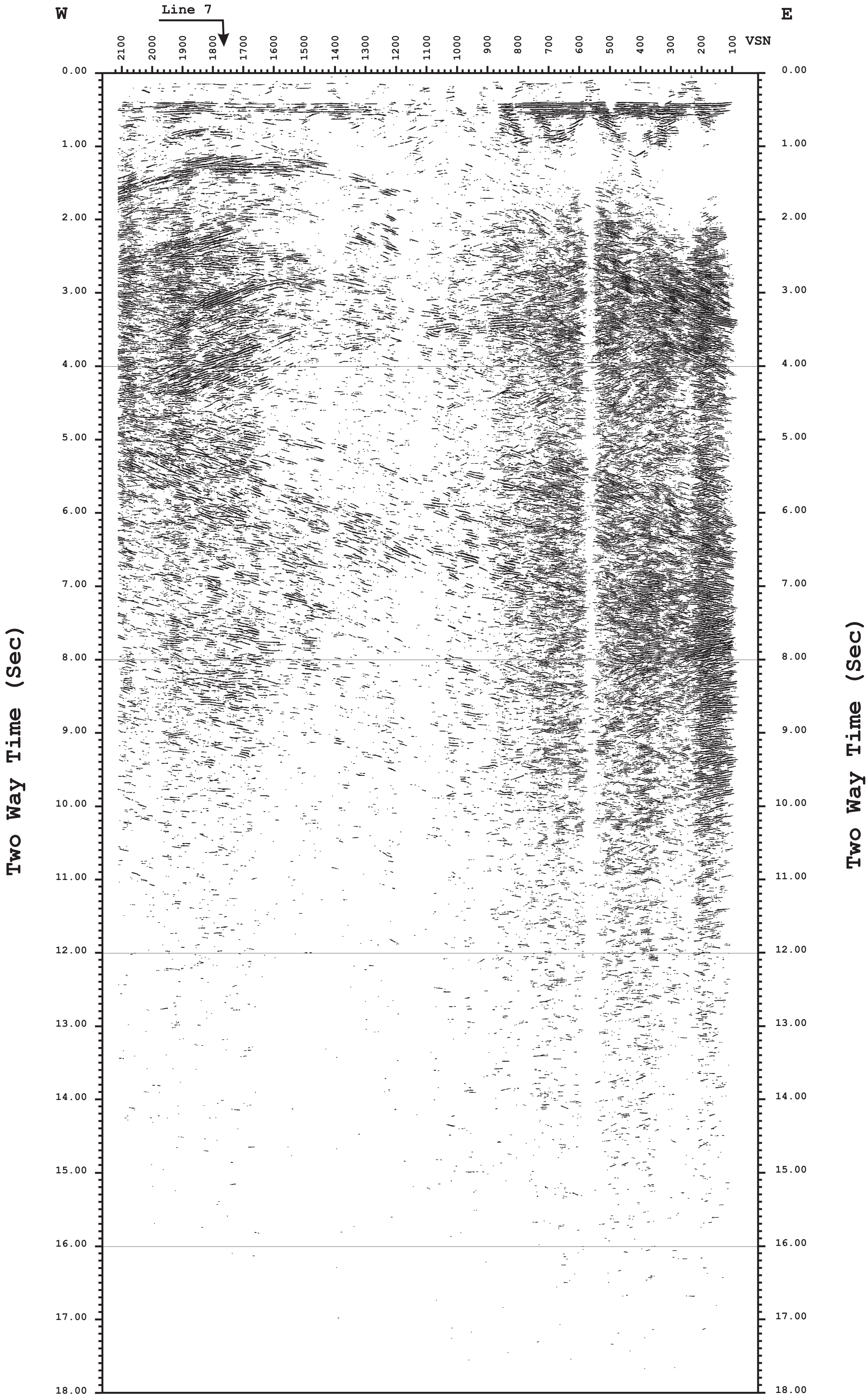


Figure 3b: Stack seismic section (distance, Two-way time) for SOS line 6.

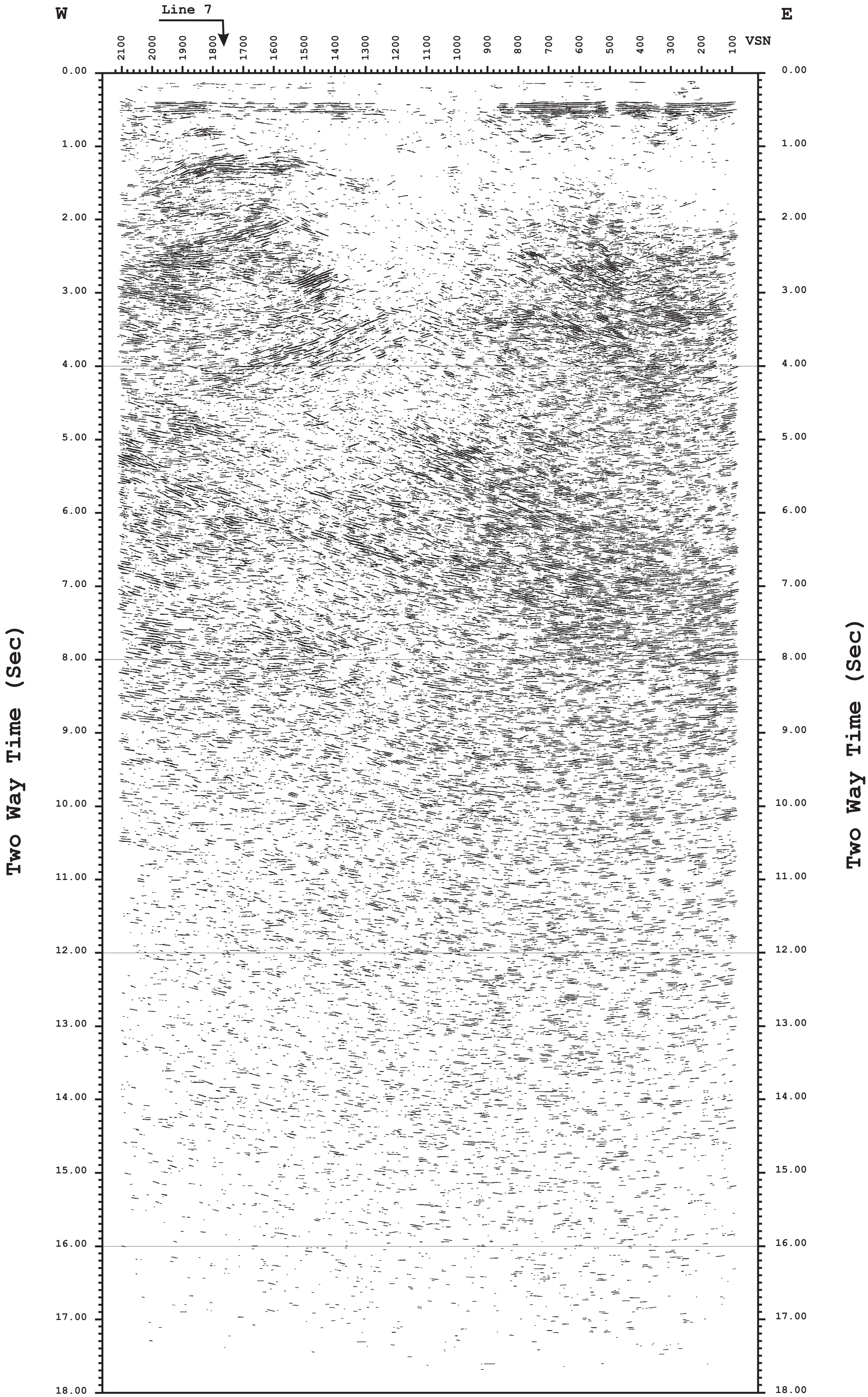


Figure 3c: Time migrated seismic section (distance, Two-way time) for SOS line 6.

Figure 3d: SOS 6

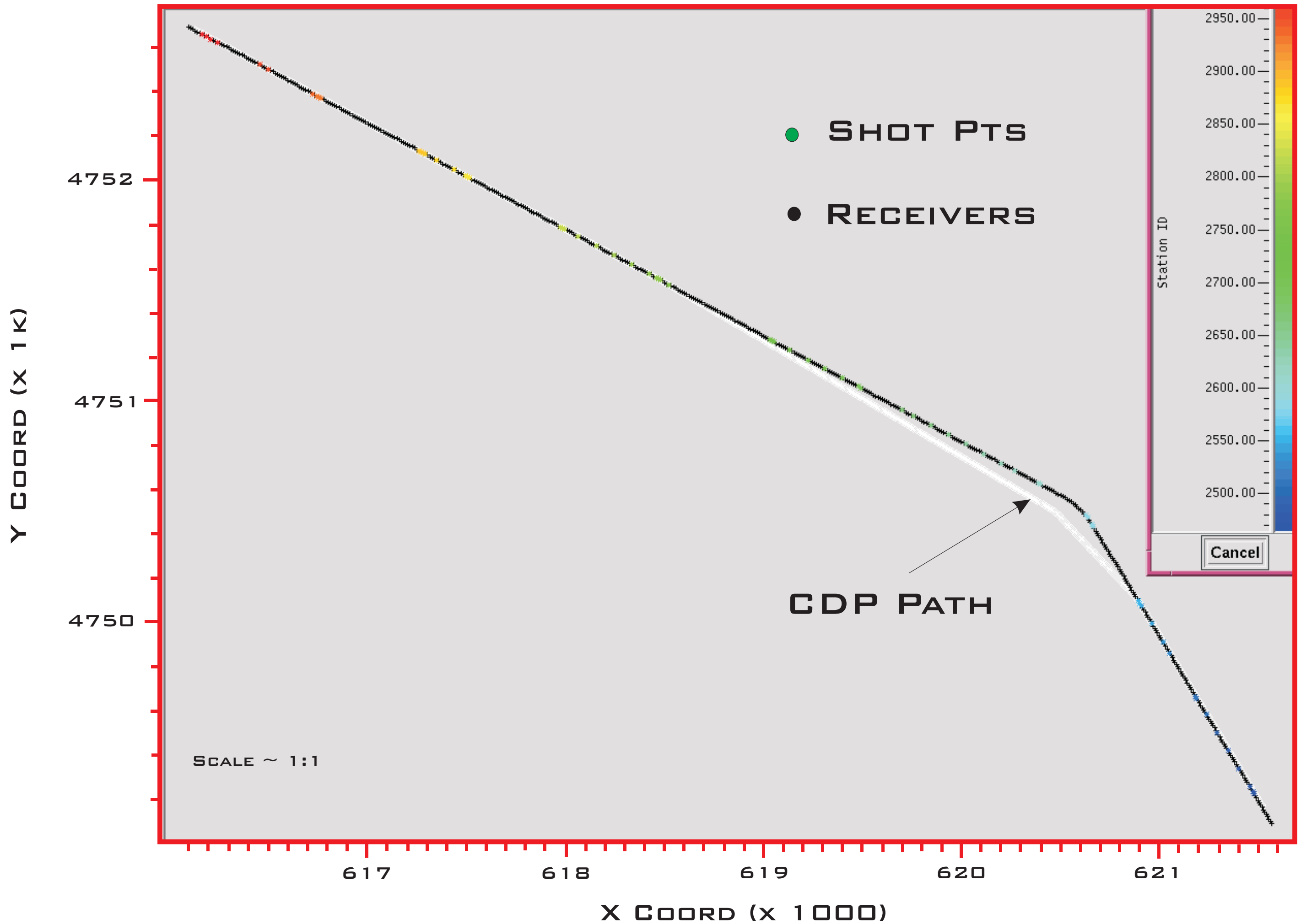


Figure 4a: Survey line and slalom line used for crooked line processing of SOS Line 7. The shot station ID is increasing from blue to red color.

