Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Earth Physics Branch
Direction de la physique du globe

1 Observatory Crescent
Ottawa Canada
K1A 0Y3

1 Place de l'Observatoire
Ottawa Canada
K1A 0Y3

Seismological Service of Canada

Service séismologique du Canada

REPORT ON A SEISMIC SURVEY ACROSS THE SUPERIOR-CHURCHILL BOUNDARY ZONE IN SOUTHERN CANADA

A.G. Green and O.G. Stephenson

165 pp. including 60 illustrations

Price $34.00

Earth Physics Branch Open File Number 78-9
Ottawa, Canada 1978

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Earth Physics Branch
Direction de la physique du globe

1 Observatory Crescent
Ottawa Canada
K1A 0Y3

1 Place de l'Observatoire
Ottawa Canada
K1A 0Y3

Seismological Service of Canada

Service séismologique du Canada

REPORT ON A SEISMIC SURVEY ACROSS THE SUPERIOR-CHURCHILL BOUNDARY ZONE IN SOUTHERN CANADA

A.G. Green and O.G. Stephenson

165 pp. including 60 illustrations

Price $34.00

Earth Physics Branch Open File Number 78-9
Ottawa, Canada 1978

78-9 Report on a seismic survey across the Superior-Churchill Boundary Zone in Southern Canada, by Centre for Precambrian Studies, University of Manitoba, 165 pp including 60 illustrations, Price

Approximately 80 km of 400%, near-vertical, seismic reflection profiling and two 250 km, reversed, seismic refraction profiles were recorded in 1977 in the Churchill-Superior Boundary Zone area in Southern Canada, by a consortium of Canadian Universities and the Earth Physics Branch. The report describes the rationale, location, field procedures, computer tape formats, the data and some preliminary refraction results. A detailed account of how the boundary-zone has been traced southwards from the exposed Shield in Northern Manitoba is also included.

"Report on a seismic survey across the Superior-Churchill Boundary Zone in Southern Canada", du précambriennes, Université du Manitoba, par le Centre des Etudes, 165 pp incluant 60 illustrations, Prix

Un consortuim formé d'universités canadiennes et de la Direction de la physique du globe a enregistré en 1977 quelques 80 km de profil de réflection séismique près de la verticale avec couverture à 400% ainsi que deux profils inversés de réfraction séismique dans la région de la zone frontalière Churchill-Supérieur. Le rapport décrit les raisons de l'expérience, le lieu, la façon de procéder sur le terrain, les formats des bandes d'ordinateur, les données et quelques résultats préliminaires de la réfraction. On a aussi ajouté un compte rendu détaillé de la façon dont on a tracé la zone frontalière vers le sud à partir des affleurements du Bouclier dans le nord du Manitoba.

COOPERATIVE NEAR VERTICAL INCIDENT REFLECTION AND REFRACTION/WIDE ANGLE REFLECTION SEISMIC SURVEYS ACROSS THE SUPERIOR-CHURCHILL BOUNDARY ZONE IN SOUTHERN CANADA

PART I

Rationale, Locations, Field Procedures,

Field Parameters and Computer

Tape Information

A.G. Green* and O.G. Stephenson+

* Department of Earth Sciences
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

\+ Centre for Precambrian Studies
University of Manitoba
Winnipeg, Manitoba
R3T 2N2

CONTENTS

* Appendices B, D, E are not included

COOPERATIVE NEAR VERTICAL INCIDENT REFLECTION AND REFRACTION/WIDE ANGLE REFLECTION SEISMIC SURVEYS ACROSS THE SUPERIOR-CHURCHILL BOUNDARY ZONE IN SOUTHERN CANADA

In July 1977 the Canadian Crustal Studies Group* conducted its first cooperative seismic survey in the southern parts of Manitoba and Saskatchewan. The principal objective of the survey was to obtain information on the nature of the transition zone between the Superior and Churchill tectonic provinces of the Canadian Shield. Although the transition zone is hidden beneath Phanerozoic sediments in this region, its location is well defined by gravity and magnetic data. A combination of near vertical incident reflection and refraction/wide angle reflection seismic techniques were employed.

Part I of this report describes the rationale, location, field procedures, field parameters and computer tape formats used for the project. In addition, there is a detailed account of how the boundary zone has been traced southwards from the exposed shield in northern Manitoba.

Part II of this report presents the data on a number of seismic sections. An interpretation of the refraction data, based mainly on first arrival times, is given in section (A). This preliminary analysis shows that a significant change in crustal structure (crustal layering and crustal thickness) occurs close to the transition from the Superior tectonic province to the boundary zone, as defined in Part I. To the east of the transition the crust is typical of the Superior province (with some minor refinements), while to the west the crust in the boundary zone is

* Initially composed of geophysicists from the Earth Physics Branch (EMR) and the universities of Alberta, British Columbia, Manitoba, Saskatchewan, Toronto and Western Ontario.

strikingly similar to the crust in Alberta and western Saskatchewan (i.e. the Churchill Province). Two profiles of reversed coverage of approximately 250 km in length and 10 km. trace intervals were recorded. One of these is a N/S profile within the Superior Province, the other, an E/W profile, covering the Superior-Boundary Zone-Churchill crustal suture.

Section (B) of Part II describes the data processing that has been applied to and is planned for the near-vertical reflection profiles. Approximately 80 km of four-fold coverage over two E/W profiles from the Superior into the Boundary Zone was recorded.

The refraction and reflection field data are contained on two reels of digital magnetic tape. These, the computer printouts of header information, sections of uncorrected reflection data and some enlarged diagrams are not included in this report. This material is available for the cost of reproduction (approximately $200.00) from;

Center for Precambrian Studies
University of Manitoba
Winnipeg, Manitoba, R3T 2N2
Attn: Professors D.H. Hall/A.G. Green

or

Div. of Seismology and Geothermal Studies
Earth Physics Branch, EMR
1-Observatory Crescent
Ottawa, K1A 0Y3
Attn: Dr. J.A. Mair

RATIONALE

The Superior-Churchill boundary zone is associated with at least two economically important geological deposits (Fig. 2). In the boundary zone of northern Manitoba ore is being mined from the Thompson nickel belt, one of the world's major nickel deposits. A large number of geologists from the Manitoba Department of Mines, Resources and Environmental Management, INCO and Falconbridge, among others, are currently engaged in vigorous exploration programs within the exposed parts of the boundary zone.

In the southern parts of Manitoba and Saskatchewan, significant volumes of oil and gas have accumulated in Phanerozoic sediments that overlie the boundary zone. It has been postulated that tectonic activity associated with the boundary zone has influenced the development and altered the position of the Phanerozoic sediments, creating the necessary traps for the oil and gas reservoirs (McCabe 1967, 1971). In 1976-1977 several oil companies (e.g. Chevron, Shell, Francana) were using shallow seismic reflection techniques in their search for oil and gas from this region.

Most earth scientists agree that mineral, oil and gas exploration in northern and south-central Canada will be more successful if there is a proper understanding of the magmatic, metamorphic, structural and stratigraphic development of the rocks within the boundary zone. Target areas may be better defined and exploration more systematic with such an understanding.

Recent major advances in the earth sciences have resulted from the studies of modern ($\sim$250 m.y. age) tectonic boundaries, where some of the most prominent geophysical anomalies (magnetic, gravity, electromagnetic, seismic, heat flow, radiometric ages) are observed. It is expected that a detailed study of the Superior-Churchill boundary zone, which also has distinctive magnetic and gravity signatures, will greatly improve our knowledge and understanding of the tectonic processes that occurred in the earth's early history. Whether or not a modified form of present-day plate tectonics can explain the Precambrian structures is one major question that might be answered by a detailed interpretation of the new crustal seismic data.

The decision to locate the survey in southern Canada, rather than in northern Manitoba where the boundary zone is exposed, was based on a number of factors. In the southern locations there was:

(i) easy access for the drilling, shooting and recording equipment on the almost continuous one mile grid of roads;

(ii) a surficial unconsolidated sedimentary layer for easy drilling;

(iii) evidence of shallow and deep reflecting horizons within the crust;

(iv) well defined gravity and magnetic expressions of the boundary zone;

(v) small topographic corrections ($\sim$42 m for the 1977 reflection survey);

(vi) good control on the depths and characteristics of the Phanerozoic sediments from oil company drill holes and seismic data.

It would have been extremely difficult and expensive to conduct a survey of comparable quality in northern Manitoba. A good system of roads was not available, so lines would have to be cut; transport and other costs would be considerably increased. A conservative estimate of the cost of a northern survey would be from 2-4 times the cost of the present survey.

DEFINITION OF THE SUPERIOR-CHURCHILL BOUNDARY ZONE

Before discussing the geophysical anomalies across the plains in southern Manitoba and Saskatchewan it is necessary to review briefly the geological and geophysical expressions of the exposed boundary zone in northern Manitoba.

(a) Boundary zone in northern Manitoba

Since 1939 a number of authors have used geological and/or geophysical data to infer the position and nature of the boundary between the Superior and Churchill tectonic provinces. Bell (1971a) showed that the early conflicts and ambiguities in the location of the boundary were largely the result of insufficient and sometimes inaccurate data. An additional problem is created when the transition from the Superior to the Churchill province is defined as a boundary line. The geological and geophysical data clearly show that there is no single line that separates the two provinces. This is not surprising, in modern global tectonics a single line rarely represents a plate boundary (except at some transform faults). The transition from the Superior to the Churchill province is taken to be the boundary zone described below.

With improved coverage and the recognition of a boundary zone rather than a sharp boundary, the various geologic, magnetic, gravity and radiometric age data are found to be remarkably consistent with the location of the boundary zone shown in Fig. 3. The extent and nature of the boundary zone is still uncertain. Bell (1971b) originally defined the boundary zone as the Pikwitonei subprovince (province) and included the Wabowden subprovince as part of the Churchill province. However, recent geological field work and Rb-Sr radiometric dating (Cranstone and Turek, 1976; Weber and Scoates, 1978; Scoates and Clarke, 1978) have shown that this interpretation needs modifying. Weber and Scoates (1978) have mapped a sharp prograde metamorphic transition from the greenschist/amphibolite facies of the Superior terrain to the granulite facies of the Pikwitonei terrain. Rocks of the Pikwitonei subprovince have also been traced into the Wabowden subprovince.

To accommodate these new data, the boundary zone has been expanded to include the Wabowden subprovince as shown in Fig. 3. The Pikwitonei and Wabowden subprovinces will be collectively referred to as the boundary zone, but their separate identities, as outlined by Bell, will be maintained. It is worth mentioning that this new definition of the boundary zone is consistent with the newly acquired magnetic data from south-central Canada.

The geology and geophysics of the tectonic provinces and subprovinces in northern Manitoba are described briefly in the following text.

(1) Superior province

E-W trending granite/greenstone belts (or subprovinces) and granite/gneiss belts characterize the Superior province in Manitoba and much of northwestern Ontario (Wilson, 1971). The granite/greenstone belts consist of interlayered igneous and sedimentary rocks that have been deformed and metamorphosed to greenschist-lower amphibolite facies. These formations have been extensively intruded by granitic batholiths. The granite/gneiss belts are composed of undifferentiated granitic material and large volumes of paragneisses that have been metamorphosed to amphibolite and occasionally granulite facies.

In both types of belt the lithology, bedding, gneissosity, folding, faulting, magnetic anomalies and gravity anomalies strongly parallel the E-W trend of the belts (Figs. 4 to 7; Wilson and Brisbin, 1962; Kornik, 1969, 1971; Kornik and Maclaren, 1966; Bell, 1971b; Wilson 1971).

Distinct magnetic patterns are observed across the two types of belt. Granite/greenstone belts have a low background magnetic field with linear, moderate to high amplitude anomalies across the igneous rocks and ironstone formations and elliptical high amplitude anomalies across the granitic bodies (Hall, 1968, 1971, 1974). Broad E-W trending magnetic highs, with little relief, are recorded across the granite/gneiss belts. These characteristic magnetic signatures have been used to map the boundaries between the belts (Wilson, 1971; Kornik, 1971) and later in this report they are used to define the edge of the Superior province in southern Manitoba.

(2) The boundary zone - Pikwitonei province

The E-W fabric of the Superior province is sharply truncated by the NE-SW trending boundary zone (Figs. 4 to 7).

Bell (1971b) states that the Superior province and Pikwitonei subprovince are metamorphosed unconformities, but as stated above, recent mapping and Rb-Sr dating have shown that the Pikwitonei rocks are higher metamorphosed equivalents of the Superior rocks. Granulite facies gneisses (stratiform, foliated and massive), layered mafic granulites and hypersthene bearing granites (charnockites) are the dominant rock types. Amphibolite facies gneisses that are often interlaminated with the granulite gneisses constitute the major component in a small area on the west of the subprovince, adjacent to the Wabowden subprovince (Fig. 8). Both facies of gneiss show evidence of retrograde metamorphism (Bell, 1971b).

The Nelson River gravity high anomaly (Figs. 6 and 9; Innes, 1960; Wilson and Brisbin, 1961, 1962; Gibb, 1968a, 1968b; Bell 1971b) is coincident with the Pikwitonei subprovince. Gibb (1968a, 1968b) has shown that the surface granulites have a relatively higher density than the surrounding rocks and that the gravity high anomaly can be explained if these rocks extend to $\sim$ 7 km depth. Potential field interpretation is non-unique, so a depth varying density contrast that extends to the Mohorovicic discontinuity may also explain the anomaly; a deep crustal source to this anomaly was first proposed by Wilson and Brisbin (1961).

The granulite facies rocks also have a 'unique' magnetic signature. Several authors (Kornik and Maclaren, 1966; Kornik, 1969, 1971; Bell, 1971b) have noted their characteristic 'bird's eye maple pattern' of small ovoid high and low magnetic anomalies of relatively high amplitude. There is almost a one-to-one relationship between this magnetic pattern and the outcrops of granulite gneisses.

(3) The boundary zone - Wabowden subprovince

The NE-SW trending Wabowden subprovince has been variously referred to as the 'Thompson-Moak Lake nickel belt', 'Moak Lake-Setting Lake nickel belt', 'Manitoba nickel belt', 'Thompson nickel belt', 'Thompson lineament' and the 'Nelson River lineament'. Layered gneisses in the mid to upper amphibolite facies of metamorphism are the dominant rock types. These enclose the linear belts of sediments, volcanics and serpentinized ultramafic (peridotite) bodies (Fig. 8) from which the nickel is extracted. The sediments and volcanics have been metamorphosed to the greenschist-lower amphibolite facies. Large stocks of monzonite, granodiorite and granite occur at several locations (Fig. 8). The subprovince is underlain by amphibolite facies gneisses that were formed by a metamorphic and structural overprint of Pikwitonei type granulites.

The boundary between the Wabowden subprovince and the Pikwitonei province is possibly a major fault zone (Assean Lake fault zone) in the north

(Bell, 1971b) and a metamorphic transition zone in the south and central regions (Cranstone and Turek, 1976; Weber and Scoates, 1978). The definition of the boundary in the south is not well established as similar gneisses occur in both provinces. On the basis of field relationships and Rb-Sr dating (discussed later), Cranstone and Turek (1976) and Weber and Scoates (1978) have argued that the Wabowden gneisses are remetamorphosed equivalents of the Pikwitonei rocks.

A line of faults that extend from Setting Lake to Moak Lake (Fig. 8) and possibly further north to Assean Lake, defines the western edge of the Wabowden subprovince. Similar NE-SW striking faults are observed throughout the subprovince (Wilson and Brisbin, 1962; Kornik, 1971).

The subprovince is marked by a prominent gravity low (Wilson and Brisbin, 1961, 1962; Gibb, 1968b) of similar magnitude and dimensions as the adjacent Nelson River gravity high anomaly (Figs. 6 and 9). Gibb (1968b) has interpreted the anomaly as due to the relatively low density of the surface to near surface ($\sim$ 7 km depth) gneisses and granitic rocks. Broad, high intensity magnetic anomalies are observed across the gneisses and smaller dimension magnetic highs are recorded across the mafic and ultramafic rocks. Most of the anomalies are elongated (length/width $\sim$ 5) parallel to the trend of the belt.

(4) <u>Churchill province</u>

Except for the economically important Flin Flon-Snow Lake and Lynn Lake granite/greenstone belts, the Churchill province is less studied than the Superior province and the boundary zone. In the region under discussion, greywacke- and shale-derived gneisses comparable to the Kisseynew sedimentary gneisses extend in a westerly direction from the contact with the Wabowden subprovince. To the west, these gneisses separate (surround) the Flin Flon-Snow Lake and Lynn Lake granite/greenstone belts. These are the only known occurrences of post-Archean granite/greenstone belts.

Generally, the geologic and geophysical trends in the Churchill province are more variable than the neighbouring provinces. In particular, the gravity and magnetic fields immediately to the west of the junction with the Wabowden subprovince are somewhat subdued and do not show any strong trends (Figs. 4 to 7).

(5) Age of the provinces

Radiometric dates have offered useful constraints on the evolutionary models of this region. Generally, the rocks from the Superior province yield Kenoran ages of 2300 to 2800 m.y., while the Churchill province rocks yield Hudsonian ages in the range 1600 to 1900 m.y. There are exceptions though, younger ages are obtained from within the Superior province (mostly from young dykes and sills) and Archean ages are frequently obtained from the 'basement' rocks in the Churchill province.

In the boundary zone, rocks from the Pikwitonei subprovince yield Kenoran ages, while most ages in the Wabowden subprovince indicate the effect of a strong overprinting during the Hudsonian orogeny (Bell, 1971b). An age of 2760 m.y. was recently obtained from basement rocks in the Wabowden subprovince (Cranstone and Turek, 1976; see discussion by Weber and Scoates, 1978).

(6) Mafic and ultramafic intrusions near the boundary zone

There are a large number of mafic and ultramafic dykes within the Pikwitonei subprovince and along the western edge of the Superior province. These dykes, which usually parallel the NE-SW trend of the boundary zone, have been dated as Hudsonian or younger and are probably related to the formation of the boundary zone.

(b) Boundary zone in southern Manitoba and southern Saskatchewan

The southward extension of the boundary zone beneath the Phanerozoic sediments is based primarily on gravity and magnetic data. In northern Manitoba the potential fields of the boundary zone have the following characteristics:

(i) high amplitude positive and negative gravity anomalies across the Pikwitonei province and Wabowden subprovince respectively. Both anomalies trend NE-SW;

(ii) 'bird's eye maple' magnetic pattern across the Pikwitonei province and high amplitude, elongated NE-SW trending magnetic anomalies in the Wabowden subprovince;

(iii) they truncate the dominant E-W trends of the Superior province.

Which of these features can be used to extend the boundary zone southwards?

South of latitude 54°35'N, where the boundary zone disappears beneath the Phanerozoic sediments, the gravity high broadens (Fig. 9), and eventually bifurcates near latitude 53°N. Further south there are a number of high anomaly axes that may be related to the Nelson River high. Without further information, it is not possible to be more definite about the correlation of the various anomaly axes. In the region south of latitude 52°N the most easterly gravity axis (A) truncates the E-W fabric of the Superior province (best observed on the 1:500,000 gravity maps of the Earth Physics Branch), so it is probably close to the western edge of the Superior province. Unfortunately this anomaly axis cannot be confidently extended south of latitude $\sim$50°40'N.