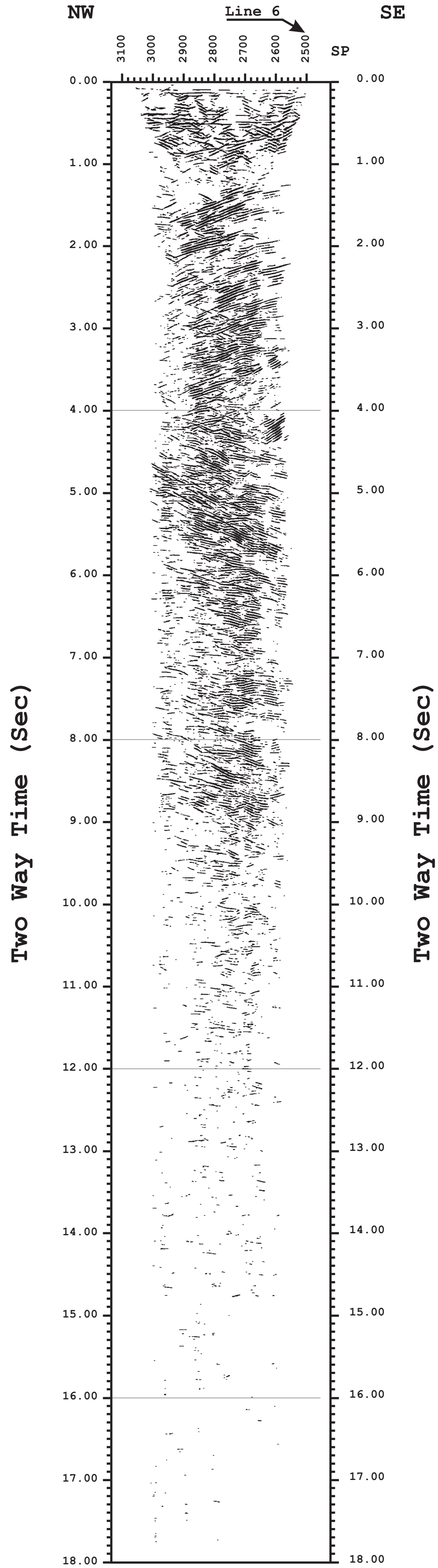


Figure 4b: Stack seismic section (distance, Two-way time) for SOS line 7.

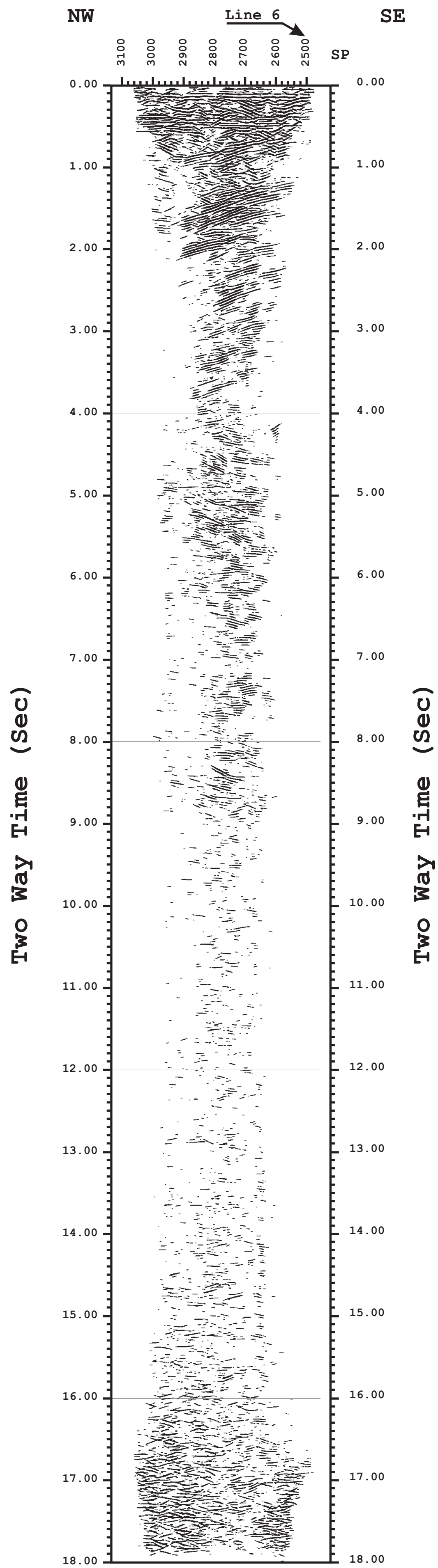
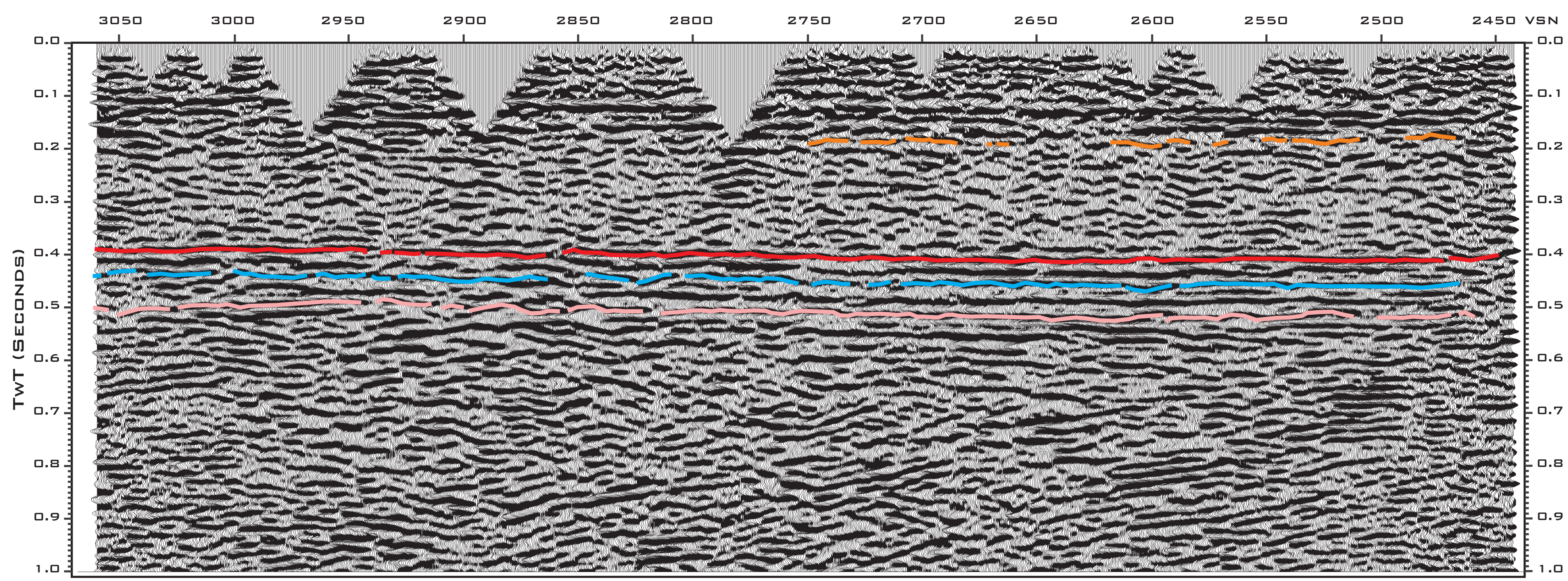


Figure 4c: Time migrated seismic section (distance, Two-way time) for SOS line 7.

Figure 4d: SOS 7



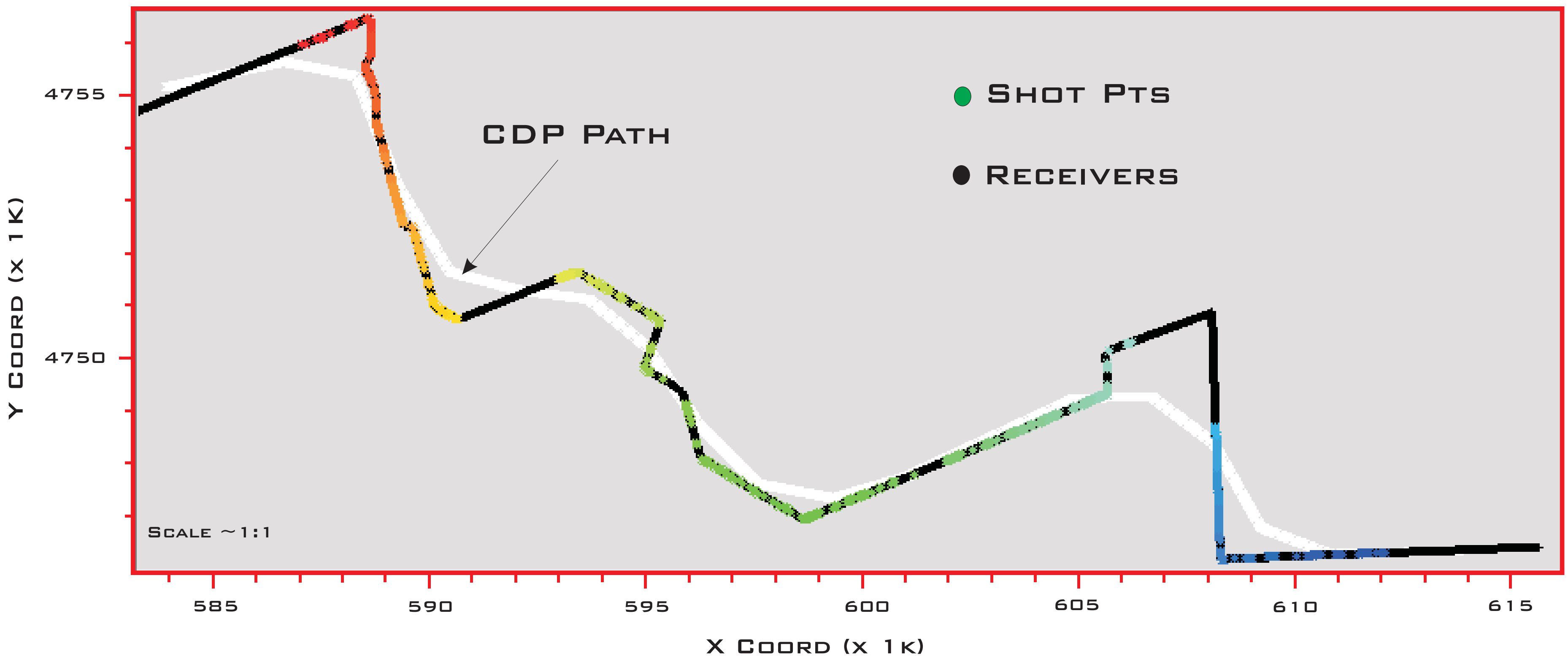


Figure 5a: Survey line and slalom line used for crooked line processing of SOS Line 8. The shot station ID is increasing from blue to red color.