The characteristic magnetic pattern across the Pikwitonei province does not exist south of the Phanerozoic sediment boundary, but elongated magnetic anomalies that parallel the NE-SW anomalies in the Wabowden subprovince can be followed to the limit of the Federal-Provincial aeromagnetic map coverage near latitude 52°N (Fig. 4). Bell (1971b) has postulated that ultramafic sills (similar to the Fox River Sill) may be the source to two of the more prominent of these anomalies. Again, Superior province E-W magnetic trends are truncated by the zone of NE-SW trending anomalies (extension of the Wabowden subprovince?).

The eastern edge of the black zone in Fig. 4 shows the western limit of the Superior province magnetic fabric (from Kornik, 1971). As this line is practically coincident with the most eastern positive gravity anomaly axis (A), it is taken to represent the western limit of the Superior province.

To extend the magnetic coverage to the Canada-U.S. border, oil company ground- and aero-magnetic data were obtained (Fig. 10, and a new compilation of several aeromagnetic sheets held by the Manitoba government, a recently released aeromagnetic map from Gulf Research and Development Company, and a new survey by the University of Alberta). In this newly acquired data there are three distinct magnetic zones. To the east of the dotted line in Fig. 10, the magnetic anomalies are dominantly E-W trending, while to the west of the line the anomalies are elongated N-S; the impressive N-S fabric of the western area is most clear on the recently released Gulf map. The zone of N-S striking anomalies is <u>sharply</u> truncated in the west along a N to NNW line that extends from longitude $102^{\circ}40'$W on the international border. West of this line the magnetic field is extremely flat. The sharp nature of the transition at longitude $102^{\circ}40'$W probably indicates a fault contact.

The interpretation adopted in this report, is that the Superior province lies to the east of the dotted lines in Figs. 10 and 11, the boundary zone extends from this line to approximately longitude 102°40'W, and the Churchill province lies to the west of this meridian. The gravity data is consistent with this Superior province-boundary zone transition line (Figs. 9a and 11). The N-S positive gravity anomaly marked X in Fig. 11 (extension of the axis A? in Fig.9a) partly overlaps the large N-S high magnetic anomaly marked X in Fig. 10, and the E-W trend of the Superior province gravity field extends to at least longitude 100°10'W at this southern latitude. The gravity field between longitudes 100°10'W and 100°30'W is dominated by the nose of a broad regional E-W anomaly (Fig.9a).

The 'best' estimate of the western limit of the Superior province is shown by the dotted and dashed lines in Figs. 9 to 12. This position lines up with the postulated Superior province boundary in the northern U.S. (Fig. 12), based on gravity data (Muehlberger et al., 1967) and radiometric age dating of basement rocks (Fig. 13). Although radiometric dates from the Precambrian basement of southern-central Canada are sparse, they do support the interpretation presented here (Fig. 13).

THE DEEP CRUSTAL PROJECT

The contract with the Department of Supplies and Services (Federal Government) supported two 240 km reversed seismic refraction/wide angle reflection profiles and 85 km of continuous near vertical incidence seismic reflection coverage. The continuous reflection survey, which was mostly at 400% coverage, included a 1400% expanding spread at the eastern end of the profile.

Although the data from these surveys may be interpreted independently, the information from the different types of survey complement each other:-

Survey	Location	Information gained
Refraction/wide angle reflection	One N/S profile in the Superior province and one E/W profile that crosses from the Superior to the Churchill province	(i) Gross velocity structure of crust and uppermost mantle over a wide area. (ii) Approximate depths of the crustal discontinuities (most crustal discontinuities are refraction defined).
Near vertical incidence reflection survey	E/W profile that crosses the transition from the Superior province to the boundary zone	(i) From the 400% coverage the fine structure of the crust and uppermost mantle (for the same cost, the coverage is much smaller than from a refraction survey). Only poor control of velocities with 400% data.
	E/W profile in the Superior province	(ii) From the 1400% coverage accurate velocity-depth data.

The locations of the surveys relative to the boundary zone are shown in Fig. 12.

THE REFRACTION SURVEY

(a) Receiver information

Two reversed refraction/wide angle reflection profiles were completed, one N-S within the Superior province and one E/W traversing the Superior province, the boundary zone and the Churchill province (Fig. 12). The receivers on the N/S profile were located beside minor (gravel) roads within 9 km of Manitoba highway 10, its northerly extension highway 20 and a gravel road that leads to Lake Winnipegosis (Figs. 14a and 14b). For the E/W profile, receivers were set up beside minor roads within 6 km of Manitoba highway 3 and its westerly extension into Saskatchewan, highway 13. The recording sites do not deviate more than ± 4 km from a straight line on either profile. The latitudes, longitudes and elevations of the receivers are given in table 1 and the locations are shown in Figs. 14a and 14b. The accuracies of the absolute latitudes, longitudes and elevations are approximately $\pm$ 0.0005° ($\sim$60 m), $\pm$ 0.0005° ($\sim$60 m) and $\pm$ 8 m respectively (taken from 1:50,000 topographic maps and 4" to 1 mile air photographs).

Earth Physics Branch (EPB) and University of Toronto (UT) automatic digital seismic refractive units were deployed with 1 Hz vertical and horizontal refraction seismometers. At each recording site, the EPB crew set up one vertical, one N/S horizontal and one E/W horizontal seismometer at the same location (Local in Table 1), while the UT crew set up one vertical and one radial horizontal seismometer at the Local position and one vertical seismometer approximately 0.6 km away at the Remote position.

(b) Shot point information

A total of eight shots were detonated, a large shot (816 to 1119 kg) and a smaller shot (363 kg) were fired at the end of each profile. Charges of 60% GEOGEL were detonated in deep drill hole (20 to 37 m depth, 13 to 15 cm diameter) arrays at the locations shown in Fig. 14. The southern shot of the N/S profile and the eastern shot of the E/W profile were detonated at a common location within 0.8 km of the junction of highways 3 and 10. The northern shot was located near the end of the gravel road to Lake Winnipegosis, Manitoba and the western shot was located approximately 4 km west of Froude, 2.4 km south of highway 13, Saskatchewan.

The various shot parameters are given in the following tables and figures.

Table 2	Shot hole depths and charge sizes
Table 3	Total shot charge sizes, GMT dates and GMT times of detonation, latitudes, longitudes and elevations of shots.
Fig. 14a	N/S and E/W refraction lines - shot and receiver locations
Fig. 14b	Fold-out map at 1:250,000 of Fig. 14a
Fig. 15	Shot hole configuration for northern shot points 1 and 2
Fig. 16	Shot hole configuration for eastern and southern shot points 3, 4, 5 and 6
Fig. 17	Shot hole configuration for western shot points 7 and 8

The accuracies of the latitudes, longitudes and elevations of the shot points are approximately $\pm$ 0.0005°($\sim$60 m), $\pm$ 0.0005°($\sim$60 m) and $\pm$ 8 m respectively. Shot locations are for the shot holes closest to the receiver spread, marked X in Figs. 15 to 17. An exception occurs at the western shot point 8 where the X is midway between shot holes 19 and 20.

All shots were successfully detonated during relatively quiet periods of the day. On firing the large southern shot number 3, some explosives primed for another shot were sympathetically detonated by the shock wave. This resulted in the detonation of a total charge of 1119 kg, as compared to the 816 kg used for the other large shots (table 3). The distance between the holes was approximately 15 m.

(c) Field procedure and shot to receiver information

In the field, 16 or 17 instruments were set up along one half of the N/S spread, as shown in Fig. 18. The automatic timers turned the recording system on at specified times in the late evening and early morning. These two time periods were chosen to reduce the effects of industrial, agricultural and wind generated noise. During separate recording time windows, the smaller shot was detonated at the end closest to the receivers and the larger shot was fired at the other end of the profile. The receiver spread was moved to the second half of the profile and the process repeated. To tie the information from the large and small shots, the centre recorder of the profile was common to the two spreads. The complete process was repeated for the E/W profile.

Receiver and shot point chronometers were compared with the WWV radio time signal before and after the explosions. This allowed a relative timing synchronization of better than 30 m.s. between the shot and receiver positions.

A WWVB radio signal was also recorded on the University of Toronto equipment.

All data were recorded with a 16.7 m.s. sampling interval.

The distances between shot points were approximately 245 km for the N/S profile and 242 km for the E/W profile. Distances between adjacent receivers ranged from 2.4 to 16.2 km with an average value of 7.7 km (table 4).

The tape format for the refraction data is given in Appendices A and B together with a computer printout of the trace header blocks from the submitted tapes.

THE REFLECTION SURVEY

(a) Location of the survey

The location of the near vertical incidence reflection survey was chosen such that it:

(i) crossed in an E-W direction a well defined section of the N-S striking Superior province-boundary zone transition. Approximately 3/5 of the 400% recordings were taken in the Superior province and 2/5 in the boundary zone. The expanding spread lies in the Superior province;

(ii) was accessible for drilling, shooting and recording rigs;

(iii) avoided large topographic changes (e.g. Duck, Riding and Turtle mountains and the Brandon Hills);

(iv) avoided crossing wide rivers (e.g. Assiniboine and Souris rivers);

(v) was along a continuous series of roads that would allow the profile to eventually cross from the Superior province to the Churchill province. The roads must not carry a heavy traffic load;

(vi) was reasonably close to accommodation;

(vii) was in an area where (1) good reflections from within the basement are known to occur, and (2) there is good control on the depths, velocities and structure of the Phanerozoic sediments.

After excluding the major E-W highways 1, 2 and 3, because of their heavy traffic loads observed during the reconnaissance surveys, there were two sets of roads that met most of the above requirements.

The southern profile was logistically the most suitable of the two alternatives, but it crossed a major structural anomaly in the Paleozoic sediments. This anomaly, the Hartney structure (see McCabe, 1971), is 13 km in diameter and sits astride the transition from the

Superior province to the boundary zone. Francana Oil and Gas Ltd. sent several single fold lines of reflection data (1971 data) and a line of 600% (1976 data) coverage that samples the anomaly. Examination of these data demonstrated that it would have been extremely difficult to distinguish Precambrian basement anomalies from those due to the Hartney structure. Therefore, this profile was rejected.

The profile that was completed consists of three lines (Fig. 19). The 1 mile northerly displacement of line 2 relative to lines 1 and 3 was required to bypass a temporary swamp. There is sufficient east to west overlap (Fig. 20) to tie the information obtained from the three lines. The expanding spread was shot along the eastern end of line 1.

Fig. 20 is a 1:50,000 map showing the locations that were used as shot points.

(b) Technical details

The important technical details are either given below or in the computer printouts of Appendices C to E. Three lines of 400% common reflection (depth) point data were collected over the 72.18 km (84.54 km including overlap) profile. In addition, an expanding spread of up to 1400% coverage was completed near the eastern end of line 1. The percent coverage at each sub-surface point is shown in Fig. 22 and in more detail in Fig. 23 .

Shot points

number of holes/shot	1
number of shots/line 1 (includes expanding spread shots, 2 repeat shots and 2 test shots)	38
number of shots/line 2	8

number of shots/line 3	12
total number of shots	58
average depth to bottom of charge	18 m
(see table 5 for details) range	(14 to 18 m)
average depth to top of charge	15 m
(see table 5 for details) range	(12 to 15 m)
average diameter of shot hole	15 cm
average charge/shot	38 kg
(see table 5 for details) range	(15 to 167 kg)
distance between neighbouring shot points	1.17 to 2.05 km (most
(see Appendix D for details)	distances 1.46 km or 1.76 km)
explosive	60% GEOGEL (46 cm x 13 cm sticks)
average number of shots/day	5 to 6
(see table 6 for details)	

Receiver points

geophones	nine L-10A / L-15A 10 Hz - 338 ohm / 600 ohm
	geophones on A30 DDC stringers
	(total length of stringer
	~73 m)
takeouts	292.5 m (surveyed)
number of takeouts/1.609 km	5.5
total length of spread	12.87 km
number of recording trucks	3
(see Fig. 25 for details)	

total number of takeouts/spread	47 (2 overlaps see Fig. 20)
recording systems	U of M - DS 1590 automatic gain varying digital system (1 m.s. sample used at recording) recorded traces 11 to 34; U of S - analogue recording system (small amount of gain ranging at the beginning) recorded traces 34 to 45; U of A - fixed gain digital system; (5.6 m.s. sample used at recording) recorded traces 1 to 11.

<u>Shot/receiver information</u>

CDP coverage for reflection spread (see Fig. 23 for details)	400%
CDP coverage for expanding spread (see Fig. 23 for details)	1400%
length of line 1 (distance between furthest receivers)	44.17 km
length of line 2	19.31 km
length of line 3	21.06 km
total surface coverage	84.54 km
surface overlap line 1/line 2 (see Fig. 20)	8.11 km

surface overlap line 2/line 3	4.25 km
length of profile (E/W distance between furthest receivers)	72.18 km
total number of traces (includes null traces and overlapping traces) on the tape	2575 (see Appendix C for details of excluded traces)
digital interval	4 m.s.
timing (see table 7 and Field procedure section for details)	U of M - hard wire time break; U of A and U of S radio time break; for expanding spread WWV radio signal at shot and receiver

(c) The line survey

(Receiver locations

Receivers were located at 292.5 m (960') intervals along three sections of road (Fig. 21). The line survey started at the junction of Provincial highway 21 and Provincial road 349 and proceeded east. Receiver 144 of line 1 was placed 38 m east of highway 21 (all distances are measured relative to the centre of roads) and successive receivers, with decreasing receiver numbers, were located at 292.5 m intervals to the east. The most easterly receiver number 4 has coordinates: Lat. $49.7387^{\circ} \pm 0.0005^{\circ}$, Long. $99.8956^{\circ} \pm 0.0005^{\circ}$.

For line 2, receiver 144 was placed 1.609 km north of road 349 and 38 m west of highway 21. The survey proceeded to the west for increasing receiver numbers.

It was planned that line 3 receivers would lie due south of the equivalent receivers on line 2. A minor survey error caused the line 3 receivers to be displaced approximately 136 m to the west of their respective line 2 receivers (Fig. 20).

A 146.3 m (480') length of recording cable was used for receiver to receiver distance measurements and a standard 30 m (100') steel chain was used for the receiver to road intersection measurements. The recording cable was susceptible to contraction and expansion that resulted in errors of 0.5 to 1.0 m per 300 m of measurement. In order to compensate for this, approximately every 5th or 6th receiver location was tied to a road grid intersection (Fig. 24). Table 8 shows the distances of these receivers to the road intersections. The shot holes are close to these receivers (see next section).

If it is assumed that the road grid in S.W. Manitoba has been correctly surveyed (1 mile sections plus 99' road allowances), then the known distance of any receiver to a road intersection, for each line, allows all other receivers to be located relative to the grid. The third column in table 8 shows the predicted distances of the receivers to the road intersections, using the surveyed distances of the receivers marked *. Differences between the surveyed and predicted distances (column 4 in table 8) are caused by a combination of an inaccurate grid and changes in the length of the measuring cable. Although recent municipal surveys have shown that the 1 mile sections may be in error by up to 30 m, the trends of increasing differences away from the receivers marked * are probably caused by the changing cable length. This conclusion is supported by the information in table 9, where lengths of the surveyed lines are compared to the distances between the ends of the lines using the military grid and the road grid. The total difference is less than .3 km over the 72.18 km length of profile.

At 7 locations (table 10) the seismometer stringer was displaced (9 to 61 m) from the surveyed location to avoid major roads, railway crossings, etc.

Shot locations

It was planned to locate shot holes close to every 5th or 6th receiver, but poor drilling conditions prevented this in a number of areas (table 9). Shot parameters are given in tables 5 and 8 , and the coordinates of the shot holes relative to the closest receiver locations are given in Appendix D .

Elevations

The area surveyed is extremely flat. Elevations vary by less than 3 m between receivers and by less than 42 m over the complete 72.18 km of profile. At locations 43 to 93 (line 1) and 182 to 244 (line 3) elevations were taken from E/W Chevron Oil surveyed lines. All other elevations were taken from 1:50,000 topographic maps with occasional ties to N/S Chevron Oil survey lines.

(c) Field procedure

Drilling

The drilling crew (Ransom Brothers, Boissevain, Manitoba) maintained a 4 hole lead on the shooting and recording crew. Holes were drilled into the ditches beside the roads.

On line 1 the drill penetrated a wedge of clay, which contained lenses of coarse sand, on top of a westerly rising layer of sand. The sand layer reached the surface at the western end of line 1, near shot point 144. Beneath lines 2 and 3 the drill passed through a layer of fine sand on top of a layer of coarse sand.

Shooting

The shooting schedule is given in table 6. At the shot point, time break leads from the blasting box were connected to (a) the recording cable from the University of Manitoba system, and (b) to a tone break system that was broadcast by radio to the other recording systems. On detonation, a low voltage pulse was transmitted through the time break leads. The time of the recorded pulse or tone break was taken as the shot time.

Information from an uphole geophone was usually recorded by one of the systems (table 11).

For the expanding spread, the shot point to receiver distances were often too great to allow efficient transmission of the time or tone break. A second timing system was required. At the shot point, the detonation circuit was connected to a chronometer unit that effectively fired the explosives. The chronometer was accurately synchronized (usually better than 1 m.s.) with the WWV radio signal. With this unit the detonation circuit would only be closed at the 0.000 second mark. There was a delay in detonation of 30 to 50 m.s. from the 0.000s mark, due to the movement of mechanical relays in the system. An estimate of this delay for most shots was obtained by comparing the detonation time from the time or tone break with a WWV radio signal (usually at the closest recording truck). By recording the WWV radio signal at the receiver points, relative timing between shot and receiver was established.

This second timing system was used as a backup throughout the survey (see table 7 for the number of occasions it was required).

Recording

Three recording systems were employed (Fig. 25). The University of

Alberta had a fixed gain digital recorder (5.6 m.s. sampling interval), the University of Manitoba had an automatic gain digital recorder (1 m.s. sampling interval) and the University of Saskatchewan had a programmed gain analogue recorder.

Generally, Alberta recorded traces 1 to 11, Manitoba recorded traces 11 to 34 and Saskatchewan recorded traces 34 to 45. Trace 1 was recorded at the most easterly receiver. As long as one of the systems recorded a good time signal, the overlapping traces effectively allowed a third method of timing for the other systems.

The most common receiver spread/shooting sequence for the 400% coverages is shown in Fig. 26. After 4 shots the complete 12.87 km spread was moved 6.44 km to the west. This inefficient method was adopted to ensure that most of the shots were detonated on the University of Manitoba spread, as the gain ranging digital system had the widest dynamic range of the three systems.

Deviations from the above may be discerned from the computer printouts in Appendices C to E.

(e) Information for future interpretation

Static corrections

Static corrections are given in table 11. These corrections have not been included on either the tapes or the sections.

Each static correction is the sum of an elevation correction plus a near surface low velocity (weathered) correction. The elevation correction effectively places all shots and receivers on a common datum of 380m above sea level. A velocity of 1.89km/s (see below) was used in the calculations.

The low velocity correction was estimated from uphole times (table 11) obtained from the present survey and a seismic survey by Chevron Oil. Interpolated corrections are marked with an *. It was not possible to resolve the thickness of the low velocity layer from first breaks on either survey data sets. Sub-weathered layered velocities from first breaks average 1.89km/s.

Well velocity surveys

To aid the future interpretation of the reflection data, the results of velocity well surveys from two deep wells that are close to the reflection profile are given in Figs. 27 and 28. The location of the wells are given in figure captions. Velocity information (including shallow acoustic logs) from other wells close to the survey (Fig. 23) may be obtained from the Manitoba Department of Mines, Resources and Environmental Management.

Details from the bedrock/sedimentary cross-section

The sedimentary cross-section (Fig. 29) was compiled from the Revised Stratigraphic maps of Manitoba (1976), the Bedrock Topography and Geology of Southern Manitoba map and papers by Bannatyne (1970) and McCabe (1967, 1971). The above maps and publications are based on deep drill data and oil company interpretation of seismic data. This cross-section represents the expected sedimentary pile directly beneath the survey line. It is noted that: (i) the profile crossed the ancient Souris River valley between sites 30 and 50 (it is not possible to have an E-W traverse that crossed from the Superior province to the boundary zone without also crossing the ancient Souris or Assiniboine river valleys);

(ii) unconsolidated sediments along the profile vary in thickness from ∼ 70 m to ∼ 130 m; these deposits are mostly till with some stratified drift near the surface. There is reasonably good control on the thickness of the unconsolidated sediments from deep drill holes that are located at intervals of ~ 12 km;

(iii) there is a major unconformity between the Paleozoic and Mesozoic sediments. All the sediments have a regional S.W. dip; the Paleozoic and Mesozoic sediments have projected westerly dips of ~ 9 m/km and ~ 1.5 m/km respectively;

(iv) the Prairie evaporites, which are less than 30 m thick along most of the profile, thicken to almost 80 m at the western end of the line;

(v) there is considerable relief and variation of subcrop material on the Paleozoic erosion surface.

Details from existing seismic data

Available seismic data includes:

(i) selected 100% (mixed-1953 and straight-1976) and 1200% (1976) traces recorded from within the Virden oilfields (records from either 3 miles, 7 miles or 13 miles north of the profile in ranges 26 to 29) - supplied by Chevron;

(ii) complete lines (~20 km total) of 100% (1971) and 600% (1975-76) data that cross the Hartney anomaly and neighbouring areas, ~ 30 km to the south of the profile - supplied by Francana Oil and Gas Ltd.;

(iii) ~ 37 km of 600% data that samples the Paleozoic section near Dawson Bay, 400 km to north of the profile (1975-6 University of Manitoba data);

(iv) two sets of 300% data (1968-74) from locations to the west of the profile; both sets of data, at Viewfield (~ 10 km coverage) and Dumas (~ 3 km coverage), were taken from areas within 20 km of the probable extension of the 1977 profile into the Churchill province);

(v) ~ 37 km of 100% data (1966) from the Wapella area of Saskatchewan, 65 km to the north west of the profile - supplied by University of Saskatchewan;

(vi) ~ 35 km of 100% data from near Yorkton, Saskatchewan, 250 km to the north west of the profile. Up to 5 sec of data interpreted by McClure and Hajnal - supplied by University of Saskatchewan;

(vii) 4 sets of deep crustal reflection data from expanding spreads, each ~ 30 km long with 500% to 700% coverage. Recorded across the 'Superior-Churchill boundary', 250 km to the north and north west of the profile - supplied by the University of Saskatchewan;

(viii) a number of sonic logs and uphole velocity surveys from wells on, or close to the profile.

Some of the important data mentioned above are still confidential.

From these data:

(i) reflected energy can be expected from many of the sedimentary horizons shown in Fig. 24; in particular from the <u>Favel</u> (white specks), Amaranth (Watrous), <u>Paleozoic erosion surface</u> (mostly Mississippian formations along the profile), Nisku, <u>Prairie evaporite-Winnipegosis</u>, Ashern-Interlake, <u>Winnipeg</u> and the <u>Precambrian basement</u>. Large amplitude reflections are usually obtained from the formations or members that are underlined;

(ii) ground roll was not a major problem with the modern exploration surveys, but on the deep crustal records of Sereda and Hajnal, ground roll or some other slow travelling direct wave (velocity ~ 2 km/s with a dominant frequency ~ 8 Hz) affects the more distant records for several seconds after the first arrivals (200 lbs. in a 4 hole shot array was employed).

High pass frequency filtering (cut off 10 Hz) reduced the energy in this wave considerably. It is certain that a CDP stack would improve the reduction;

(iii) strong reflections that appear to originate from within the Precambrian basement are observed on most of the oil exploration records. Unfortunately their times coincide with the predicted times of some important multiples, in particular multiples that involve reflections from the underlined formations above. Further processing would be required to determine whether these events are primary reflections or multiples. If they are multiples, then combined deconvolution and CDP stacking should help to reduce these noise components in the 1977 data.

MISCELLANEOUS

(a) Sub-Contracts - Participants

Refraction Survey

Status	Organization	Leader(s)	Involvement	Number of Crew
Sub-Contract	University of Toronto	Dr. G. West	record 65% of data	3 to 4
Sub-Contract	Ransom Brothers	W. Ransom	drilling	2
Outside Contract	Earth Physics Branch	Dr. A. Mair	record 35% of data	5
Main Contract	University of Manitoba	Dr. A. Green Mr. O. Stephenson	Surveying, loading explosives, blasting, logistics and coordination	6 to 7

Reflection Survey

Status	Organization	Leader(s)	Involvement	Number of Crew
Sub-Contract	University of Alberta	Dr. E. Kanasewich Dr. G. Cumming	record 25% of data	4
Sub-Contract	University of Saskatchewan	Dr. Z. Hajnal Mr. I. Sereda	record 25% of data	4
Sub-Contract	Ransom Brothers	W. Ransom	drilling	2
Main Contract	University of Manitoba	Dr. A. Green Mr. O. Stephenson	record 50% of data, surveying, loading explosives, blasting, logistics and coordination	7 to 8

(b) Permits

Permits made out to Dr. A. G. Green, University of Manitoba, to conduct:

(i) near vertical incidence seismic reflection survey (Manitoba)

(ii) refraction/wide angle reflection survey (Manitoba and Saskatchewan)

Manitoba

Geophysical License No. 140

Road Allowance Permit No. 138

Saskatchewan

License to Conduct Geophysical Exploration No. 1013

Geophysical Crew Certificate No. 28

(c) Accommodation and Laboratory Space

Accommodation and food was obtained from Brandon University Halls of Residence. Laboratory and storage facilities were provided by the Geology Department of Brandon University.

(d) Clean Up

Large holes and craters caused by slumping at the shot points were filled by three local sub-contractors. Two or three holes that have developed through slumping during the winter will be repaired in the spring (1978).

All other drill holes were filled with drilling debris by the blasting crew. Flagging and surveyors stakes were collected after the experiment.

(e) Weather Conditions

During the week of the refraction/wide angle reflection experiment, there were frequent heavy rain storms (including lightning and periods of gusting wind). From information on the changing weather systems, provided by the Brandon Airport weather office, it was possible to predict the occurrence of "quiet" periods during the day (mostly early morning and late evening). Except for shots 6 and 7, all shots were detonated during quiet periods (no rain and very low wind velocities). During the time of shots 6 and 7, there were infrequent lightning flashes at the eastern end of the E/W line (no rain and low wind velocities).

For the near vertical incidence reflection survey, the wind had low to moderate velocities and the skies were mostly clear (no rain).

TABLE CAPTIONS

1. Refraction receiver latitudes, longitudes and elevations.

2. Refraction shot hole charges and depths

3. Refraction shot point parameters. Charges and depths for individual holes are given in table 2.

4. Shot to receiver distances and neighbouring receiver to receiver distances.

5. Reflection shot hole depths and charges.

6. Shooting schedule.

7. Timing for each shot used by the three recording systems.

8. Distances between the receiver (shot) locations and the intersections of the N/S grid roads with the profile lines.

9. Distances between receiver locations near the ends of lines using (a) surveyed locations, (b) military grid, and (c) road grid.

10. Seven receiver locations that have been moved from their common depth location.

11a. Uphole times and shot elevation corrections (datum 380m above sea level).

11b. Static corrections for the receivers 12 to 144 (line1), 144 to 182 (line 2) and 182 to 232 (line 3).

Refraction Receiver Locations

Receiver #		Latitude Local	Latitude Remote	Longitude Local	Longitude Remote	Elevation Local ft	Elevation Remote ft	Local m	Remote m
N-S									
1	EPB	49.6356°		99.9848°		1550		472	
2	EPB	49.6947		99.9726		1460		445	
3	EPB	49.7538		99.9848		1330		405	
4	EPB	49.8091		99.9841		1305		398	
5	EPB	49.9011		99.9807		1355		413	
6	EPB	49.9750		99.9809		1450		442	
7	UT	50.0490	50.0540	99.9801	99.9801	1650	1680	503	512
8	UT	50.1266	50.1318	99.9805	99.9805	1810	1825	552	556
9	UT	50.1969	50.1968	99.9680	99.9680	1850	1850	564	564
10	.UT	50.2696	50.2639	99.9763	99.9763	1935	1935	590	590
11	UT	50.3433	50.3372	99.9764	99.9764	1965	1965	599	599
12	UT	50.4178	50.4124	99.9288	99.9288	2000	2030	609	619
13	UT	50.4908	50.4857	99.9301	99.9301	2130	2160	649	658
14	UT	50.5655	50.5710	99.9425	99.9425	2010	2025	613	617
15	UT	50.6236	50.6188	99.9795	99.9773	2060	2040	628	622
16	UT	50.6936	50.6905	99.9722	99.9775	2125	2125	617	617
16.5	UT	50.7469	50.7464	99.9971	99.9881	2250	2250	686	686
17	UT	50.7714	50.7715	99.9948	99.9872	2155	2155	657	657
18	UT	50.8336	50.8368	100.0127	100.0136	2135	2135	620	620
19	UT	50.8960	50.8972	100.0556	100.0591	2225	2225	678	678
19.5	UT	50.9474	50.9480	100.0406	100.0406	2140	2140	652	652
20.5	UT	51.0222	51.0277	100.0388	100.0388	1070	1060	326	323
21	UT	51.0667	51.0722	100.0388	100.0388	1020	1015	311	309
22	UT	51.1218	51.1166	100.0161	100.0153	955	955	291	291
23	UT	51.2297	51.2351	99.9920	99.9920	905	905	276	276

Table 1.

Receiver #		Latitude Local	Latitude Remote	Longitude Local	Longitude Remote	Elevation Local ft	Elevation Remote ft	Local m	Remote m
24	UT	51.2874	51.2874	99.9954	99.9996	875	875	267	267
25	UT	51.3622	51.3677	99.9942	99.9942	875	875	267	267
26	EPB	51.4340		99.9927		860		262	
27	EPB	51.5078		99.9937		855		261	
28	EPB	No record							
29	EPB	51.6527		99.9720		860		262	
30	EPB	51.7390		99.9645		840		256	
31	EPB	51.7983		99.9654		835		256	
E-W									
1	EPB	49.6068		100.0066		1540		469	
2	EPB	49.6061		100.0979		1500		457	
3	EPB	49.6055		100.1891		1450		442	
4	EPB	49.6082		100.3028		1425		434	
5	EPB	49.6060		100.4153		1415		431	
6	EPB	49.6063		100.5408		1420		433	
7	UT	49.6135	49.6138	100.6441	100.6530	1420	1420	433	433
8	UT								
9	UT	49.6063	49.6063	100.9161	100.9075	1430	1430	436	436
10	UT	49.6062	49.6062	101.0619	101.0537	1500	1525	457	465
11	UT	49.6061	49.6061	101.1763	101.1687	1590	1590	485	485
12	UT	49.6062	49.6062	101.3038	101.3124	1665	1675	507	510
13	UT	49.6052	49.6052	101.4163	101.4086	1765	1765	538	538
14	UT	49.6065	49.6065	101.5290	101.5205	1825	1840	556	561
14.5	UT	49.6063	49.6063	101.5994	101.5994	1900	1900	579	579
15	UT	49.6062	49.6062	101.6327	101.6245	1925	1925	587	587
15.5	UT	49.6060	49.6060	101.7124	101.7039	1940	1940	591	591

Table 1. (cont'd.)

Receiver #		Latitude		Longitude		Elevation			
		Local	Remote	Local	Remote	Local ft	Remote ft	Local m	Remote m
16	UT	49.6061	49.6061	101.7573	101.7500	1980	2010	603	613
17	UT	49.6054	49.6054	101.8715	101.8631	2025	2025	617	617
18	UT	49.6096	49.6096	101.9854	101.9854	2055	2055	626	626
19	UT	49.6177	49.6177	102.0737	102.0737	2075	2075	632	632
20	UT	A 49.6310	B 49.6279	102.2089	102.2089	2075	2075	632	632
21	UT	49.6385	49.6385	102.3213	102.3129	2050	2050	625	625
22	UT	49.6315	49.6315	102.4348	102.4348	2050	2050	625	625
23	UT	49.6391	49.6391	102.5473	102.5389	2000	2000	609	609
24	UT	49.6401	49.6387	102.6605	102.6537	1975	1975	602	602
25	EPB	49.6387		102.7961		2010		613	
26	EPB	49.6387		102.9080		2015		616	
27	EPB	49.6390		103.0111		2025		617	
28	EPB	49.6384		103.1354		2000		609	
29	EPB	49.6449		103.2479		1990		606	
30	EPB	49.6418		103.3251		2000		609	

E.M.R. equipment consists of three instruments, 1 vertical, 1 N-S and 1 E-W, at the same location. University of Toronto equipment consists of three instruments, 1 vertical and 1 radial instrument at the Local position and 1 vertical 2000' away at the Remote position. Absolute accuracies of latitudes, longitudes and elevations are $\pm$ .0005° ($\sim$ 60 m), $\pm$ .0005° ($\sim$ 60 m) and $\pm$ 8 m respectively.

Table 1. (cont'd.)

Refraction Shot Hole Parameters

Shot	Shot #	Shot Hole #s	Charge Size (lbs)	(kg)	Bottom Depth of Charge (ft)	(m)
N. Large	1	21	450	204	65	20
		22	450	204	65	20
		23	450	204	80	24
		24	450	204	65	20
N. Small	2	25	350	159	65	20
		26	450	204	65	20
S. Large	3	1	532	241	120	37
		2	532	241	120	37
		3	550	249	120	37
		5	220	100	120	37
		9	200	91	120	37
		13	434	197	120	37
S. Small	4	4	400	181	120	37
		10	400	181	120	37
E. Large	5	6	450	204	120	37
		7	450	204	120	37
		8	350	159	120	37
		14	550	249	120	37
E. Small	6	11	200	91	120	37
		12	600	272	120	37
W. Large	7	15	450	204	90	27
		16	450	204	90	27
		17	450	204	90	27
		18	450	204	90	27
W. Small	8	19	200	91	90	27
		20	600	272	90	27

Shot locations are shown in fig. 14 and the shot holes are shown in figs. 15 to 17 . Explosive charge used was GEOGEL (C.I.L. product). Diameter of holes (13 to 15 cm).

TABLE 2

Refraction Shot Parameters

Shot	Shot #	Total Charge Size		Bottom Depth of Holes		GMT Date	GMT hr	GMT min	GMT sec	Latitude	Longitude	Elevation	
		lbs	kg	ft	m	July 1977						ft	m
N Large	1	1800	816	65	20	12	12	00	00.034	51.8216°	99.9473°	0840	256
N Small	2	800	363	65	20	14	02	00	00.043	51.8217	99.9477	0840	256
S Large	3	2468	1119	120	37	14	02	30	00.027	49.6217	99.9716	1550	472
S Small	4	800	363	120	37	12	11	30	00.039	49.6213	99.9716	1550	472
E Large	5	1800	816	120	37	17	02	30	00.031	49.6215	99.9716	1550	472
E Small	6	800	363	120	37	16	02	00	00.043	49.6215	99.9726	1550	472
W Large	7	1800	816	90	27	16	02	30	00.031	49.6449	103.3380	1989	606
W Small	8	800	363	90	27	17	02	00	00.043	49.6456	103.3376	1989	606

N.B. GMT date for shot #s 2, 3, 5, 6, 7 and 8 are local date plus one. GMT time is local time plus 5 hours.

Shot latitudes and longitudes are for the positions marked X in figs. 15 to 17 . These positions correspond to the shot holes (for each array of shots) closest to the receivers. An exception is at the western shot point 8 where the X is midway between the shot holes 19 and 20. The parameters for individual shot holes are given in table 2. The latitudes and longitudes for each hole can be obtained from the above table and the information in figs. 15 to 17 . The absolute accuracy of latitudes, longitudes and elevations are ±.0005° (~60 m), ±.0005° (~60 m) and ± 8 m respectively.

Table 3

A

N/S Receiver Numbers	Distance from N. shot 1 to Local Receivers (km)	Distance from S. shot 3 to Local Receivers (km)	N/S Receiver Numbers	Distance from N. shot 2 to Local Receivers (km)	Distance from S. shot 4 to Local Receivers (km)
1	243.153	1.815	16	125.481	119.271
2	236.571	8.120	16.5	119.591	125.212
3	230.006	14.724	17	116.862	127.935
4	223.855	20.864	18	109.991	134.874
5	213.619	31.085	19	103.230	141.909
6	205.400	39.304	19.5	97.454	147.581
7	197.169	47.533	20.5	89.145	155.892
8	188.539	56.164	21	84.209	160.839
9	180.711	63.980	22	77.987	166.927
10	172.630	72.067	23	65.914	178.904
11	164.434	80.264	24	59.516	185.323
12	156.140	88.603	25	51.206	193.641
13	148.020	96.715	26	43.232	201.626
14	139.707	104.999	27	35.056	209.834
15	133.263	111.442	29	18.870	225.944
16	125.470	119.226	30	9.270	235.543
16.5	119.580	125.168	31	2.873	242.138

B

E/W Receiver Numbers	Distance from W. shot 7 to Local Receivers (km)	Distance from E. shot 6 to Local Receivers (km)	E/W Receiver Numbers	Distance from W. Shot 8 to Local Receivers (km)	Distance from E. shot 5 to Local Receivers (km)
1	240.058	2.946	14.5	125.317	117.328
2	233.485	9.192	15	122.920	119.728
3	226.919	15.705	15.5	117.182	125.471

Table 4

E/W Receiver Numbers	Distance from W. Shot 7 to Local Receivers (km)	Distance from E. shot 6 to Local Receivers (km)	E/W Receiver Numbers	Distance from W. Shot 8 to Local Receivers (km)	Distance from E. shot 5 to Local Receivers (km)
4	218.718	23.843	16	113.949	128.707
5	210.624	31.953	17	105.732	136.938
6	201.584	40.986	18	97.508	145.134
7	194.113	48.400	19	91.110	151.479
8			20	81.322	161.202
9	174.553	68.020	21	73.207	169.294
10	164.053	78.525	22	65.052	177.476
11	155.814	86.769	23	56.927	185.573
12	146.631	95.955	24	48.774	193.726
13	138.535	104.065	25	39.011	203.495
14	130.412	112.182	26	30.953	211.555
14.5	125.344	117.256	27	23.529	218.981
15	122.947	119.656	28	14.586	227.935
15.5	117.209	125.399	29	6.461	236.030
16	113.976	128.635	30	0.995	241.594

C

N/S Receiver - Receiver	Distances (km)	N/S Receiver - Receiver	Distances (km)	N/S Receiver - Receiver	Distances (km)
1 - 2	6.632	13 - 14	8.355	23 - 24	6.422
2 - 3	6.632	14 - 15	6.970	24 - 25	8.320
3 - 4	6.151	15 - 16	7.803	25 - 26	7.986
4 - 5	10.236	16 - 16.5	6.182	26 - 27	8.208
5 - 6	8.220	16.5 - 17	2.730	27 - 29	16.185
6 - 7	8.231	17 - 18	7.032	29 - 30	9.612
7 - 8	8.631	18 - 19	7.566	30 - 31	6.596
8 - 9	7.870	19 - 19.5	5.813		

Table 4 cont'd

N/S Receiver - Receiver	Distances (km)	N/S Receiver - Receiver	Distances (km)	N/S Receiver - Receiver	Distances (km)
9 - 10	8.108	19.5 - 20·5	8.320		
10 - 11	8.198	20.5 - 21	4.949		
11 - 12	8.948	21 - 22	6.330		
12 - 13	8.120	22 - 23	12.118		

D

E/W Receiver - Receiver	Distances (km)	E/W Receiver - Receiver	Distances (km)	E/W Receiver - Receiver	Distances (km)
1 - 2	6.582	14.5 - 15	2.400	26 - 27	7.427
2 - 3	6.574	15 - 15.5	5.745	27 - 28	8.954
3 - 4	8.201	15.5 - 16	3.237	28 - 29	8.136
4 - 5	8.113	16 - 17	8.232	29 - 30	5.571
5 - 6	9.046	17 - 18	8.223		
6 - 7	7.489	18 - 19	6.427		
7 - 8		19 - 20	9.854		
8 - 9		20 - 21	8.140		
9 - 10	10.510	21 - 22	8.214		
10 - 11	8.246	22 - 23	8.148		
11 - 12	9.191	23 - 24	8.155		
12 - 13	8.110	24 - 25	9.709		
13 - 14	8.125	25 - 26	8.061		
14 - 14.5	5.075				

(A) and (B) shot to receiver distances for the N/S and E/W lines respectively. (C) and (D) are neighbouring receiver to receiver distances for the N/S and E/W lines respectively.