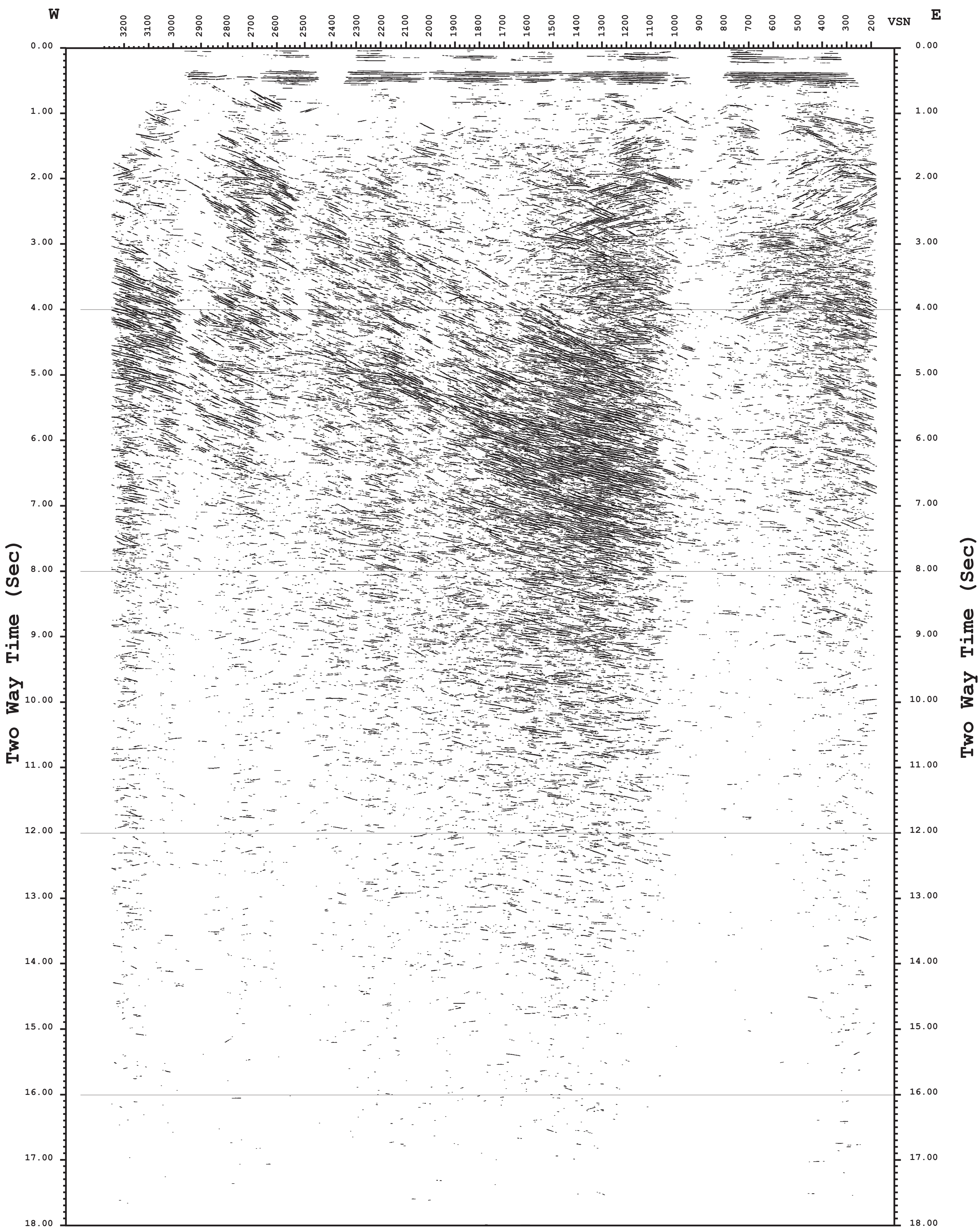


Figure 5b: Stack seismic section (distance, Two-way time) for SOS line 8.

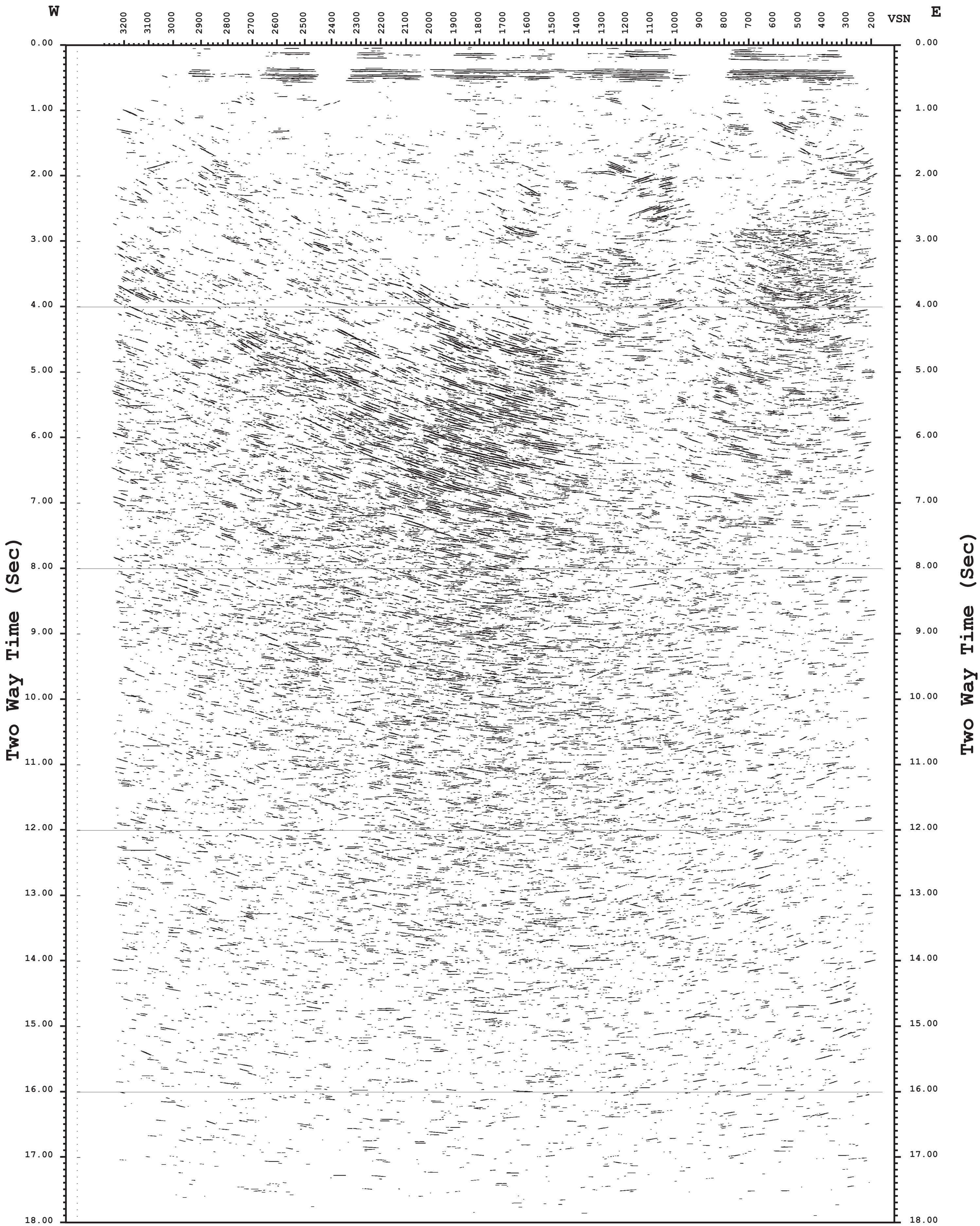
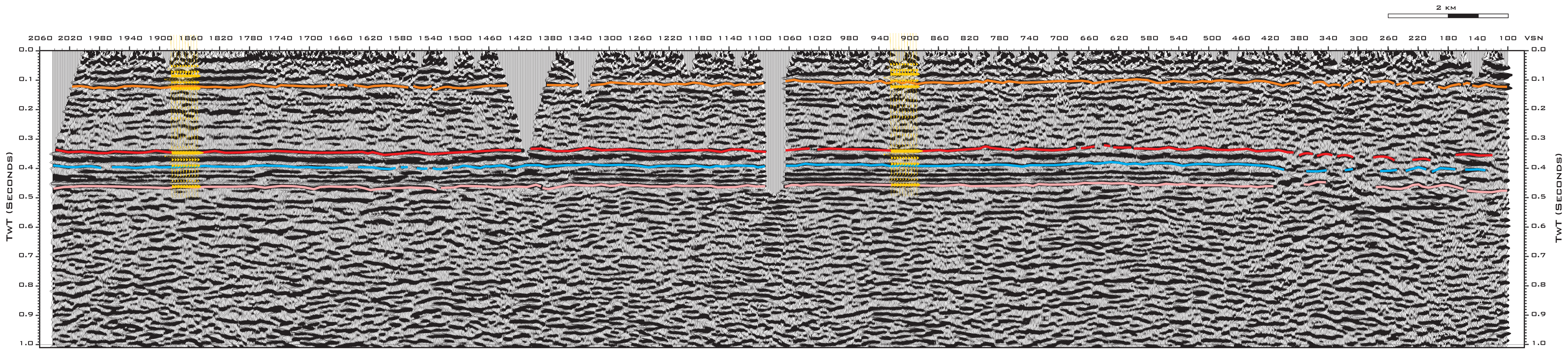


Figure 5c: Time migrated seismic section (distance, Two-way time) for SOS line 8.

Figure 5d: SOS 8



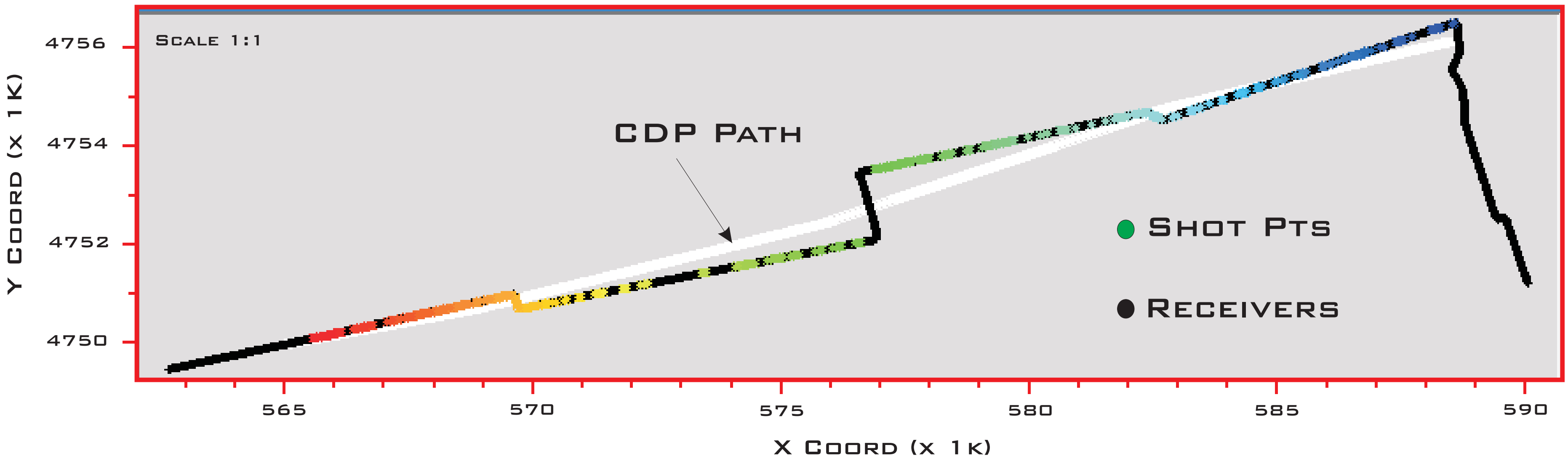


Figure 6a: Survey line and slalom line used for crooked line processing of SOS Line 9. The shot station ID is increasing from blue to red color.