Table 4 cont'd

Shot #	Bottom depth ft	Bottom depth m	Top depth ft	Top depth m	Charge lbs	Charge kg	Shot #	Bottom depth ft	Bottom depth m	Top depth ft	Top depth m	Charge lbs	Charge kg
LINE 1													
18	60	18	50	15	84	38	34A	60	18	50	15	84	38
23	60	18	50	15	167	76	34B	60	18	50	15	84	38
28	60	18	50	15	167	76	55A	60	18	50	15	66	30
34	60	18	50	15	84	38	62A	60	18	50	15	66	30
40	60	18	50	15	84	38	67A	60	18	50	15	66	30
45	60	18	50	15	84	38	72A	60	18	50	15	84	38
51	60	18	50	15	84	38							
55	60	18	50	15	84	38	LINE 2						
62	60	18	50	15	84	38	144	60	18	50	15	84	38
67	60	18	50	15	84	38	149	60	18	50	15	84	38
72	60	18	50	15	84	38	155	60	18	50	15	84	38
79	60	18	50	15	84	38	160	60	18	50	15	84	38
84	60	18	50	15	84	38	166	60	18	50	15	84	38
89	60	18	50	15	84	38	172	60	18	50	15	84	38
95	60	18	50	15	84	38	177	47	14	38	12	84	38
101	60	18	50	15	84	38	182	55	17	45	14	84	38
106	60	18	50	15	84	38							
111	60	18	50	15	84	38	LINE 3						
118	60	18	50	15	84	38	182	47	14	39	12	84	38
123	60	18	50	15	84	38	188	55	17	45	14	84	38
123A	60	18	50	15	84	38	193	55	17	45	14	84	38
127	60	18	50	15	84	38	199	60	18	50	15	84	38
133	60	18	50	15	100	45	205	60	18	50	15	84	38
139	60	18	50	15	34	15	210	55	17	45	14	84	38
139A	60	18	50	15	84	38	216	55	17	45	14	84	38
144	60	18	50	15	84	38	221	57	17	48	15	84	38
12A	60	18	50	15	84	38	226	57	17	48	15	84	38
18A	60	18	50	15	84	38	232	50	15	40	12	84	38
23A	60	18	50	15	84	38	237	57	17	50	15	66	30
28A	60	18	50	15	84	38	243	45	14	40	12	60	27

Table 5. Reflection shot hole depths and charges

July	18	19	20	21	22	23	24	25	26	27	28	29
	12B	12	34A	62	84	106		127	144	172	216	55A
		18	40	67	89	111		133	149	177	221	62A
		23	45	72	95	118		139	155	182	226	67A
		28	51	79	101	123		139A	160	182	232	72A
		34	55	34B		123A		144	166	188	237	
				28A						193	243	
				23A						199		
				18A						205		
				12A						210		
Total	1	5	5	9	4	5		5	5	9	6	4

Table 6. Shooting schedule

Shot #	Uphole time (ms)	Univ. of Man.	Univ. of Alta.	Univ. of Sask.	Shot #	Uphole time (ms)	Univ. of Man.	Univ. of Alta.	Univ. of Sask.
LINE 1									
18		TB	OT	TB	34A		TB	TB	TB
23		TB	OT	TB	34B		WWV	TB	WWV
28		TB	OT	TB	55A		WWV	EST	TB
34		TB	OT	TB	62A		WWV	EST	TB
40		TB	TB	TB	67A		WWV	EST	WWV
45		TB	TB	TB	72A		WWV	EST	TB
51		TB	TB	TB					
55		TB	OT	TB	LINE 2				
62		TB	TB	TB	144		TB	TB	TB
67		OT	TB	TB	149		TB	TB	TB
72		OT	TB	TB	155		TB	TB	WWV
79		TB	TB	TB	160		TB	TB	TB
84		OT	TB	WWV	166		TB	TB	WWV
89		OT	TB	TB	172		TB	TB	TB
95		WWV	TB	TB	177		TB	TB	TB
101		WWV	OT	TB	182		OT	TB	TB
106		OT	TB	TB					
111		WWV	TB	TB	LINE 3				
118		WWV	TB	TB	182		TB	TB	TB
123		WWV	OT	TB	193		TB	TB	TB
123A		WWV	TB	TB	199		TB	TB	TB
127		TB	OT	WWV	205		TB	TB	TB
133		TB	OT	TB	210		TB	TB	TB
139		TB	TB	TB	216		TB	TB	TB
139A		TB	TB	TB	221		TB	TB	TB
144		TB	TB	TB	226		TB	TB	TB
12A		WWV	TB	WWV	232		TB	TB	TB
18A		WWV	TB	WWV	237		WWV	TB	TB
23A		WWV	TB	WWV	243		WWV	TB	TB
28A		WWV	OT	WWV					

Table 7. Timing information. TB - time or tone break (most reliable), WWV - radio time correlation, OT - timing from overlapping traces between the different systems, EST - poor timing (no overlap). For most shots a time or tone break was recorded by at least one of the three recording systems. The timing for systems that did not record the time and tone break has been adjusted by comparing first break times at the overlapping traces. Timing may be further improved by cross-correlation of overlapping tones.

Receiver/ Shot #	Surveyed (m)	Estimate from Road Grid (m)	Difference (m)	N/S Road Intersection #
Line 1				
12	850 W	783 W	67	1
18	960 W	899 W	61	2
23	795 W	723 W	72	3
28	585 W	546 W	39	4
34	742 W	662 W	80	5
40	835 W	778 W	57	6
45	663 W	602 W	61	7
51	776 W	718 W	58	8
55	304 W	249 W	55	9
62	708 W	658 W	50	10
67	523 W	881 W	42	11
72	347 W	305 W	42	12
79	762 W	713 W	49	13
84	585 W	537 W	48	14
89	406 W	361 W	45	15
95	520 W	477 W	43	16
101	628 W	593 W	35	17
106	408 W	416 W	52	18
111	274 W	240 W	34	19
118	678 W	648 W	34	20
123	502 W	472 W	30	21
127	34 W	3 W	31	22
133	119 W	119 W	0	23
* 139	235 W	235 W	0	24
144	38 E	59 W	97	25

Table 8

Receiver/ Shot #	Surveyed (m)	Estimate from Road Grid (m)	Difference (m)	N/S Road Intersection #
Line 2				
* 144	38 W	38 W	0	25
149	146 E	138 E	8	26
155	30 E	22 E	8	27
160	207 E	199 E	8	28
166	91 E	83 E	8	29
172	24 W	34 W	10	30
177	152 E	143 E	9	31
182	318 E	319 E	9	32
189	94 W	89 W	5	33
Line 3				
* 182	213 E	213 E	0	32
188	101 E	97 E	4	33
193	287 E	274 E	13	34
199	171 E	158 E	13	35
205	55 E	41 E	6	36
210	231 E	218 E	13	37
216	133 E	102 E	31	38
221	314 E	278 E	36	39
226	500 E	455 E	45	40
232	390 E	339 E	51	41
237	567 E	517 E	50	42
243	439 E	399 E	40	43

Check on surveyed locations I. Distances between receiver (shot) locations and the intersections of the N/S grid roads with the profile lines (figs. 20 and 24). The surveyed column shows the distances

Table 8 (cont'd)

measured in the field by the survey crew. The next column is obtained by fixing one receiver position relative to the road grid (marked * in the column) and calculating the expected distances assuming the centres of the roads are exactly 1639 m (1 mile plus 99' road allowance) and the surveyed receiver locations are exactly 293 m (960') apart. The difference is a measure of either the error in the surveying or the error in the Manitoba road grid system. The next table shows the distances between the ends of the lines using (i) surveyed 293 m (960') intervals between receivers, (ii) military grid and (iii) road grid.

Table 8 (cont'd)

Line #	Receiver #s	Survey (m)	Military Grid (m)	Road Grid (m)
1	9 to 138	37670	37738	37671
1	9 to 144	39494	39340	39330
2	144 to 189	13164	13055	13169
3	183 to 244	17845	17810	17805

Table (9) Check on surveyed locations II.

Distances between receiver locations near the ends of the lines using (a) surveyed locations, (b) military grid and (c) road grid.

Receiver	Offset of receiver relative to surveyed location (m)	Offset of common depth point (m)
LINE 1		
26	30 W	15 W
73	30 W	15 W
82	9 W	4.5 W
125	61 W	30.5 W
LINE 2		
183	30 E	15 E
185	30 E	15 E
LINE 3		
220	15 W	7.5 E

Table 10. Receiver locations that have been moved from their common depth point location. The second column indicates the distance (metres) and direction of movement relative to the CDP location. These offsets have not been accounted for in either the trace headers on the tapes or any of the other tables in this report. The offsets were required to avoid placing geophone stringers across railway lines, major roads, etc.

Shot number	Uphole time (sec)	Elevation connection (sec)
LINE 1		
12	.023	.011
18	.020	.013
23	.020	.013
28	.019	.015
34	.021	.017
40	.020	.020
49	.022	.021
51	.023	.023
55	.021	.024
62	.023	.023
67	*.020	.023
72	*.020	.024
79	.021	.025
84	*.018	.026
89	*.020	.029
95	*.022	.029
101	.020	.031
106	*.021	.030
111	*.021	.029
118	*.021	.027
123	.021	.027
127	.021	.028
133	.019	.028
139	.017	.025
144	.021	.025

Shot number	Uphole time (sec)	Elevation connection (sec)
LINE 2		
144	.022	.025
149	.019	.024
155	.023	.024
160	.021	.024
166	.021	.023
172	.020	.023
177	.019	.023
182	.019	.023
LINE 3		
182	.017	.026
188	.021	.029
193	.021	.026
199	.022	.026
205	.022	.026
210	.019	.029
216	.022	.028
221	.022	.028
226	.022	.029
232	.021	.029
237	-	.028
243	-	.028

Table 11a. Uphole times and shot hole elevation corrections (datum 380 m above sea level). *Uphole corrections were obtained from Chevron Oil data. All uphole times have been adjusted to correspond to a charge 15 m below the surface. Elevation corrections were obtained with a sub-weathered layer velocity of 1.89 km/s.

Receiver number	Weathering connection from uphole times	Elevation connection	Total STATIC connections	Receiver number	Weathering connection from uphole times	Elevation connection	Total STATIC connections
LINE 1	(sec)	(sec)	(sec)	LINE 1	(sec)	(sec)	(sec)
12	.023	.002	.025	51	.023	.015	.038
13	.023	.004	.027	52	.022	.014	.036
14	.022	.004	.026	53	.022	.015	.037
15	.021	.005	.026	54	.022	.015	.037
16	.021	.005	.026	55	.021	.016	.037
17	.020	.005	.025	56	.021	.014	.035
18	.020	.005	.025	57	.021	.015	.036
19	.020	.006	.026	58	.021	.015	.036
20	.020	.006	.026	59	.021	.014	.035
21	.020	.006	.026	60	.022	.015	.037
22	.020	.006	.026	61	.021	.015	.036
23	.020	.006	.026	62	.023	.015	.038
24	.020	.005	.025	63	.021	.015	.036
25	.020	.006	.026	64	.018	.015	.033
26	.019	.007	.026	65	.018	.015	.033
27	.019	.007	.026	66	.019	.015	.034
28	.019	.007	.026	67	.020	.015	.035
29	.019	.008	.027	68	.021	.015	.036
30	.019	.008	.027	69	.021	.015	.036
31	.019	.008	.027	70	.021	.016	.037
32	.019	.008	.027	71	.020	.016	.036
33	.020	.009	.029	72	.020	.016	.036
34	.021	.010	.031	73	.020	.017	.037
35	.021	.010	.031	74	.020	.017	.037
36	.020	.010	.030	75	.020	.017	.037
37	.020	.011	.031	76	.020	.017	.037
38	.020	.011	.031	77	.020	.017	.037
39	.020	.012	.031	78	.020	.017	.037
40	.020	.012	.032	79	.021	.017	.038
41	.020	.012	.032	80	.018	.017	.035
42	.020	.013	.033	81	.018	.017	.035
43	.021	.013	.034	82	.018	.018	.036
44	.021	.013	.034	83	.018	.017	.035
45	.022	.013	.035	84	.018	.019	.037
46	.022	.013	.035	85	.018	.019	.037
47	.021	.013	.034	86	.019	.020	.038
48	.021	.014	.035	87	.019	.020	.039
49	.022	.014	.036	88	.020	.020	.040
50	.022	.015	.037	89	.020	.021	.041

Table 11b. (cont'd.)

Receiver number	Weathering connection from uphole times	Elevation connection	Total STATIC connections	Receiver number	Weathering connection from uphole times	Elevation connection	Total STATIC connections
	(sec)	(sec)	(sec)		(sec)	(sec)	(sec)
LINE 1				LINE 1			
90	.020	.021	.041	130	.020	.020	.040
91	.021	.021	.042	131	.020	.020	.040
92	.021	.021	.042	132	.019	.020	.039
93	.021	.021	.042	133	.019	.020	.039
94	.022	.021	.043	134	.019	.019	.038
95	.022	.021	.043	135	.019	.019	.038
96	.022	.022	.044	136	.018	.019	.037
97	.021	.022	.043	137	.018	.018	.036
98	.021	.022	.043	138	.017	.018	.035
99	.020	.022	.042	139	.017	.017	.034
100	.020	.023	.043	140	.018	.017	.035
101	.020	.023	.043	141	.019	.017	.036
102	.020	.023	.043	142	.020	.017	.037
103	.020	.022	.042	143	.021	.017	.038
104	.021	.022	.043	144	.021	.017	.038
105	.021	.022	.043				
106	.021	.022	.043	LINE 2			
107	.021	.021	.042				
108	.021	.021	.042	144	.022	.017	.039
109	.021	.021	.042	145	.021	.017	.038
110	.021	.021	.042	146	.020	.017	.037
111	.021	.021	.042	147	.019	.017	.036
112	.021	.020	.041	148	.019	.016	.035
113	.021	.020	.041	149	.019	.016	.035
114	.021	.020	.041	150	.019	.016	.035
115	.021	.020	.042	151	.020	.016	.036
116	.021	.020	.041	152	.020	.016	.036
117	.021	.020	.041	153	.021	.016	.037
118	.021	.019	.040	154	.022	.016	.038
119	.021	.019	.040	155	.023	.016	.039
120	.021	.019	.040	156	.023	.016	.039
121	.021	.019	.040	157	.022	.016	.038
122	.021	.019	.040	158	.022	.016	.038
123	.021	.019	.040	159	.021	.016	.037
124	.021	.019	.040	160	.021	.016	.037
125	.021	.019	.040	161	.021	.016	.037
126	.021	.020	.041	162	.021	.016	.037
127	.021	.020	.041	163	.021	.016	.037
128	.021	.020	.041	164	.021	.016	.037
129	.021	.020	.041	165	.021	.015	.036

Table 11b. (cont'd.)

Receiver number	Weathering connection from uphole times (sec)	Elevation connection (sec)	Total STATIC connections (sec)
LINE 2			
166	.021	.015	.036
167	.021	.015	.036
168	.021	.015	.036
169	.021	.015	.036
170	.020	.015	.035
171	.020	.015	.035
172	.020	.015	.035
173	.019	.015	.034
174	.019	.015	.034
175	.019	.015	.034
176	.019	.015	.034
177	.019	.015	.034
178	.019	.015	.034
179	.019	.016	.035
180	.019	.017	.036
181	.019	.017	.036
182	.019	.018	.037
LINE 3			
182	.017	.019	.036
183	.017	.019	.036
184	.017	.019	.036
185	.018	.019	.037
186	.019	.019	.038
187	.020	.019	.039
188	.021	.019	.040
189	.021	.019	.040
190	.021	.018	.039
191	.021	.018	.039
192	.021	.018	.039
193	.021	.018	.039
194	.021	.018	.039
195	.018	.018	.036
196	.018	.018	.036
197	.017	.018	.035

Receiver number	Weathering connection from uphole times (sec)	Elevation connection (sec)	Total STATIC connections (sec)
LINE 3			
198	.020	.018	.038
199	.022	.018	.040
200	.022	.018	.040
201	.020	.018	.038
202	.016	.018	.034
203	.016	.018	.034
204	.017	.018	.035
205	.022	.018	.040
206	.018	.018	.036
207	.017	.019	.036
208	.017	.020	.037
209	.019	.021	.040
210	.019	.020	.039
211	.015	.021	.036
212	.014	.019	.033
213	.014	.020	.034
214	.016	.020	.036
215	.019	.020	.039
216	.022	.020	.042
217	.018	.020	.039
218	.019	.020	.039
219	.020	.020	.040
220	.021	.020	.041
221	.022	.020	.042
222	.022	.021	.043
223	.022	.021	.043
224	.022	.021	.043
225	.022	.021	.043
226	.022	.021	.043
227	.022	.021	.043
228	.022	.021	.043
229	.022	.021	.043
230	.021	.021	.042
231	.021	.021	.042
232	.021	.021	.042

Table 11b. Receiver static corrections. The weathered (low velocity) layer correction, for receivers close to shot points, is simply the uphole time at the nearby shots (all shots were detonated beneath the near surface low velocity layer). For receivers between shot points (see Table 11a for location of shot points), the uphole times were interpolated. In some areas the interpolation was guided by the uphole times obtained from Chevron Oil seismic data. Reliable estimates of the static corrections are only available for receivers between shot points; i.e. receiver 12 to 144 on line 1, 144 to 182 on line 2 and 182 to 232 on line 3 (no uphole times for shots 237 and 243). Elevation corrections were obtained with a sub-weathered layer velocity of 1.89 km/s.