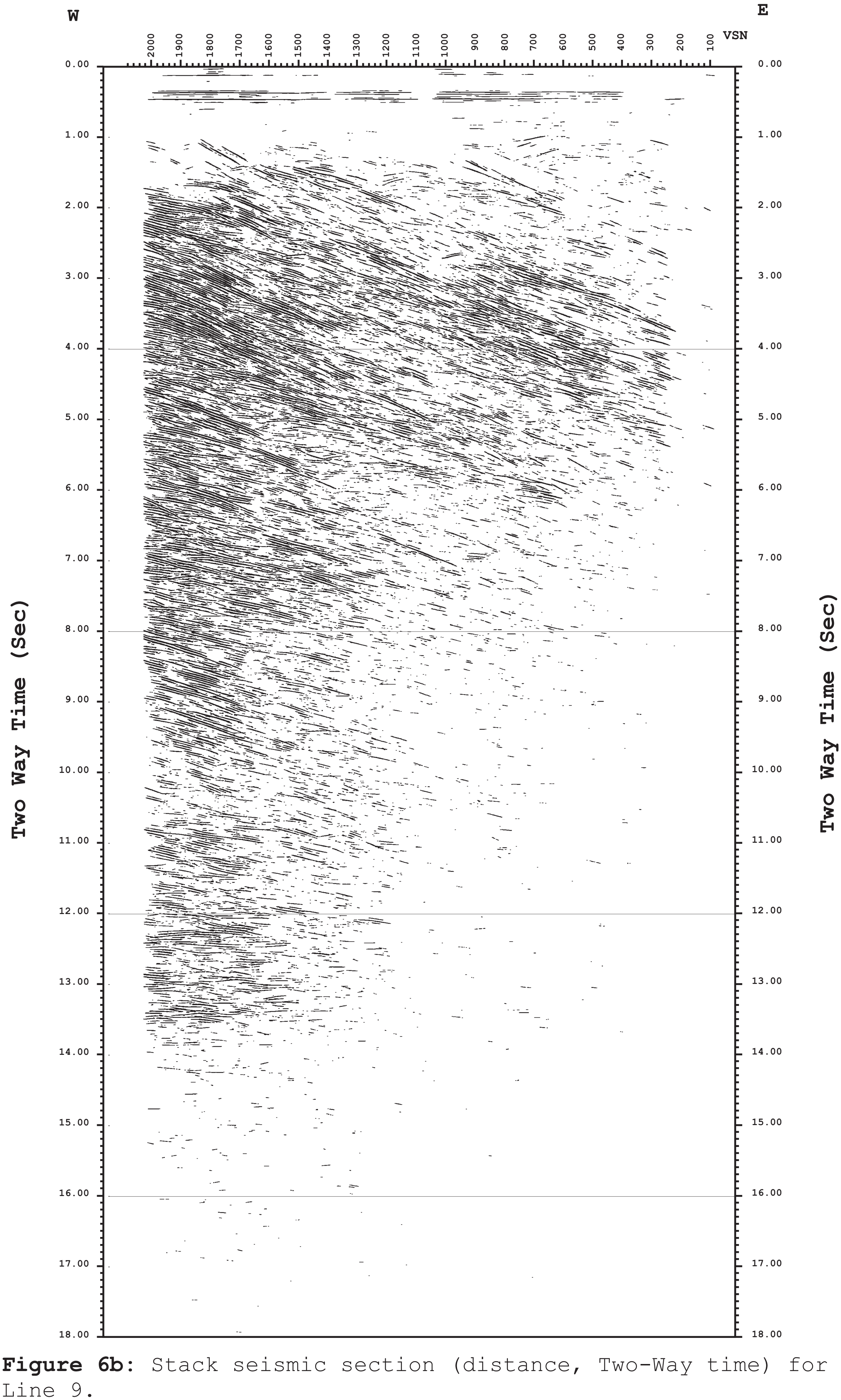


Figure 6b: Stack seismic section (distance, Two-Way time) for SOS Line 9.

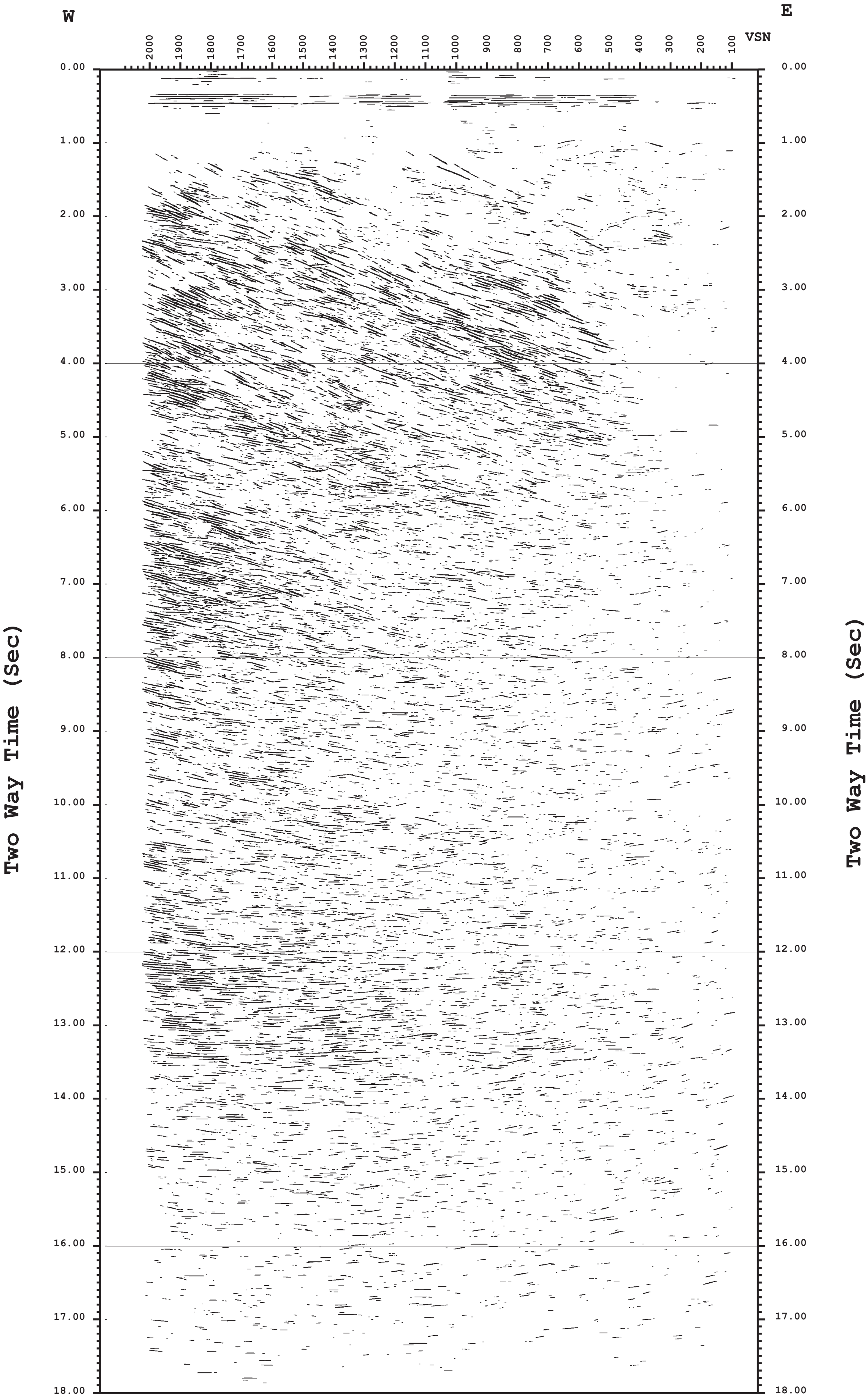
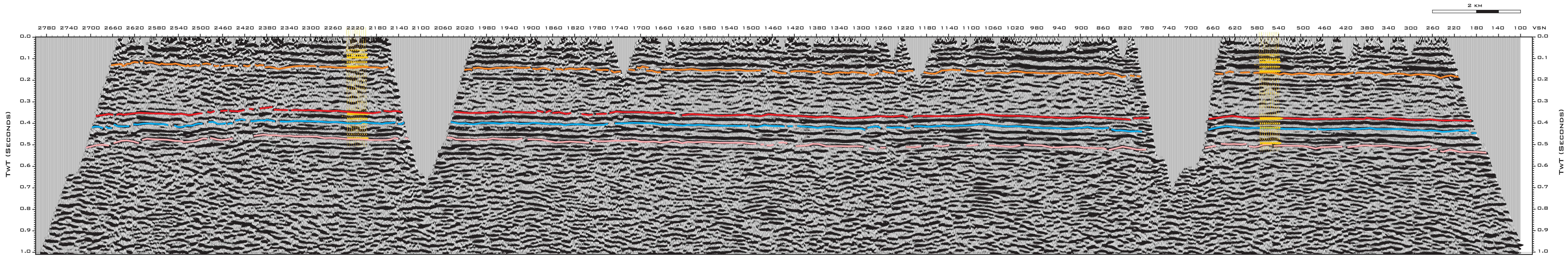


Figure 6c: Time migrated seismic section (distance, Two-Way time) for SOS Line 9.

Figure 6d: SOS 9



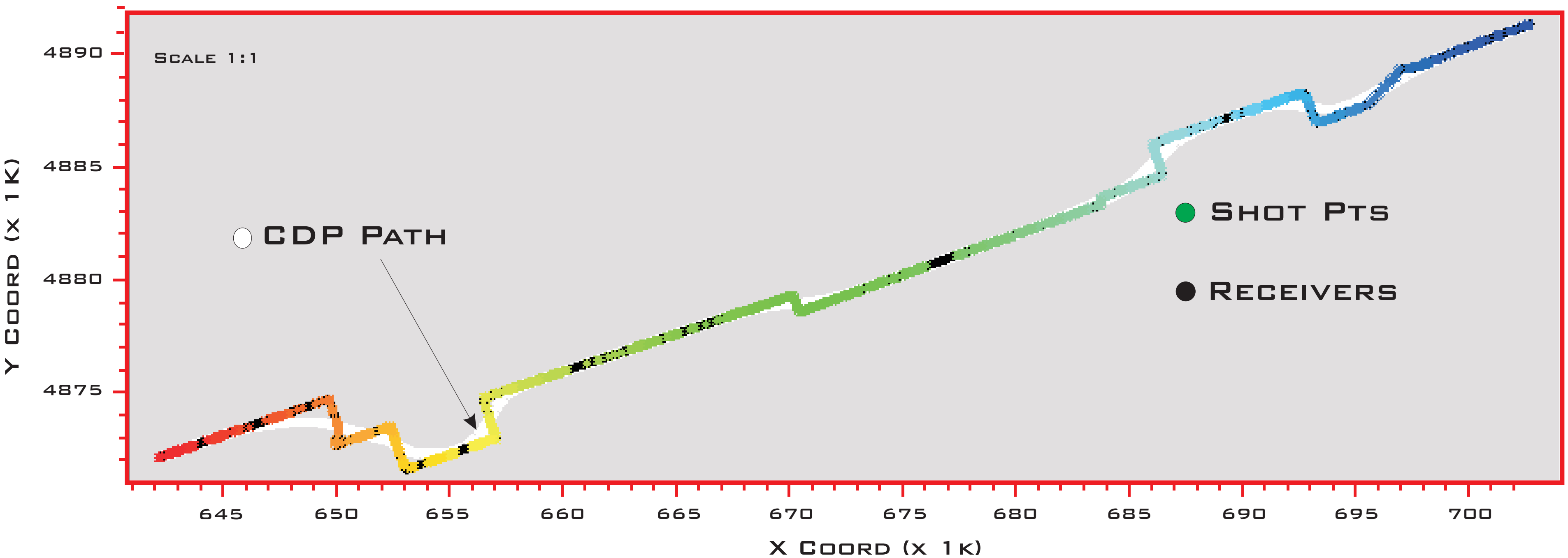


Figure 7a: Survey line and slalom line used for crooked line processing of SOS Line 4. The shot station ID is increasing from blue to red color.

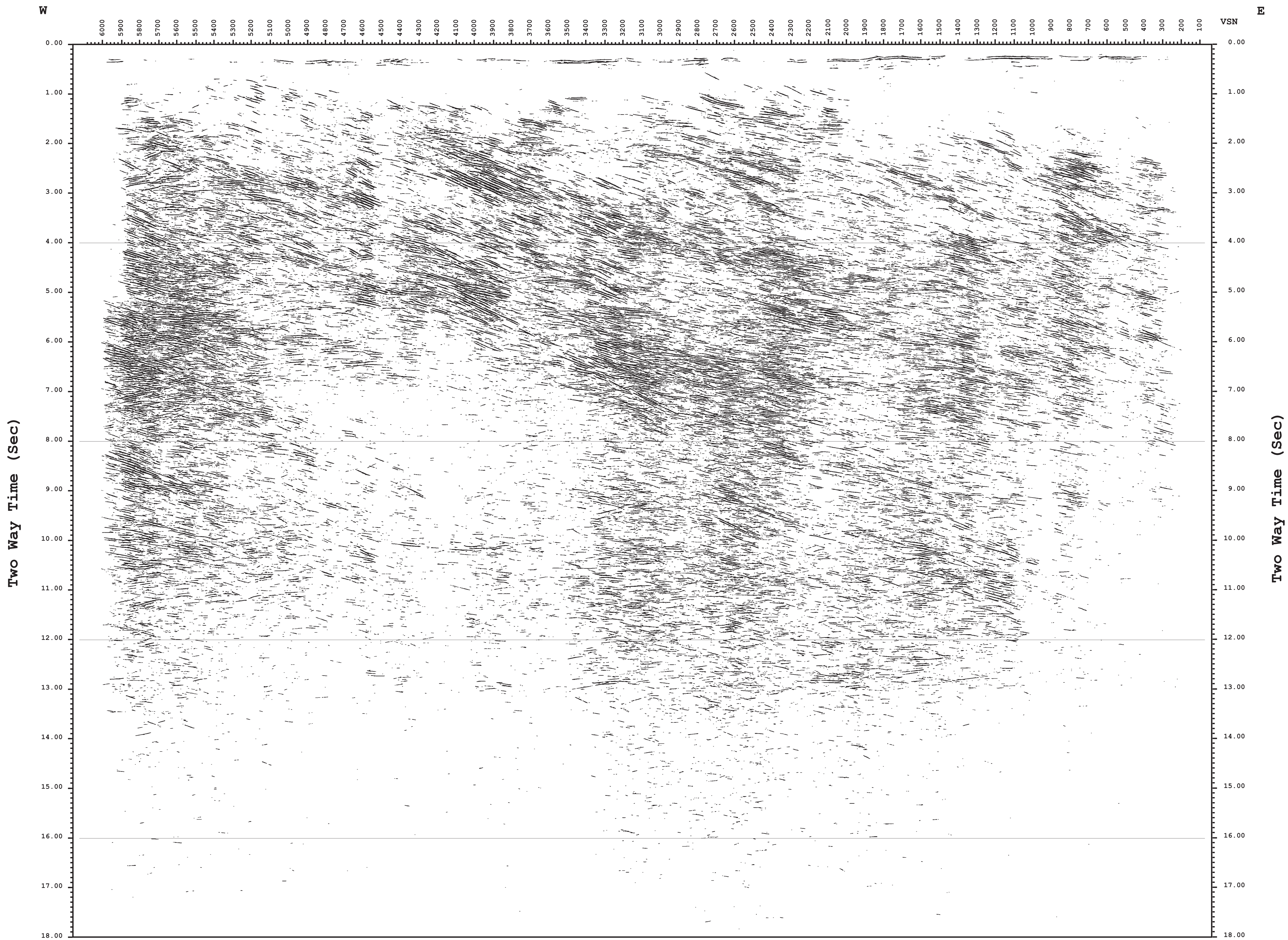


Figure 7b: Stack seismic section (distance, Two-way time) for SOS line 4.

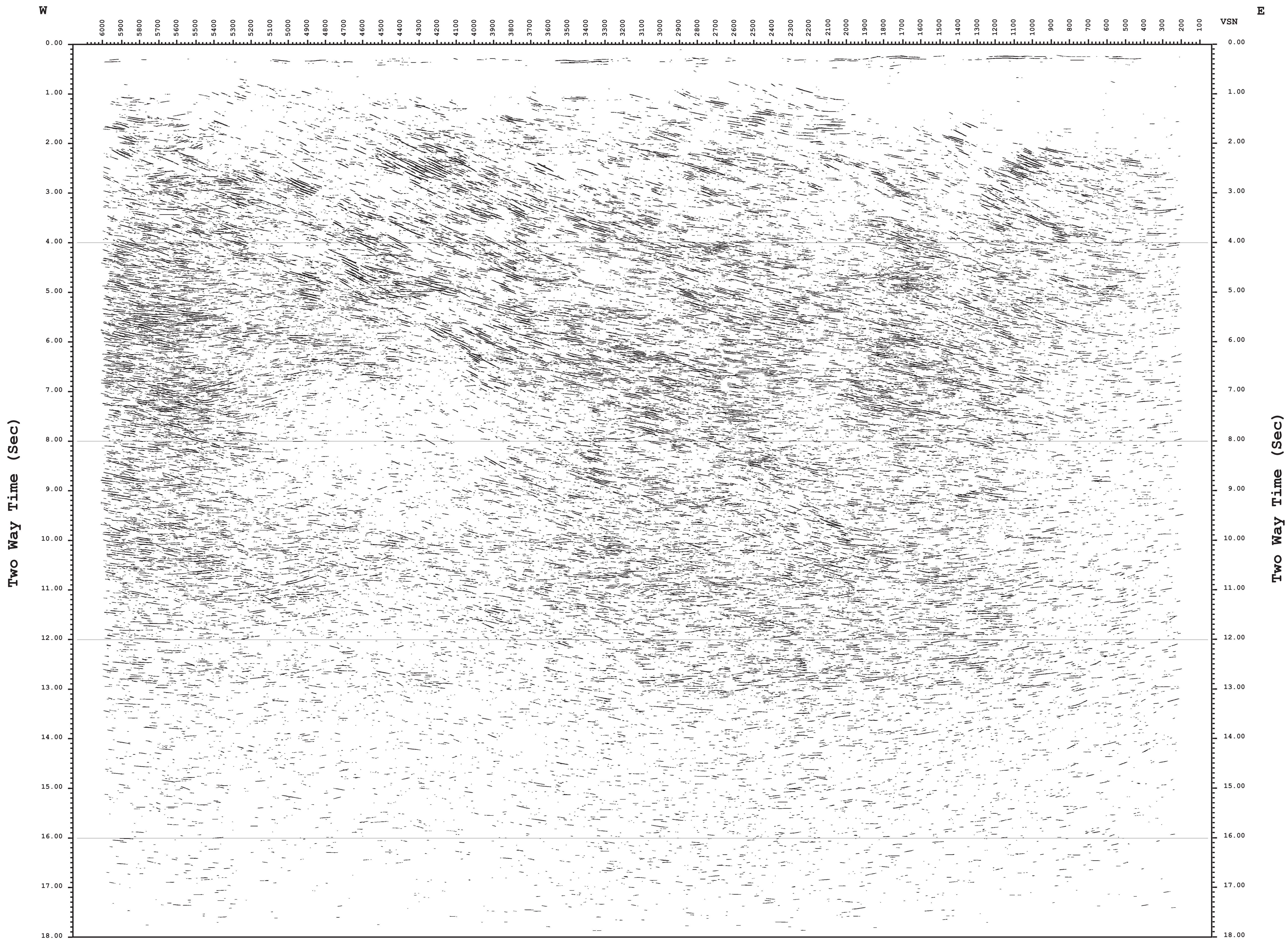


Figure 7c: Time migrated seismic section (distance, Two-way time) for SOS line 4.