FIGURE CAPTIONS

1. Structural provinces of Canada.

2. Mineral and oil deposits in Manitoba.

3. Geology of the Superior-Churchill boundary from Cranstone and Turek (1976). The large dots show the boundary zone as adopted in the text.

4. Magnetic subdivisions in northern and eastern Manitoba from Kornik (1971). The black and striped areas represent Kornik's interpretation of the boundary zone.

5. Magnetic anomalies for central Canada from the Magnetic Anomaly map of Canada (Map 1255, EMR, 1977).

6. Gravity anomalies in central Canada from the Bouguer Gravity Map of Canada (EMR, 1969).

7. Geological and geophysical trends of northern Manitoba from Wilson and Brisbin (1962).

8. Detailed geology of the Churchill-Superior boundary zone from Cranstone and Turek, (1976).

9a. Fig. 6 with the location of the Nelson River High (gravity anomaly) and its possible projections southwards.

9b. The locations of the Nelson River High is superimposed on the magnetic anomaly map of Fig. 5.

10. Oil company magnetic data compiled for S.W. Manitoba (McCabe, H.R., personal communication). The dots show the edge of the Superior province as defined by the magnetic data.

11. Gravity data from the Earth Physics Branch series, shown at the same scale as Fig. 10. The dots are the same as for Fig. 10.

12. Location of the refraction/wide angle reflection and the near vertical incidence reflection surveys relative to the boundary zone.

13. Radiometric dates obtained from the basement rocks of central North America (Goldich et al., 1966).

14a. Map of the shot points and receivers used for the refraction/wide angle reflection seismic survey.

*14b. Enlarged version of Fig. 14a (1:250,000) - in the folder at the back of the report.

15. Shot hole configuration for the northern shot points 1 and 2. The Xs mark the shot holes for which the latitudes and longitudes are given in Table 3.

16. Shot hole configuration for the southern and eastern shot points 3, 4, 5, and 6. The Xs mark the shot holes for which the latitudes and longitudes are given in Table 3.

17. Shot hole configuration for the western shot points 7 and 8. The crosses mark the locations for which the latitudes and longitudes are given in Table 3.

18. Shooting and receiver sequence. For example, on GMT 12 July, the receiver spread was set up along the southern half of the N/S profile and a small shot was detonated at location 3 and a large shot was detonated at location 1.

19. Shot locations used for the near vertical incidence reflection survey.

20. Overlap of the 3 reflection lines. The receiver numbers show the end receivers on each line or section of line. The University of Alberta set up an additional receiver (#3) approximately 293 m west of receiver location 4.

*21. Enlarged version of Fig. 19 (1:50,000) - in the folder at the back of the report.

22a to c. Common Depth Point coverage of lines 1 to 3.

*23a. Enlarged version of Fig. 22a - in the folder at the back of the report.

*23b. Enlarged version of Fig. 22b - in the folder at the back of the report.

*23c. Enlarged version of Fig. 22c - in the folder at the back of the report.

24. Surveyed locations of the shot points tied to road intersections.

25. Shot, receiver spread and recording truck configurations. Generally, Alberta recorded traces 1 to 11, Manitoba recorded traces 12 to 35 and Saskatchewan recorded traces 36 to 47. Trace 11 overlaps with trace 12, and trace 35 overlaps with trace 36.

26. Common Depth Point shooting/recording sequence.

27. Uphole velocity survey for a well at Tp 9, R 27, Sec 18.

*28. Uphole velocity survey for a well at Tp 9, R 19,Sec 5 - in folder at the back of the report.

29. Sedimentary cross-section expected beneath the reflection survey line

* Figures 14b, 21, 23a, 23b, 23c and 28 are not included.

The following figures are included in the folder at the back of the report:

Figure 14b
21
23a
23b
23c
28

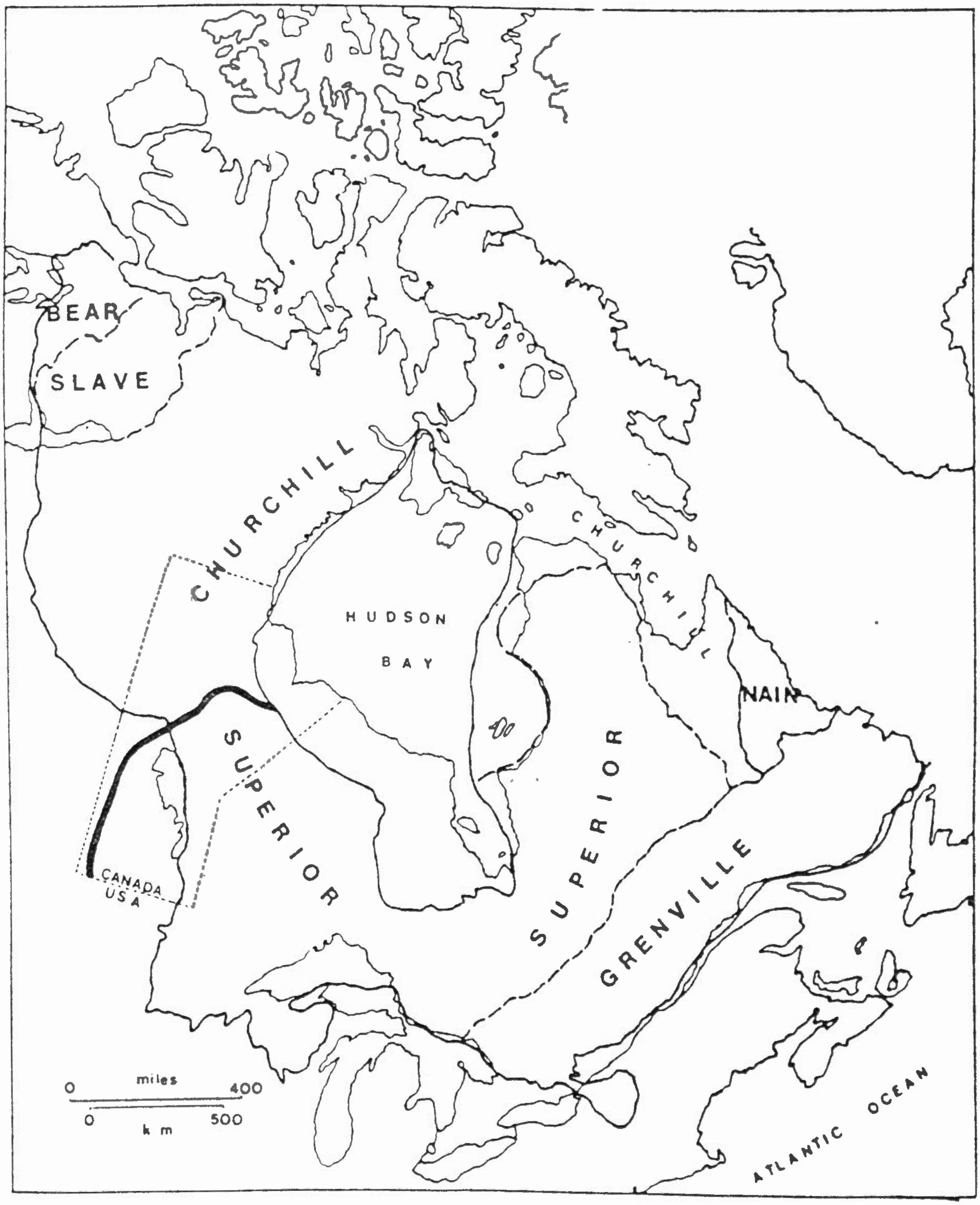


Figure 1 STRUCTURAL PROVINCES OF CANADA

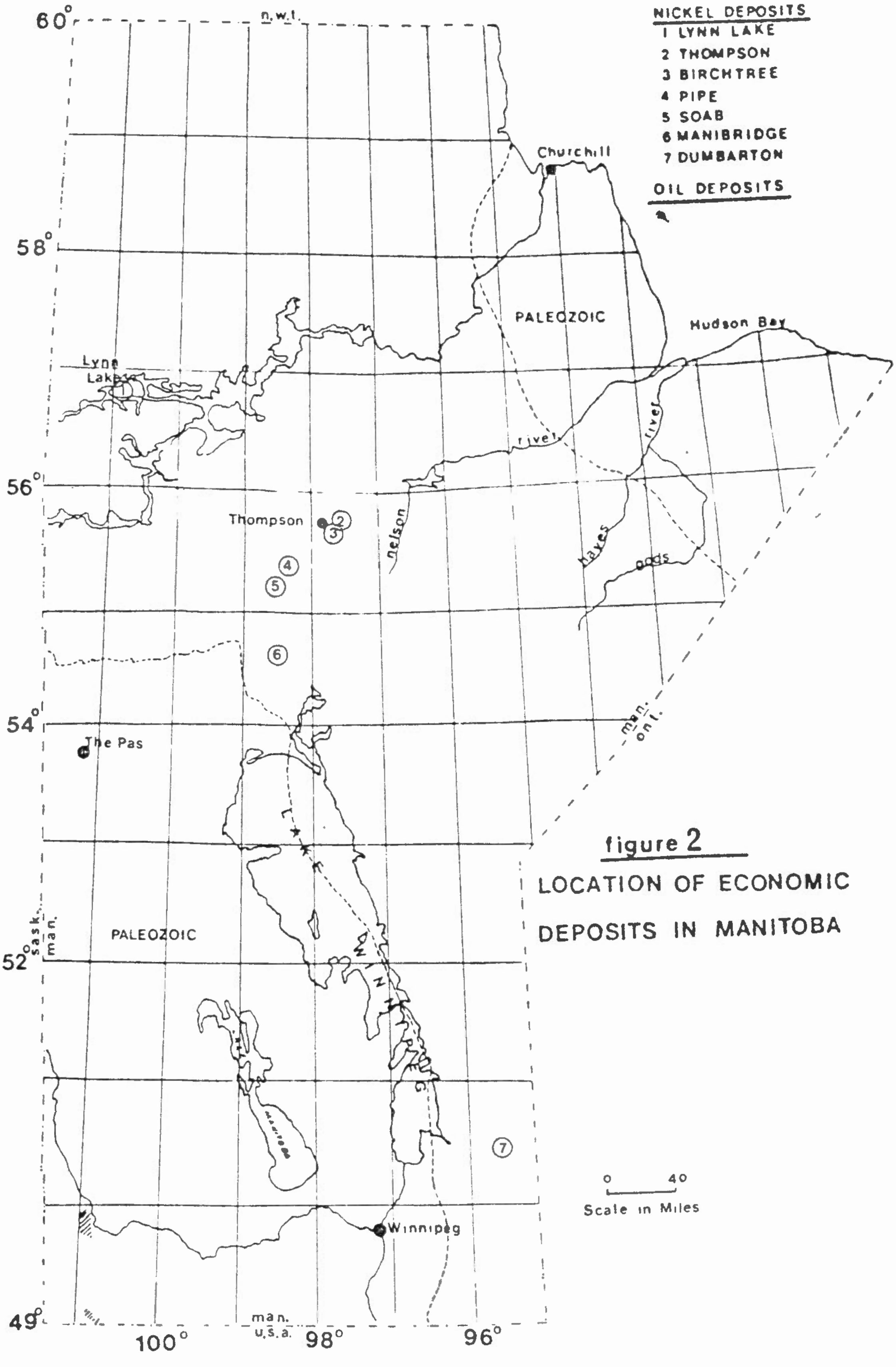
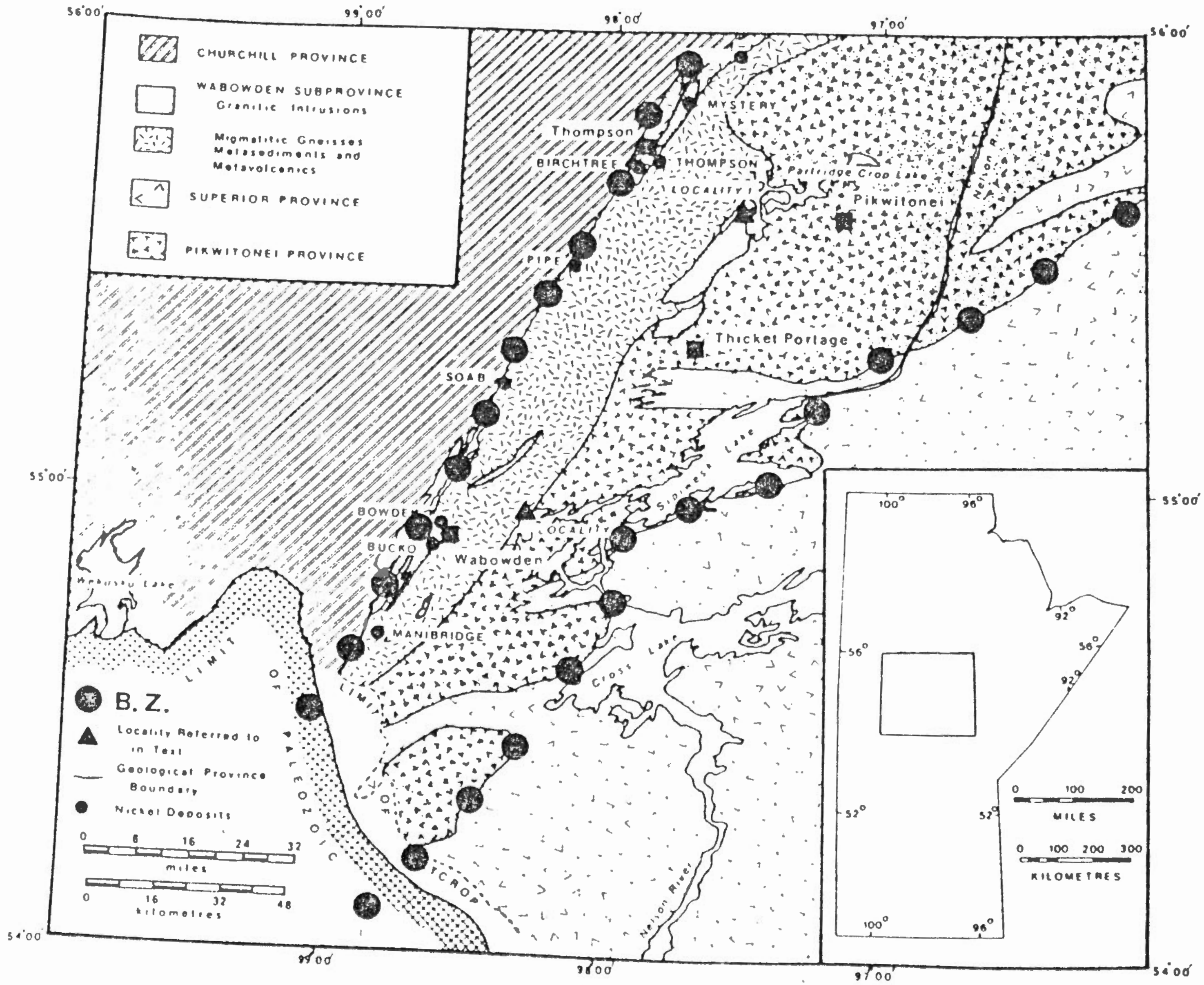


figure 2

LOCATION OF ECONOMIC DEPOSITS IN MANITOBA


CHURCHILL PROVINCE
WABOWDEN SUBPROVINCE
Granitic Intrusions
Migmatitic Gneisses
Metasediments and
Metavolcanics
SUPERIOR PROVINCE
PIKWITONEI PROVINCE
B. Z.
Locality Referred to in Text
Geological Province Boundary
Nickel Deposits
miles
kilometres
MILES
KILOMETRES
Thompson
BIRCHTREE
THOMPSON
LOCALITY
MYSTERY
Partridge Crop Lake
Pikwitonei
PIPE
SOAB
Thicket Portage
BOWDEN
BUCKO
Wabowden
MANIBRIDGE
Cross Lake
Nelson River
LIMIT OF PALEOZOIC OUTCROP
56°00'
55°00'
54°00'
99°00'
98°00'
97°00'