Figure 7d: SOS 4

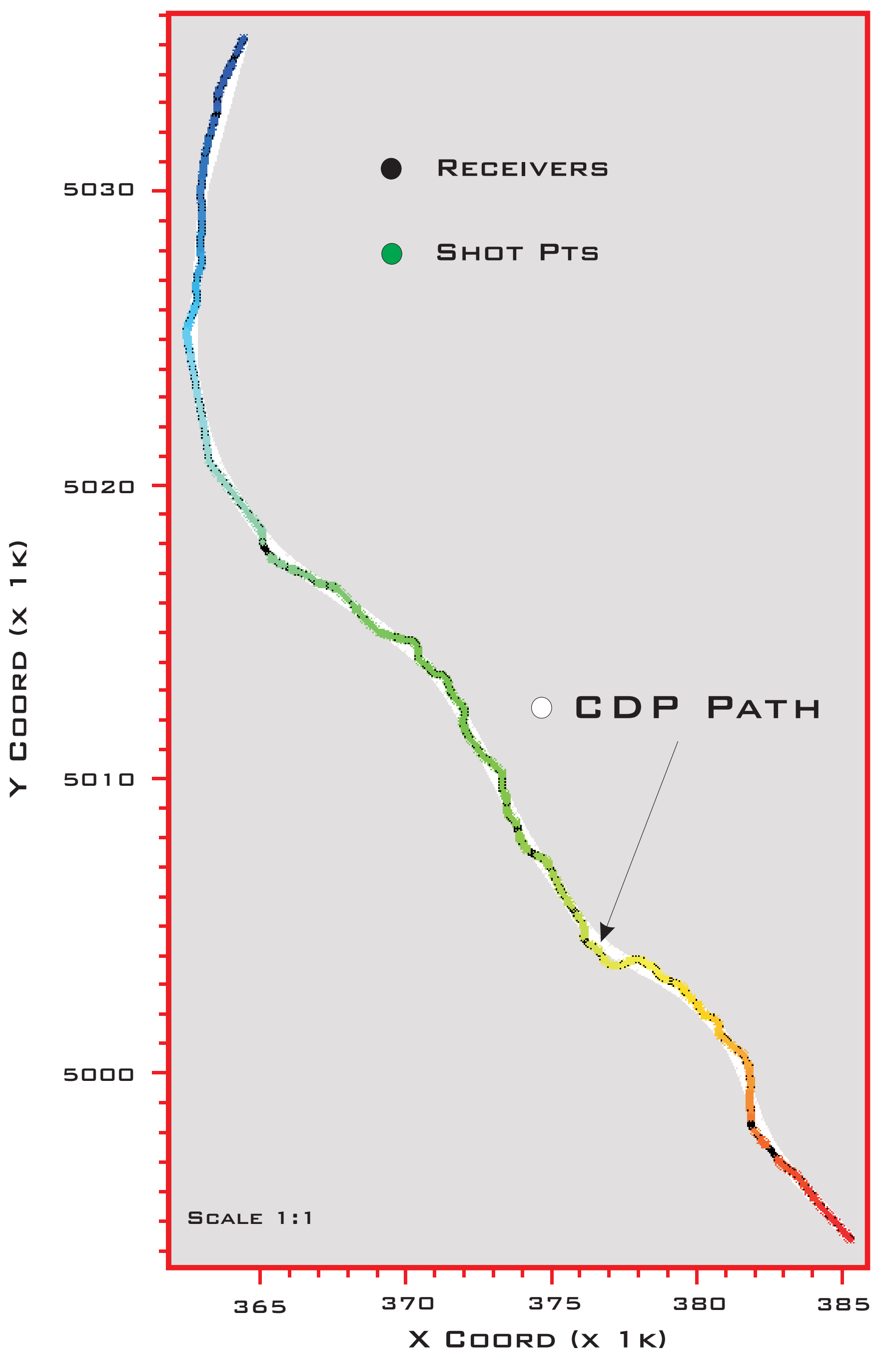


Figure 8a: Survey line and slalom line used for crooked line processing of SOS Line 1. The shot station ID is increasing from blue to red color.

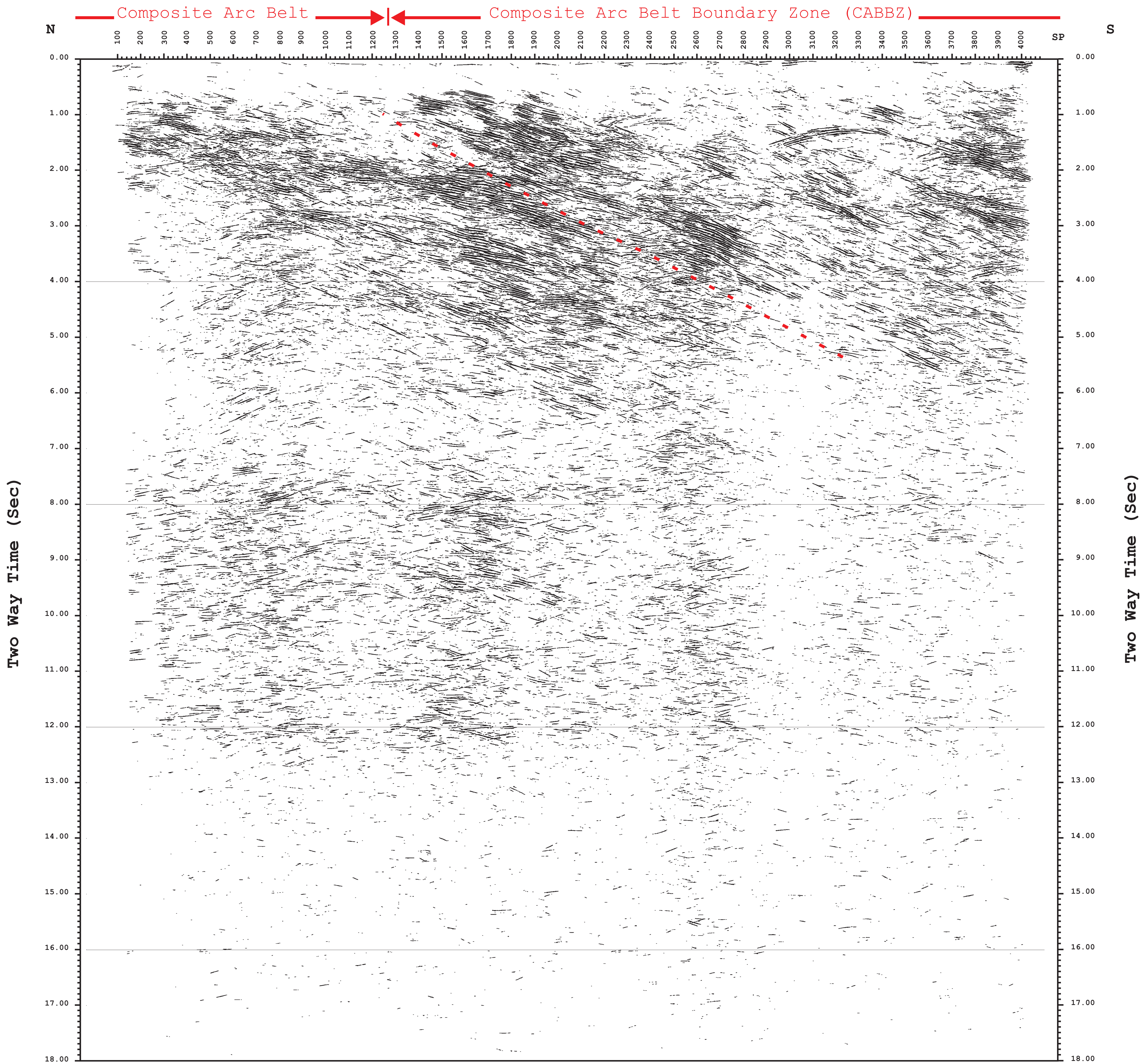


Figure 8b: Stack seismic section (distance, Two-way time) for SOS line 1.

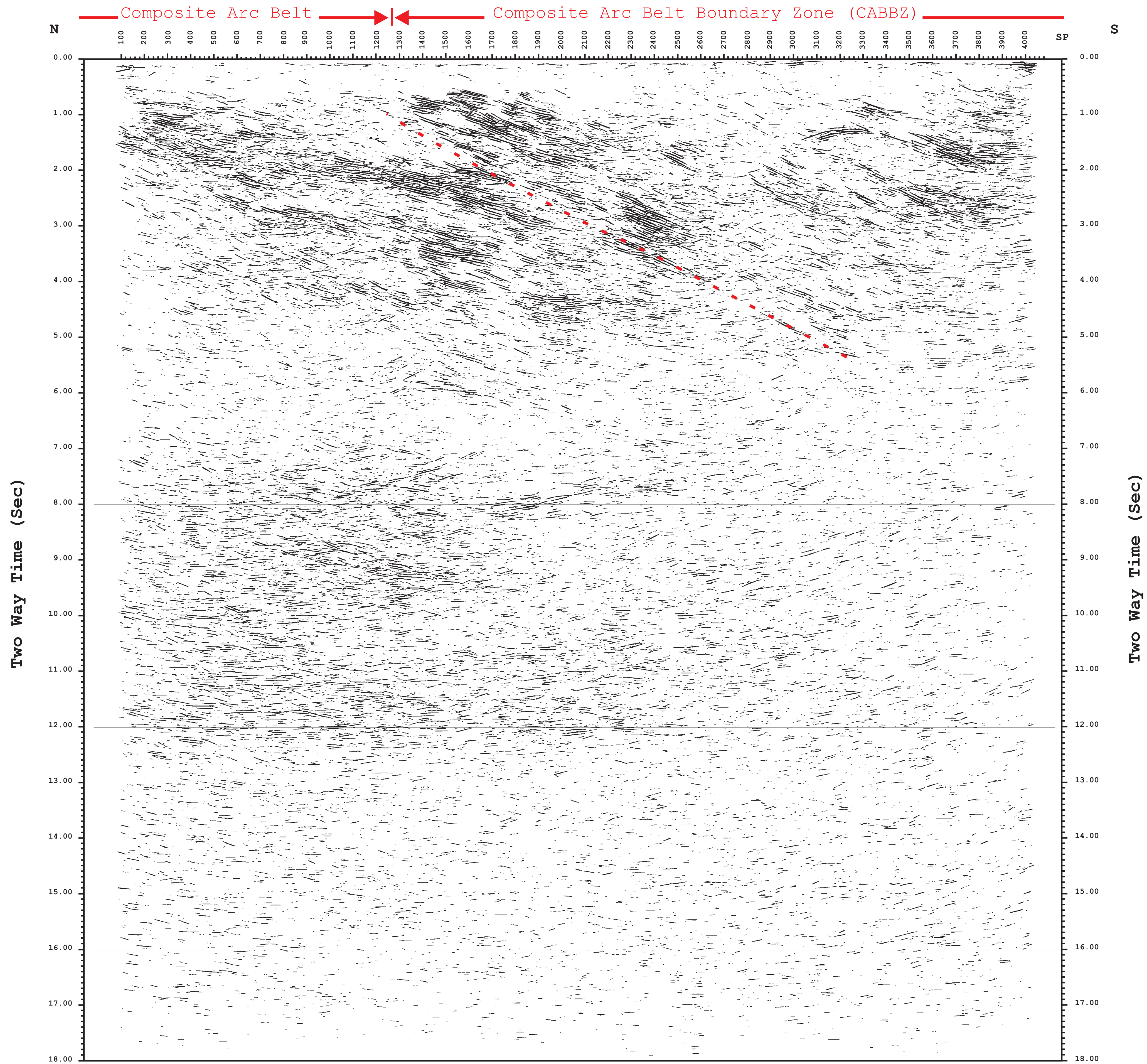


Figure 8c: Time migrated seismic section (distance, Two-way time) for SOS line 1.

Figure 8d: SOS 1

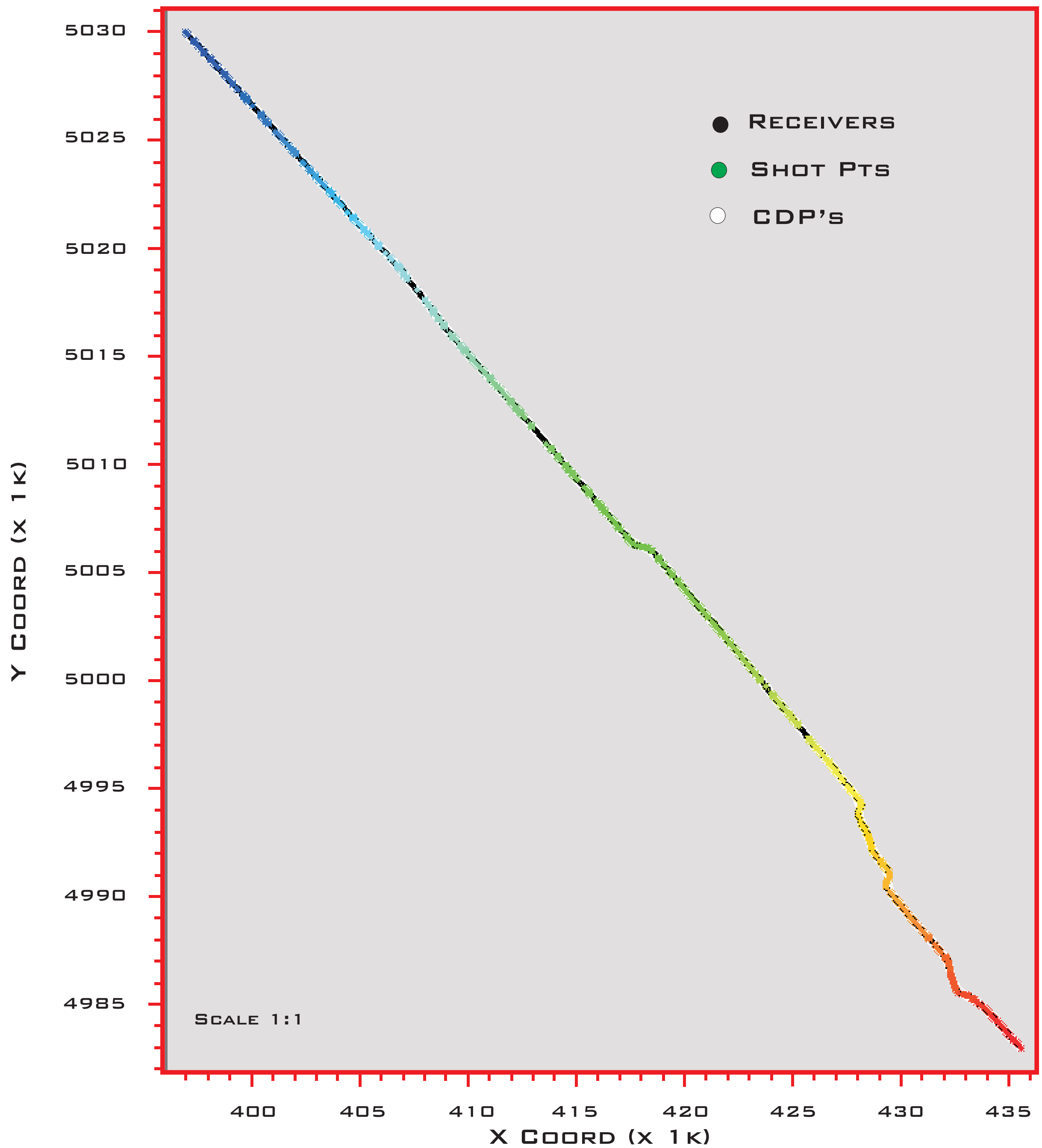


Figure 9a: Survey line and slalom line used for crooked line processing of SOS Line 2. The shot station ID is increasing from blue to red color.

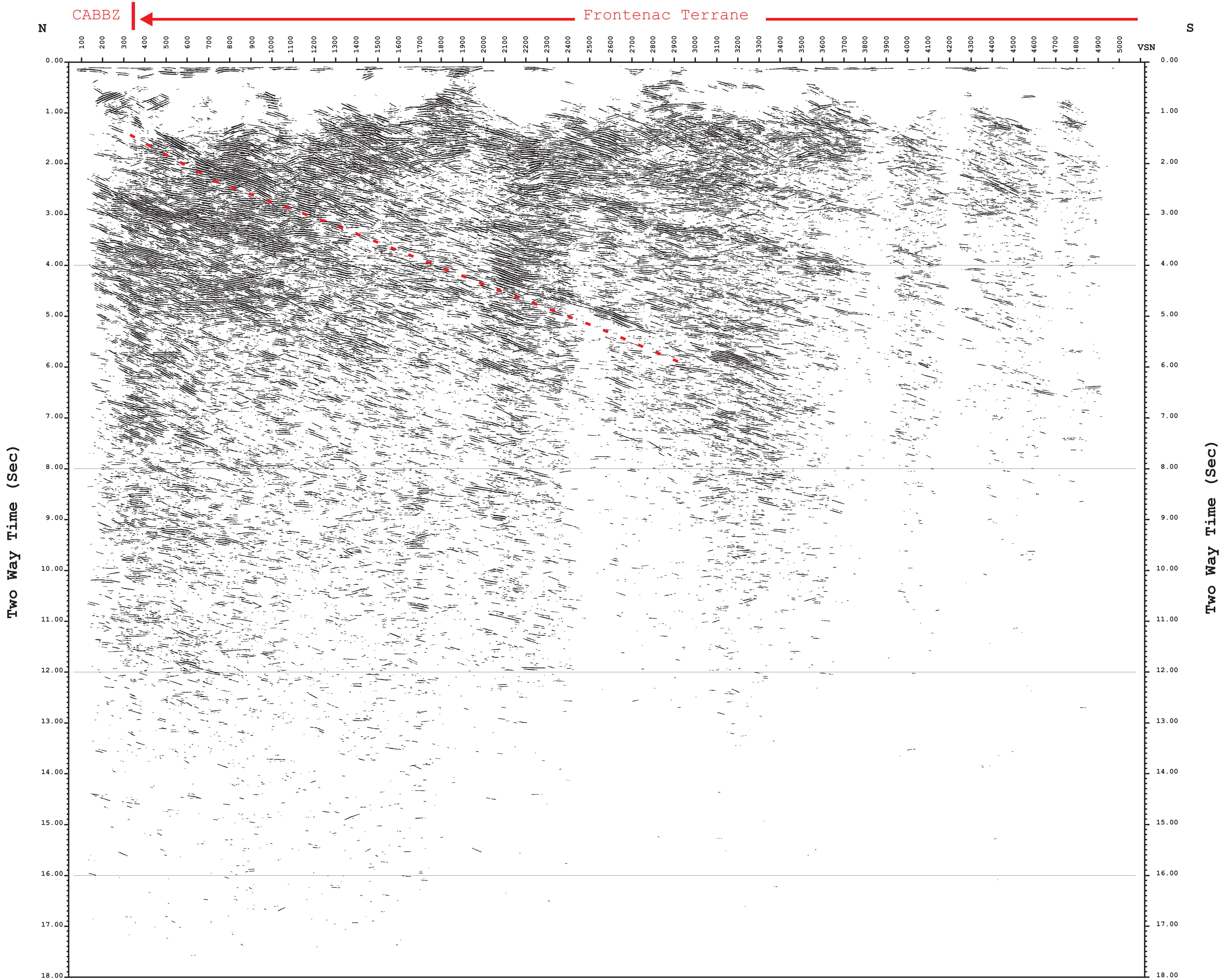


Figure 9b: Stack seismic section (distance, Two-way time) for SOS line 2.

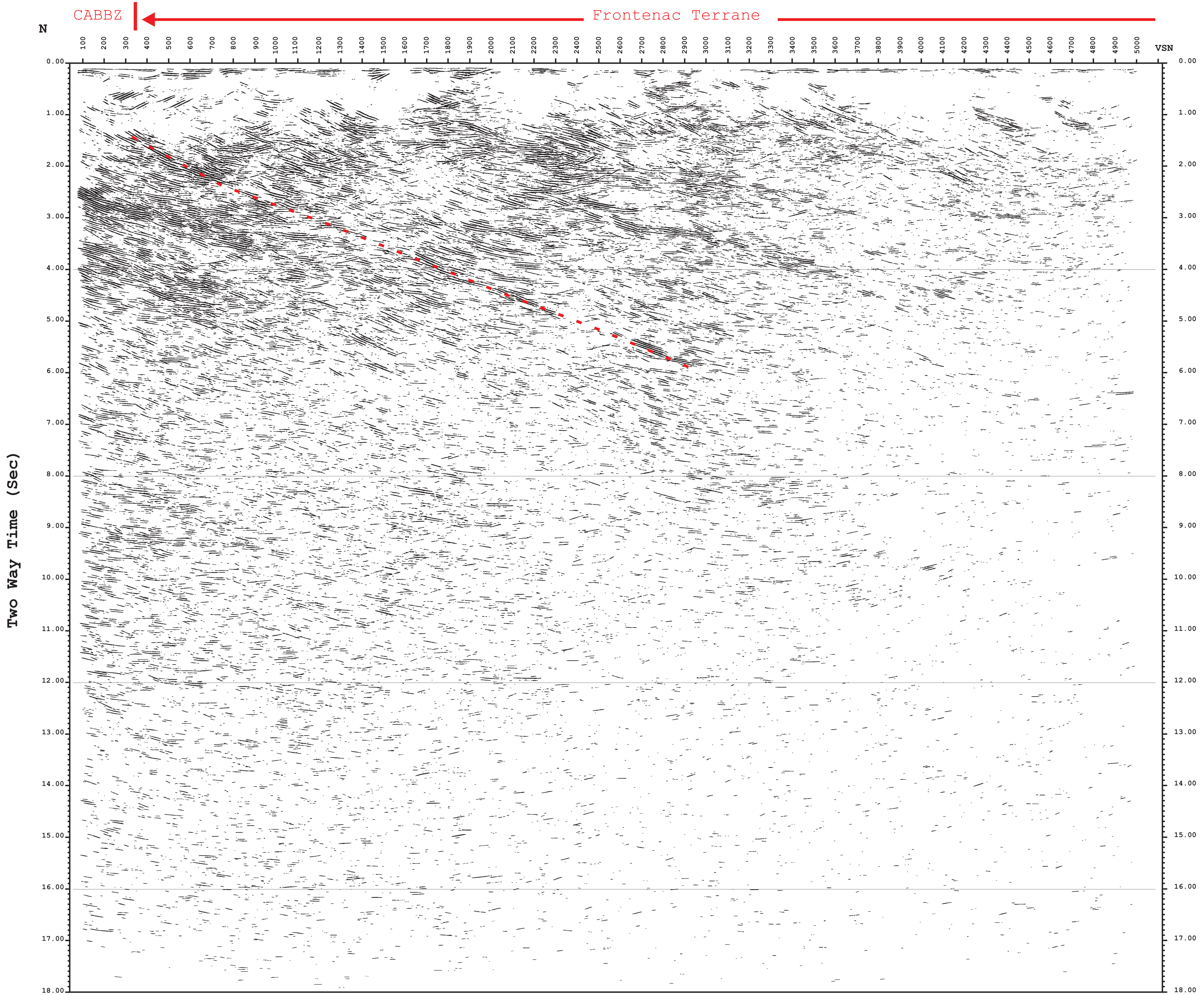


Figure 9c: Time migrated seismic section (distance, Two-way time) for SOS line 2.