3

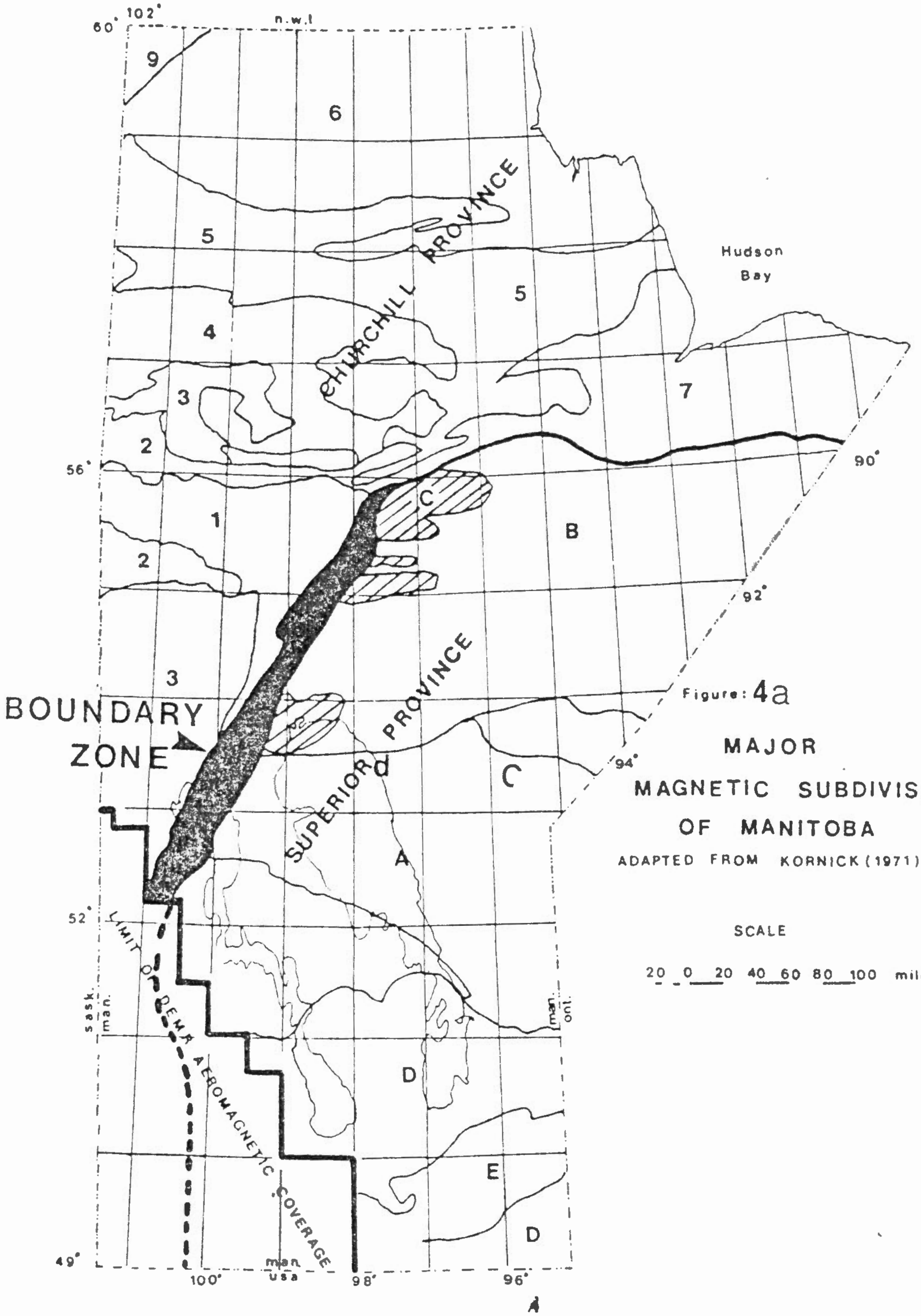


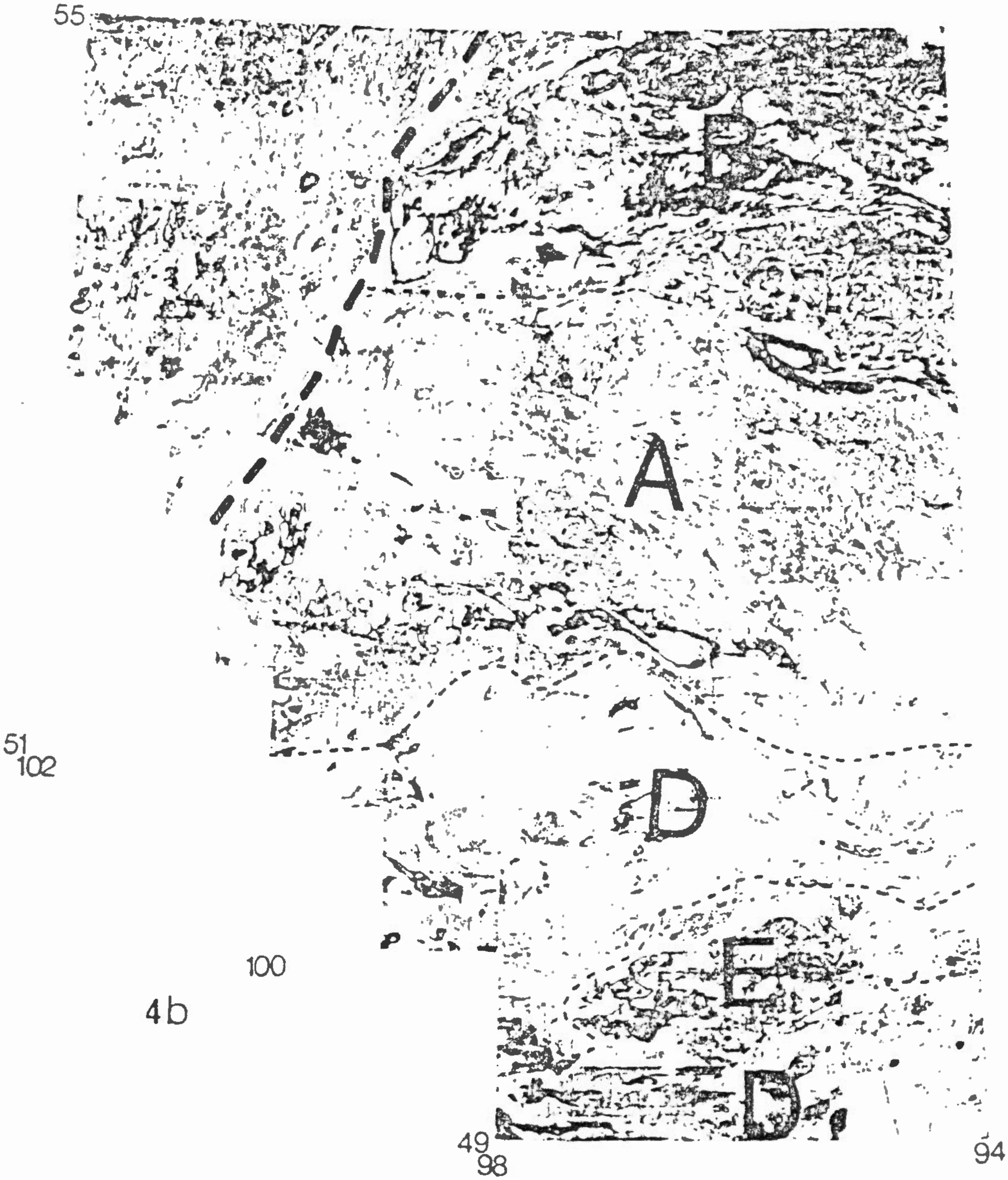
Figure: 4a

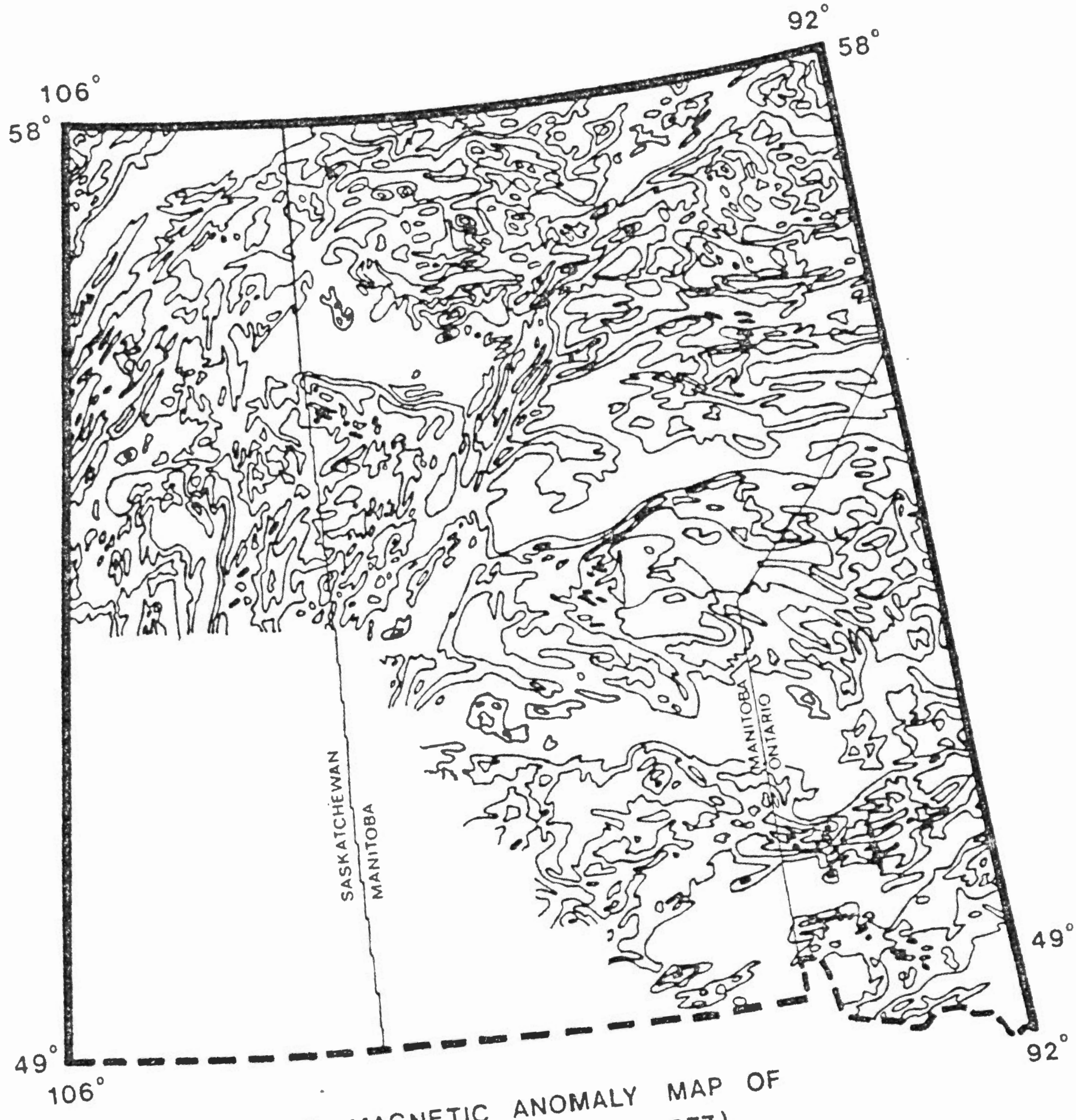
MAJOR MAGNETIC SUBDIVISIONS OF MANITOBA

ADAPTED FROM KORNICK (1971)

SCALE

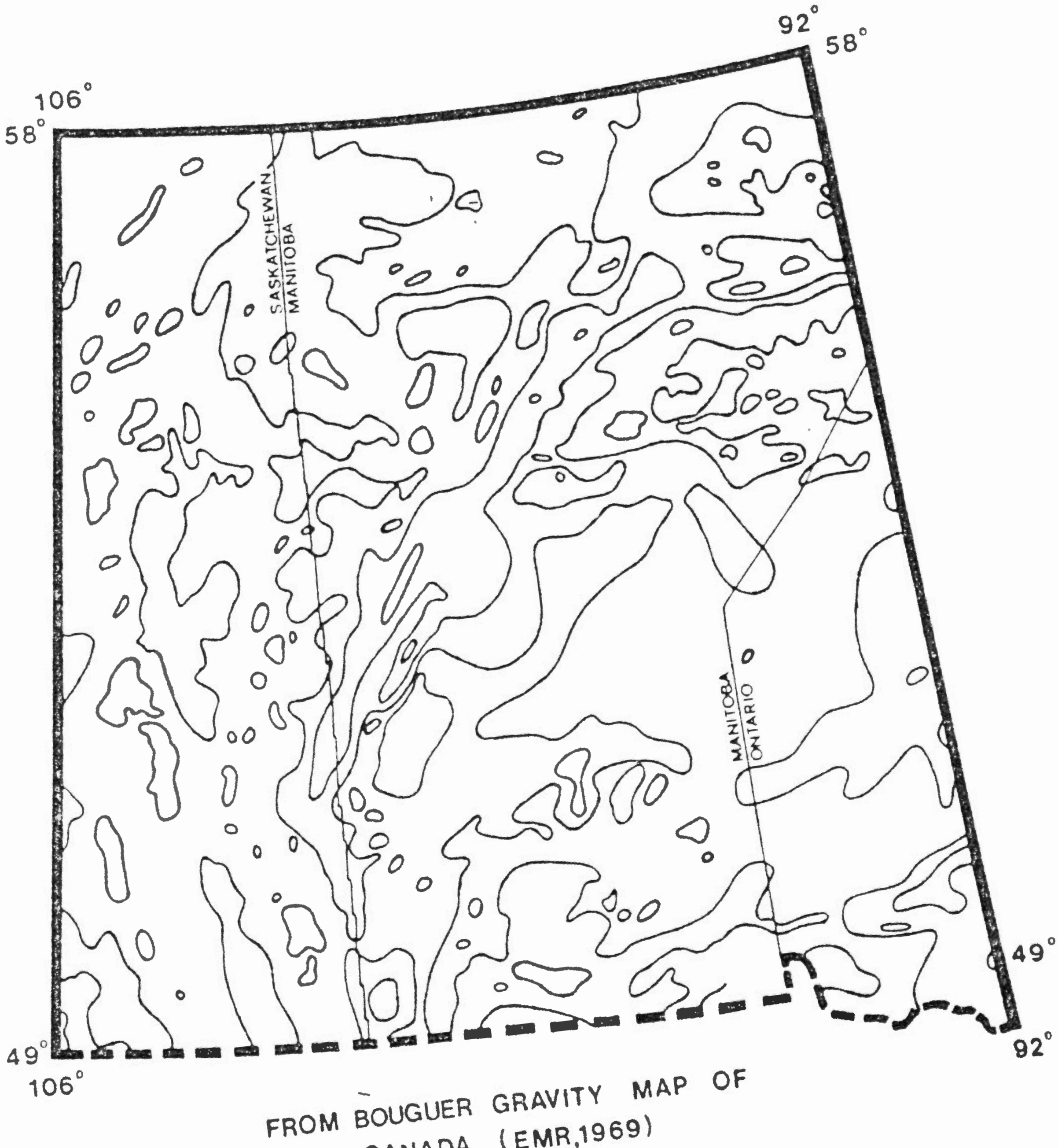
20 0 20 40 60 80 100 miles


55
B
A
51
102
D
100
4b
E
D
49
98
94



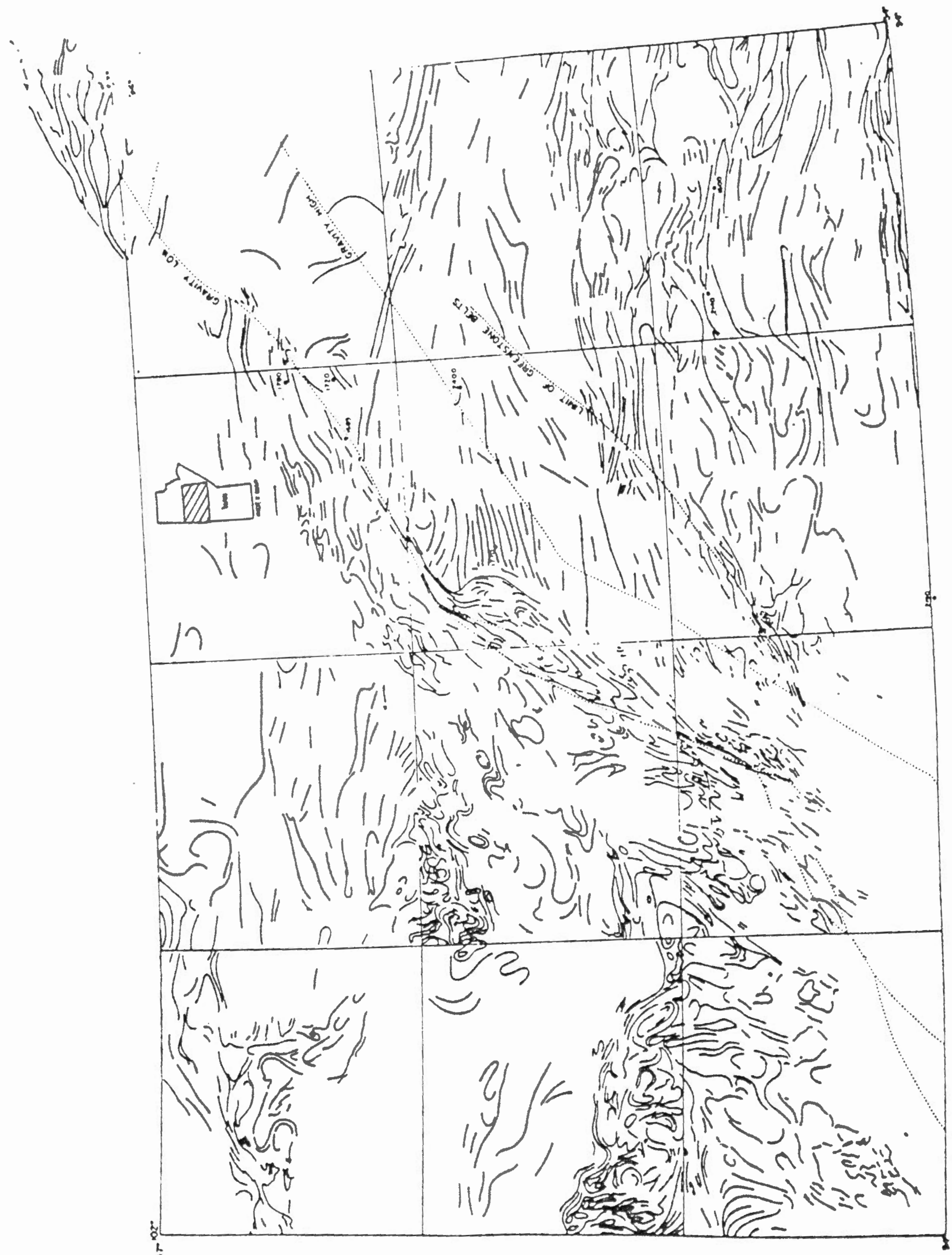
FROM MAGNETIC ANOMALY MAP OF CANADA (MAP 1255, EMR, 1977)

5

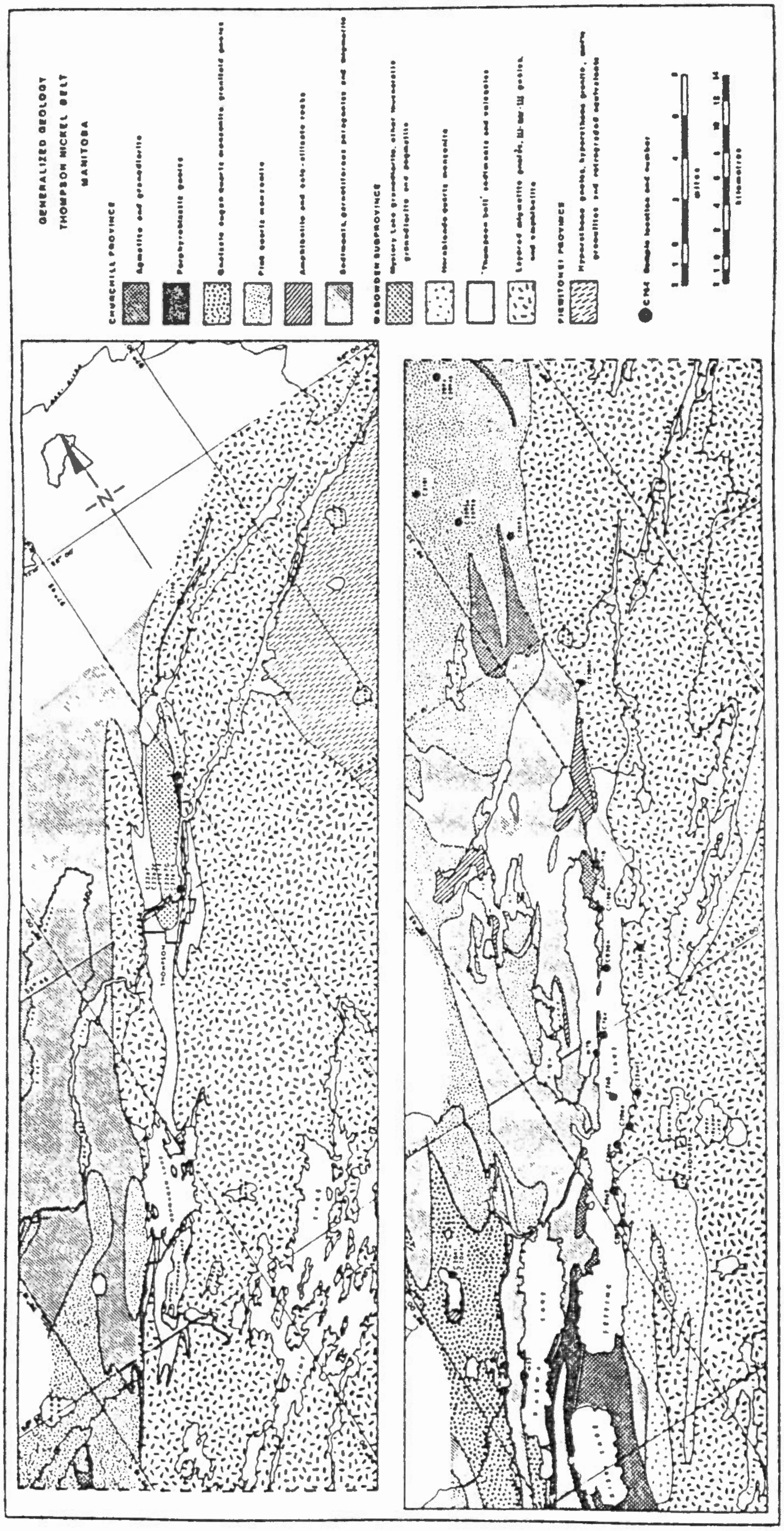


FROM BOUGUER GRAVITY MAP OF
CANADA (EMR,1969)