Figure 9d: SOS 2

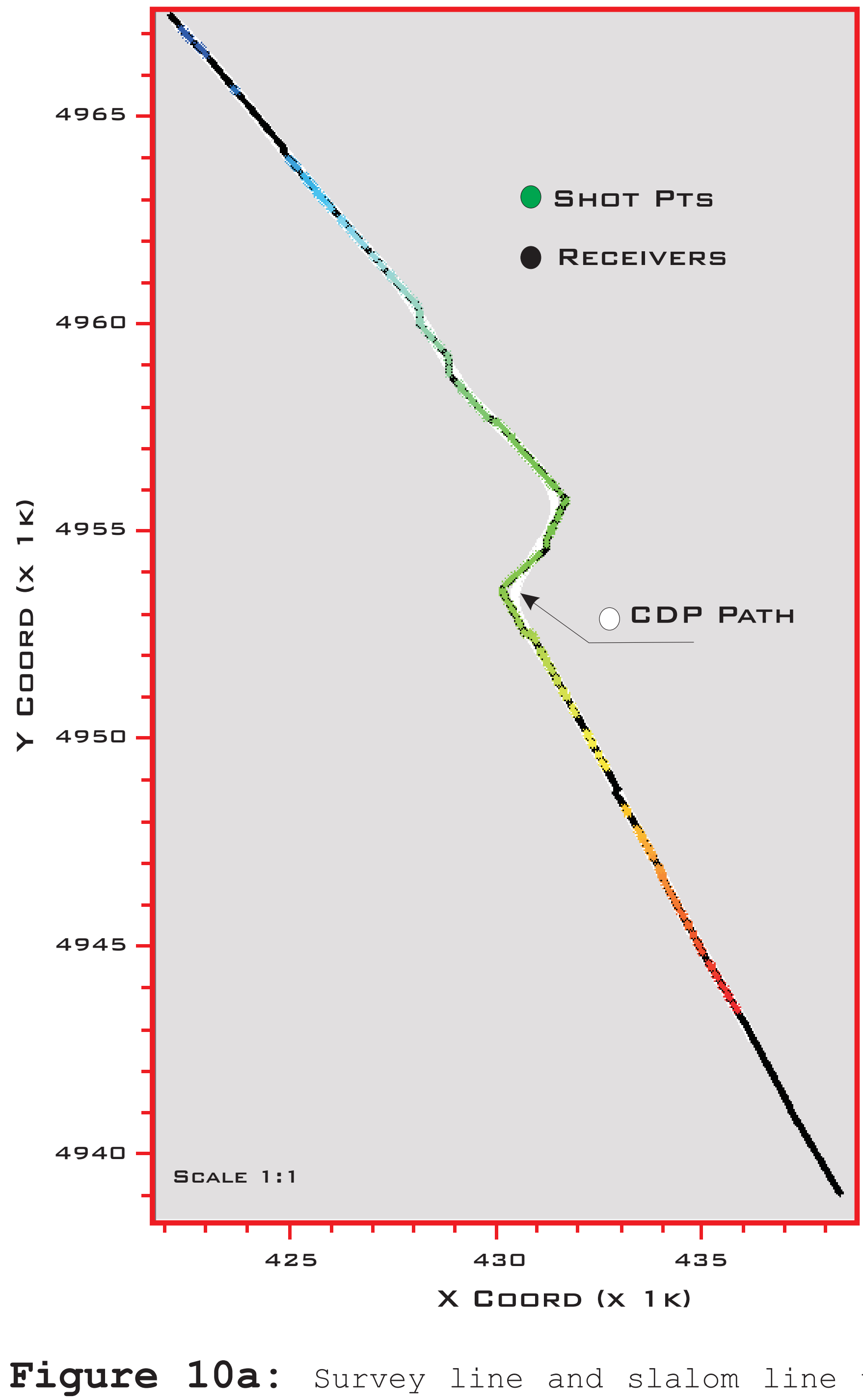


Figure 10a: Survey line and slalom line used for crooked line processing of SOS Line 3. The shot station ID is increasing from blue to red color.

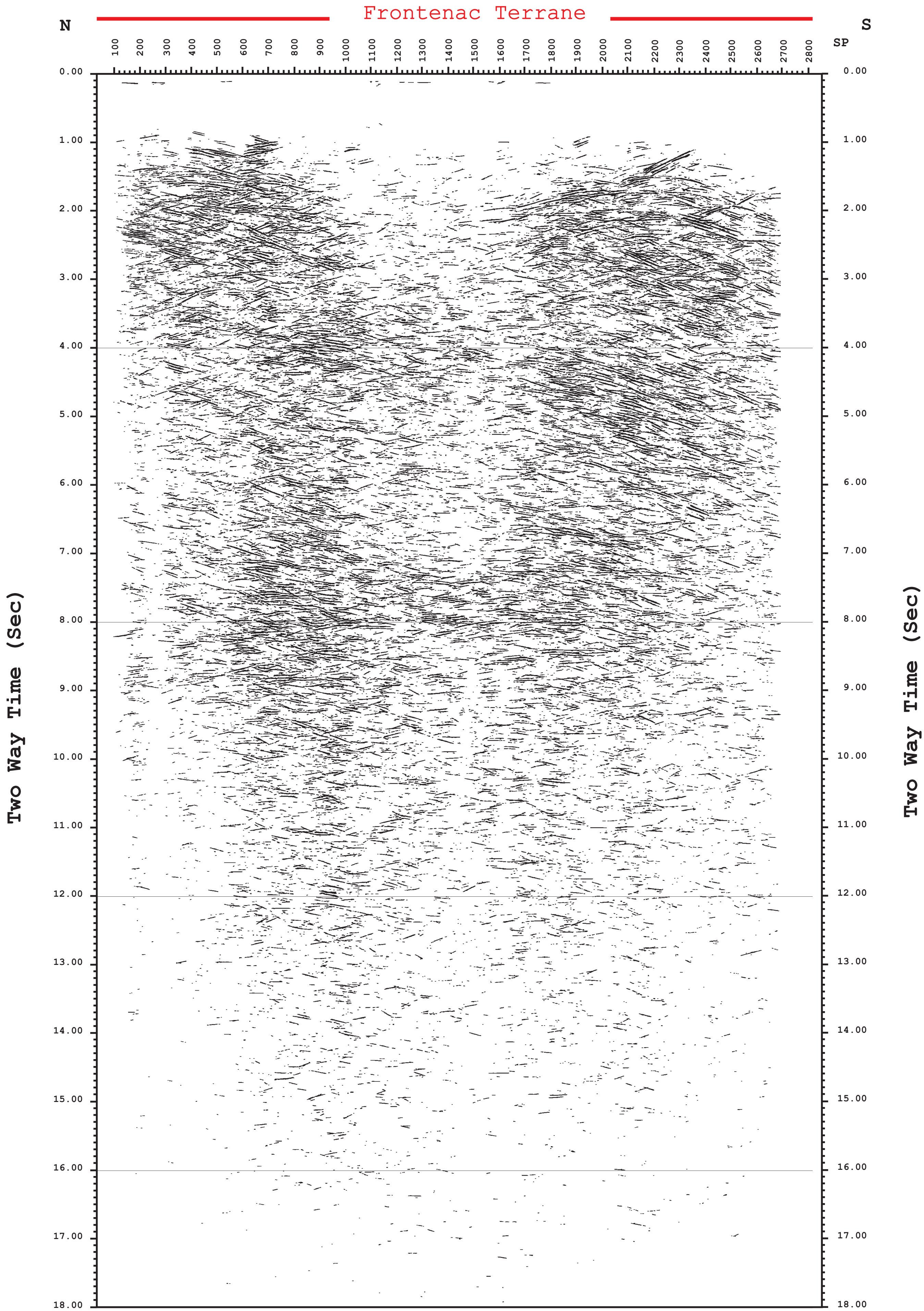


Figure 10b: Stack seismic section (distance, Two-way time) for SOS line 3.

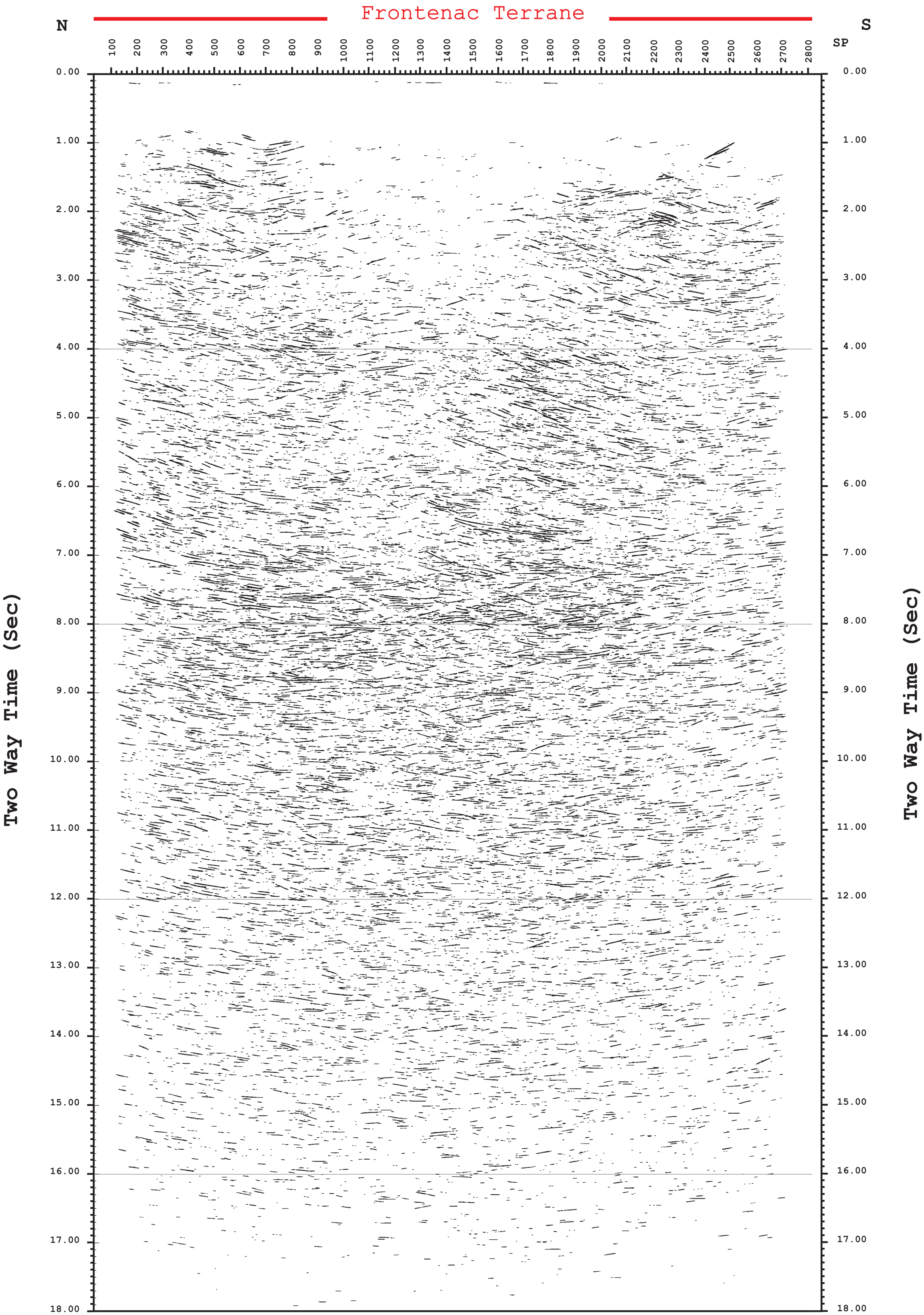


Figure 10c: Time migrated seismic section (distance, Two-way time) for SOS line 3.

Figure 10d: SOS 3