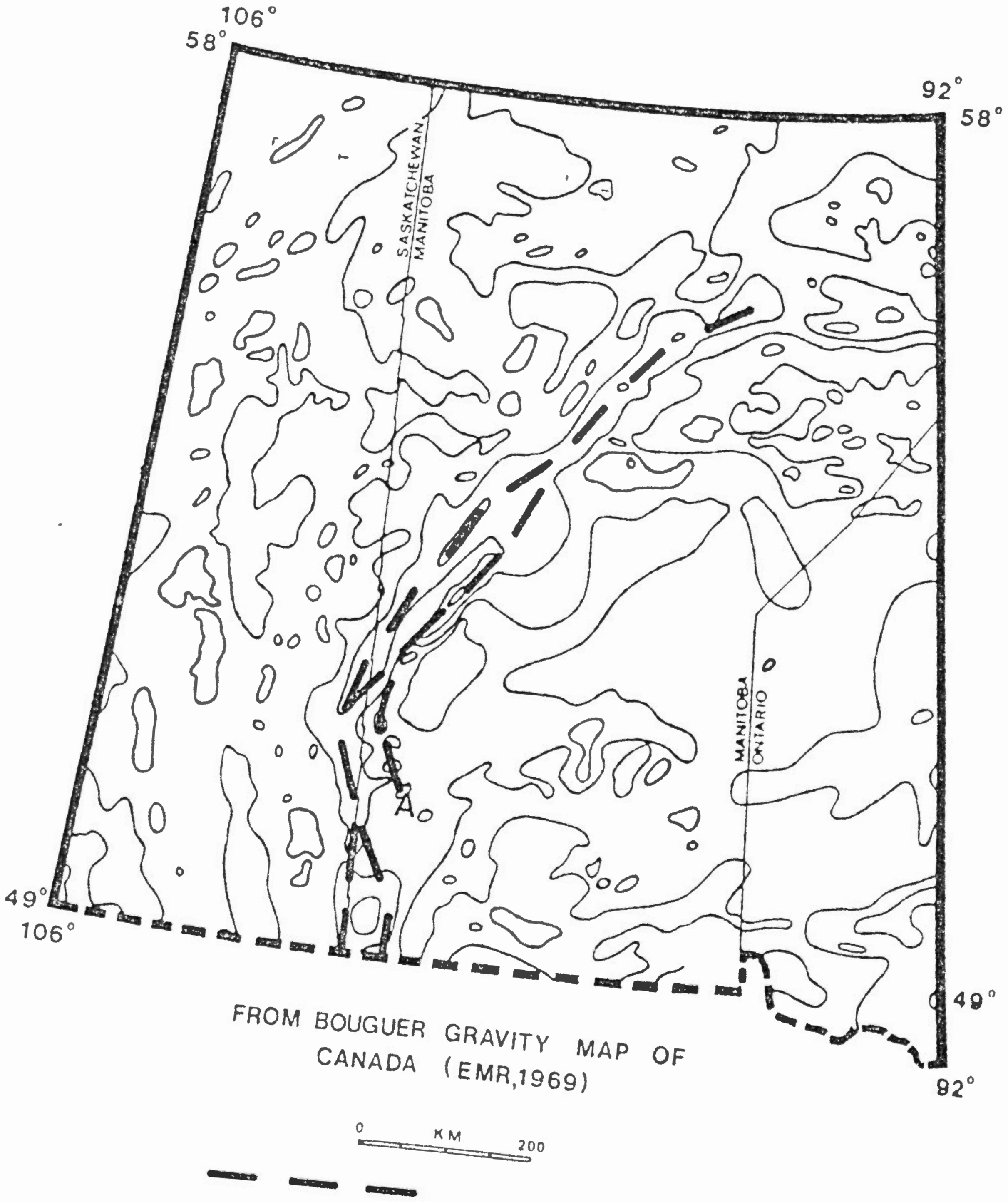
6



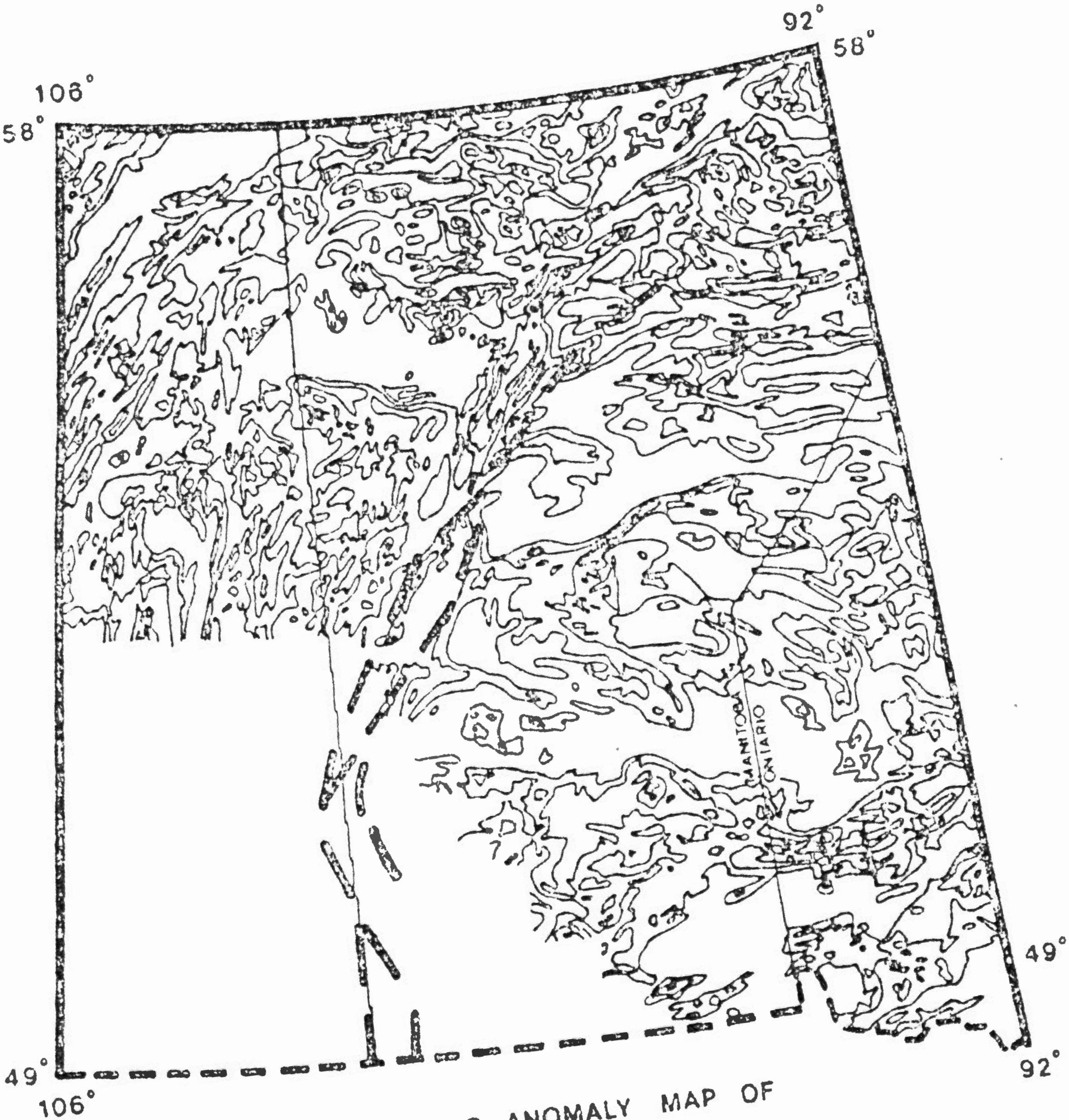
7


GENERALIZED GEOLOGY
THOMPSON NICKEL BELT
MANITOBA
CHURCHILL PROVINCE
PIKWITONEI PROVINCE
N
THOMPSON

8

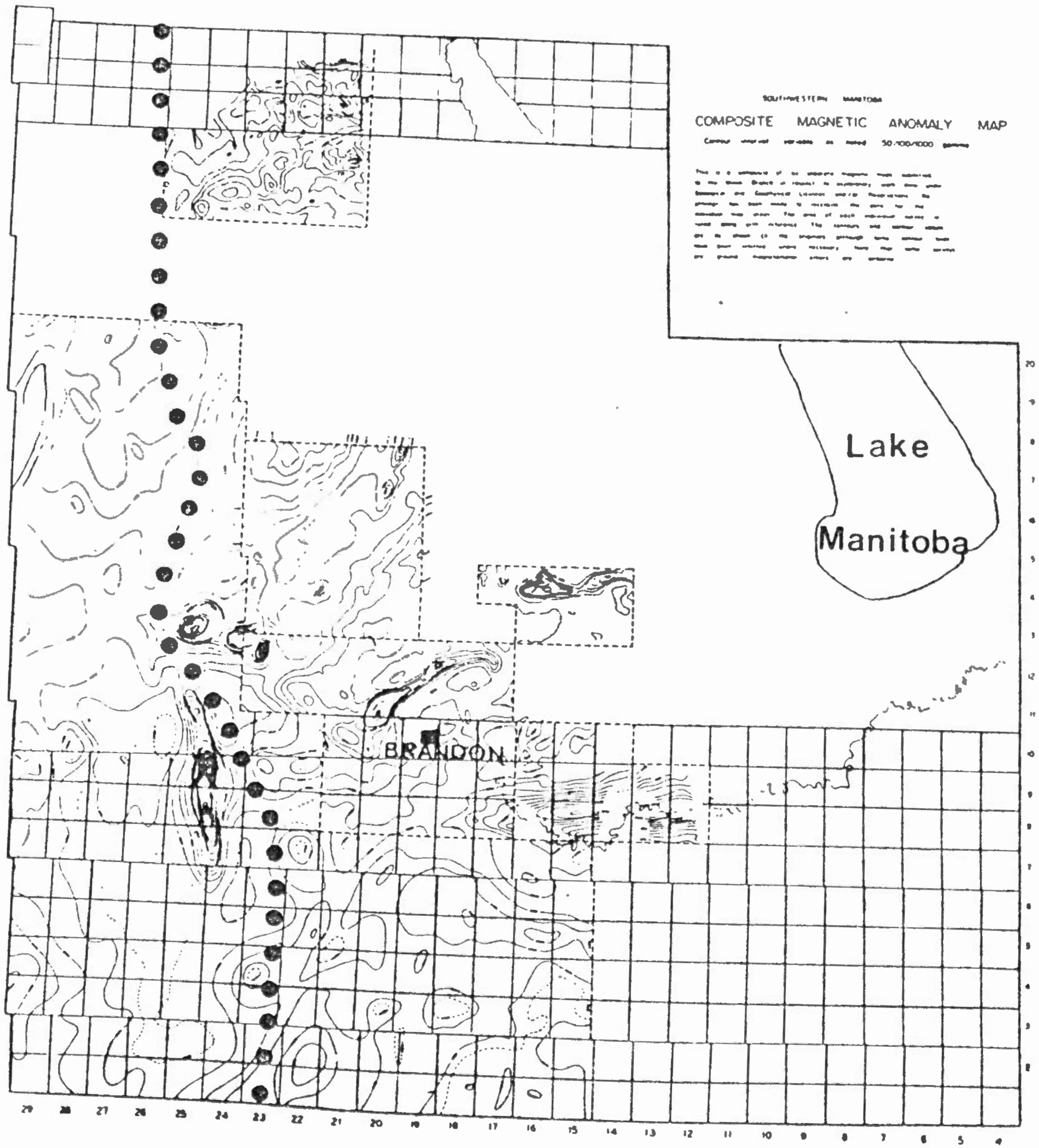

106°
58°
92°
58°
SASKATCHEWAN
MANITOBA
MANITOBA
ONTARIO
A
49°
106°
49°
92°
FROM BOUGUER GRAVITY MAP OF
CANADA (EMR,1969)
0
KM
200

9a

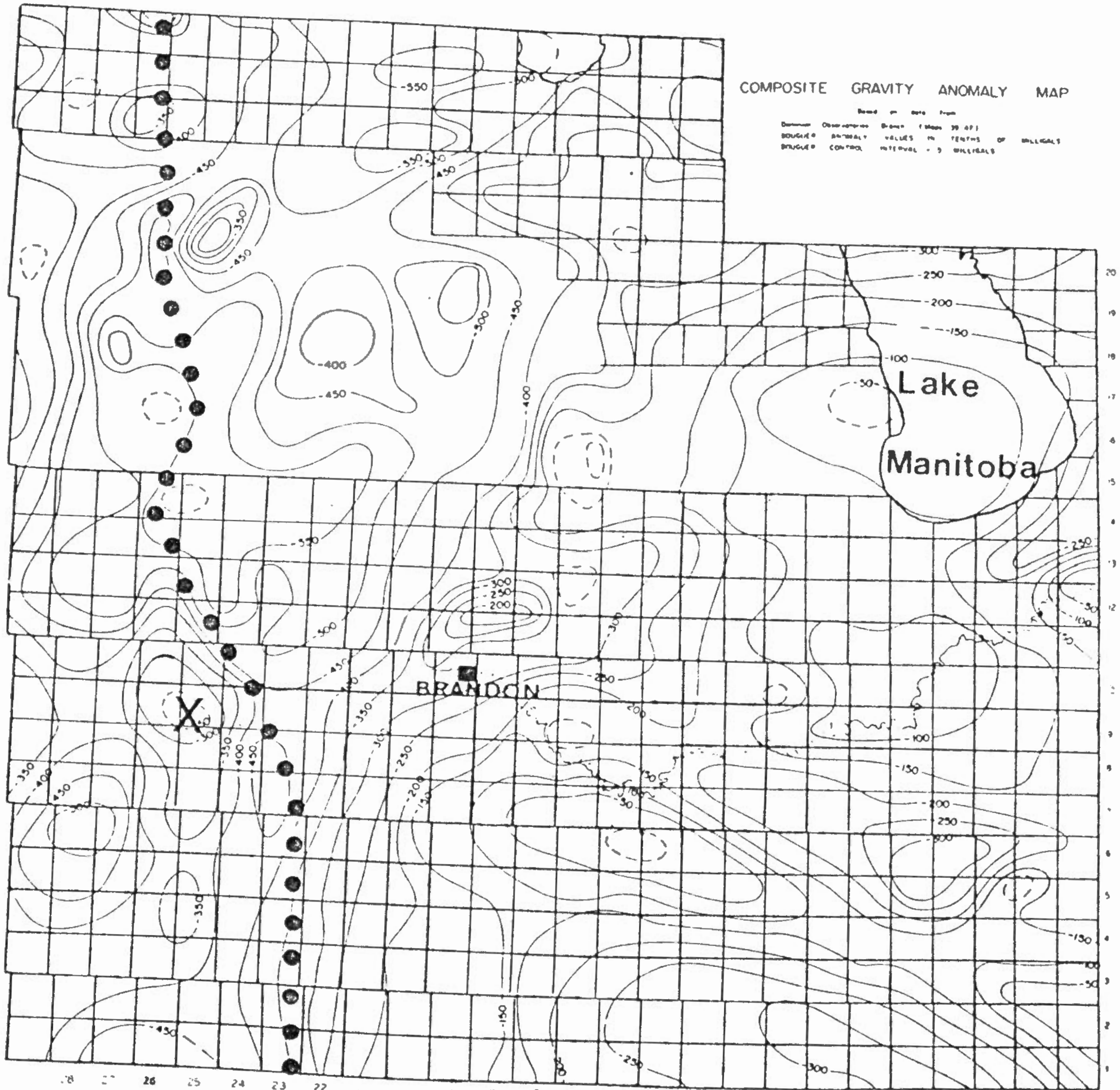


FROM MAGNETIC ANOMALY MAP OF CANADA (MAP 1255, EMR, 1977)

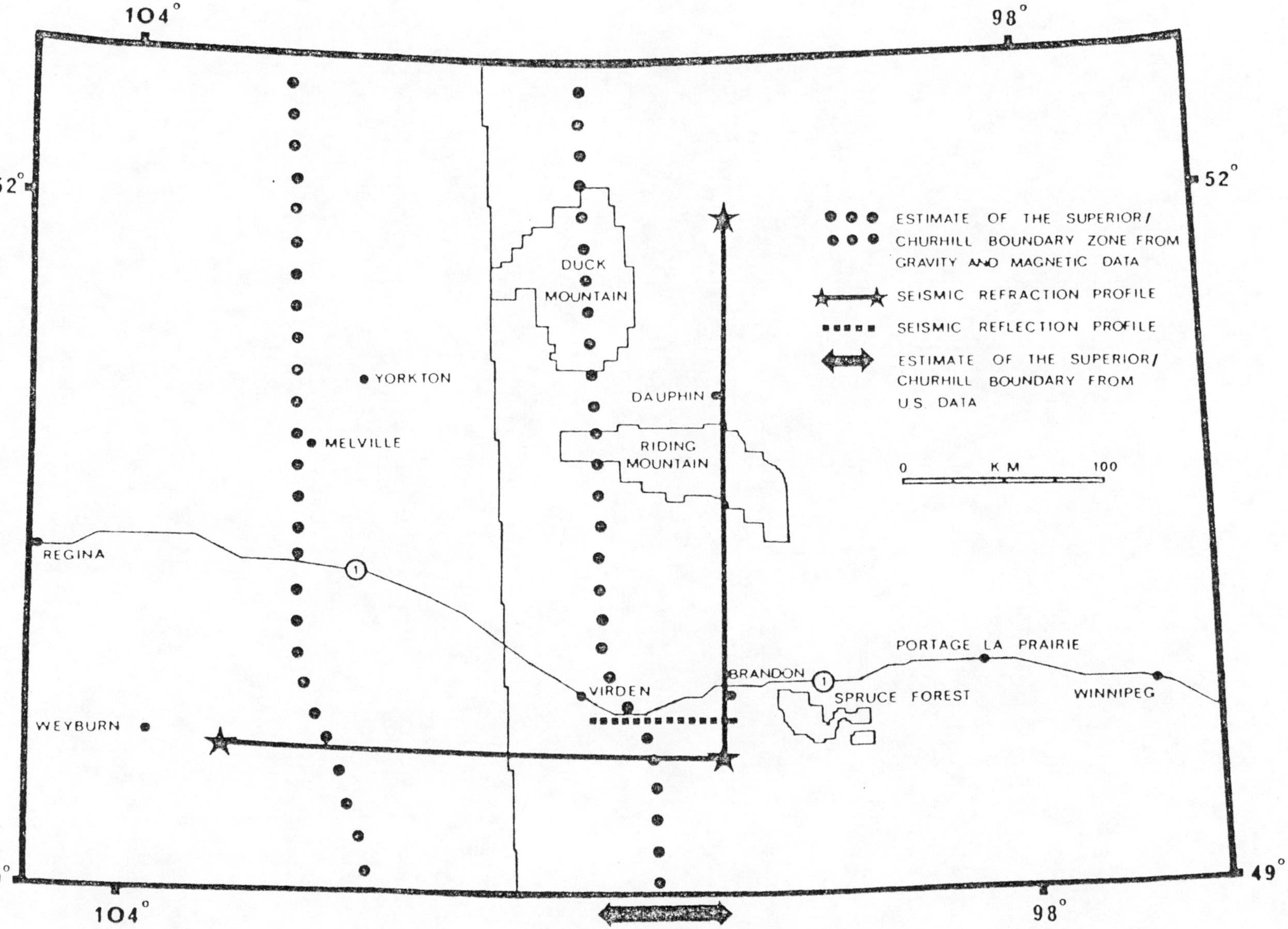
9b


COMPOSITE MAGNETIC ANOMALY MAP
Lake
Manitoba
BRANDON
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4

10

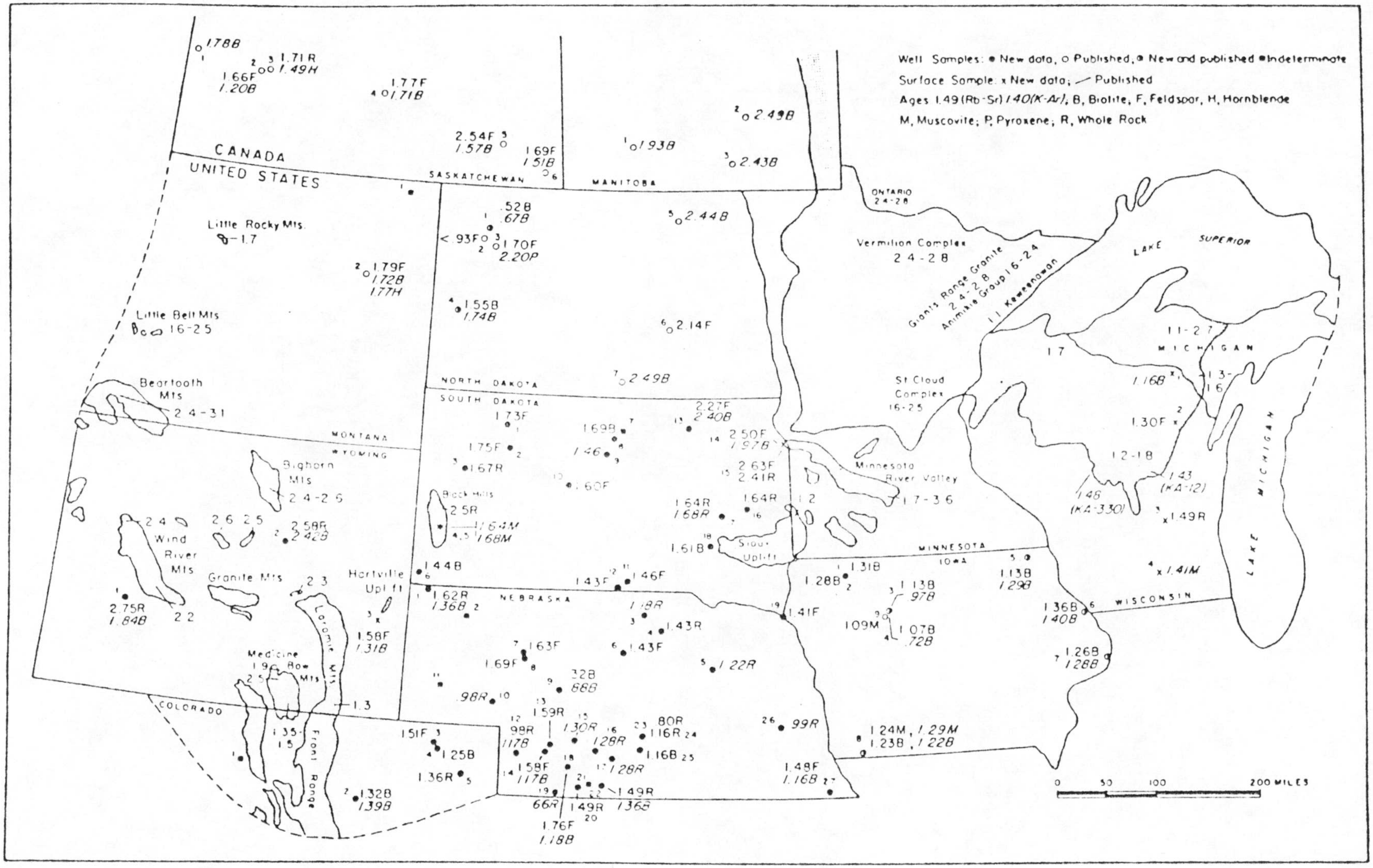


11

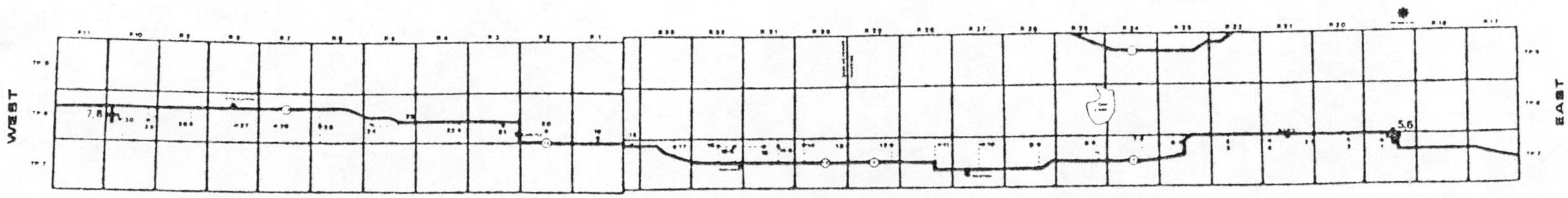


104°
98°
52°
52°
49°
49°
104°
98°
ESTIMATE OF THE SUPERIOR/ CHURHILL BOUNDARY ZONE FROM GRAVITY AND MAGNETIC DATA
SEISMIC REFRACTION PROFILE
SEISMIC REFLECTION PROFILE
ESTIMATE OF THE SUPERIOR/ CHURHILL BOUNDARY FROM U.S. DATA
0 KM 100
DUCK MOUNTAIN
YORKTON
MELVILLE
DAUPHIN
RIDING MOUNTAIN
REGINA
PORTAGE LA PRAIRIE
BRANDON
VIRDEN
SPRUCE FOREST
WINNIPEG
WEYBURN

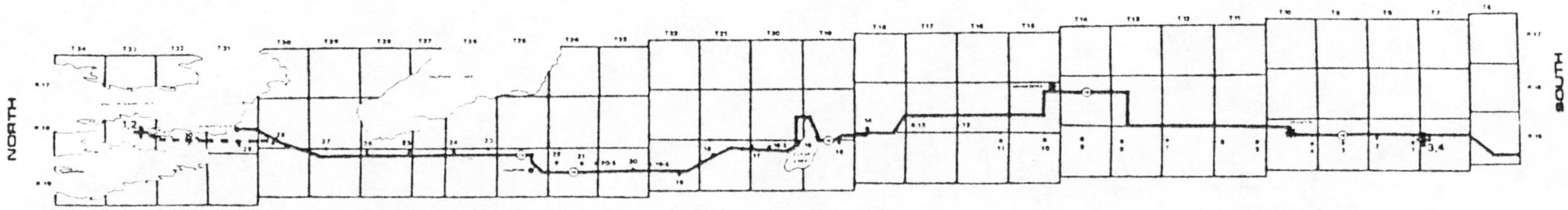
12


Well Samples: • New data, ○ Published, New and published, Indeterminate
Surface Sample: x New data; Published
Ages 1.49 (Rb-Sr) / 1.40 (K-Ar), B, Biotite, F, Feldspar, H, Hornblende
M, Muscovite; P, Pyroxene; R, Whole Rock
CANADA
UNITED STATES
SASKATCHEWAN
MANITOBA
ONTARIO
NORTH DAKOTA
SOUTH DAKOTA
MONTANA
WYOMING
NEBRASKA
COLORADO
MINNESOTA
IOWA
WISCONSIN
MICHIGAN
LAKE SUPERIOR
LAKE MICHIGAN
Little Rocky Mts.
Little Belt Mts
Beartooth Mts
Bighorn Mts
Wind River Mts
Granite Mts
Hartville Uplift
Laramie Mts
Medicine Bow Mts
Front Range
Black Hills
Sioux Uplift
Vermilion Complex 2.4-2.8
Giants Range Granite 2.4-2.8
Animikie Group 1.6-2.4
1.1 Keweenawan
St Cloud Complex 1.6-2.5
Minnesota River Valley 1.7-3.6
0 50 100 200 MILES

13



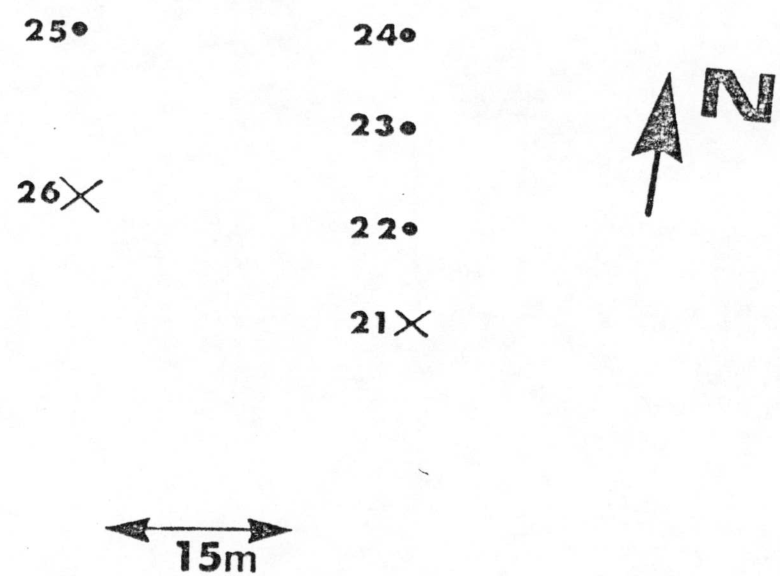
BRANDON 1977 REFRACTION SURVEY EAST/WEST LINE
SHOT LOCATIONS + ; RECEIVER LOCATIONS •



BRANDON 1977 REFRACTION SURVEY NORTH/SOUTH LINE
SHOT LOCATIONS + ; RECEIVER LOCATIONS •

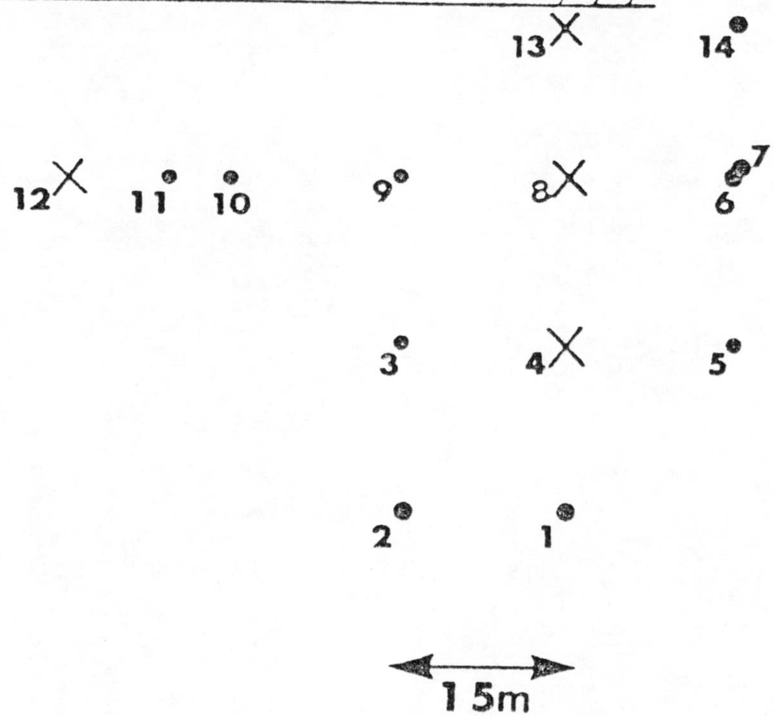
14a

N. SHOT POINTS 1,2

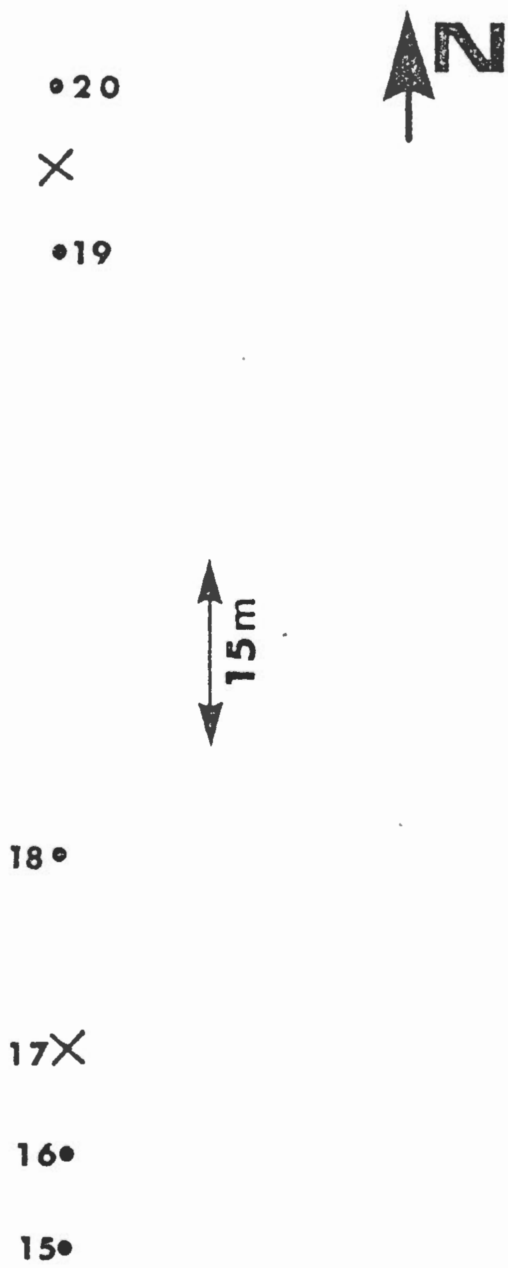


15

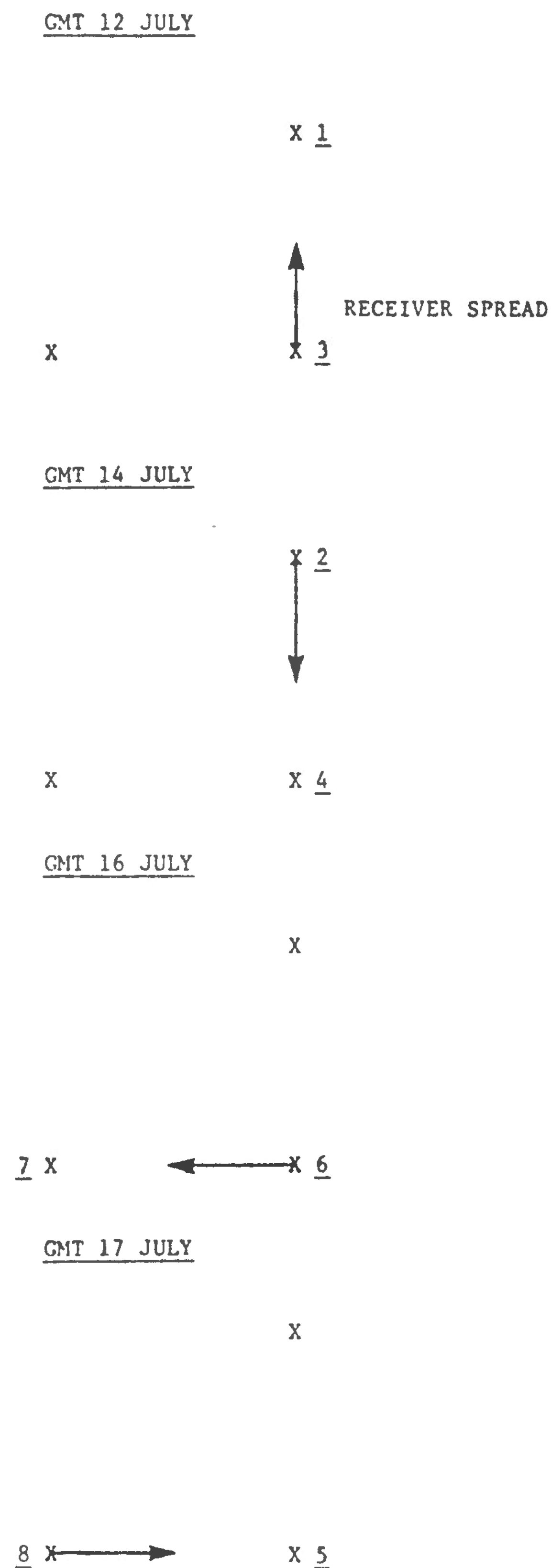
S. and E. SHOT POINTS 3,4,5,6

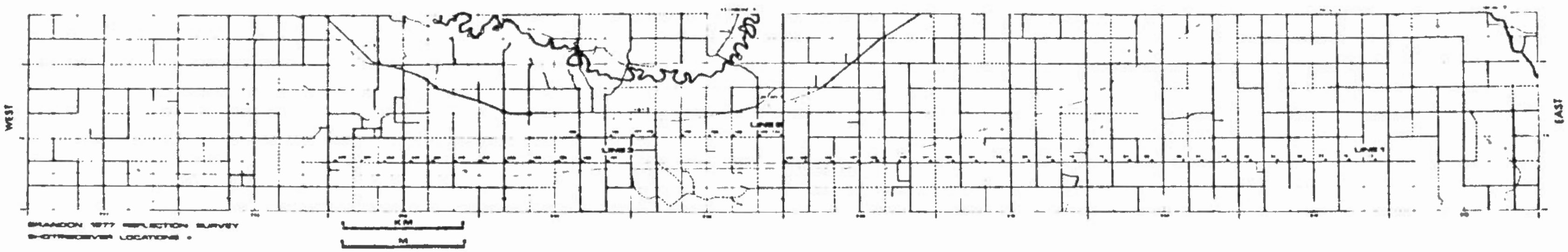


W. SHOT POINTS 7,8

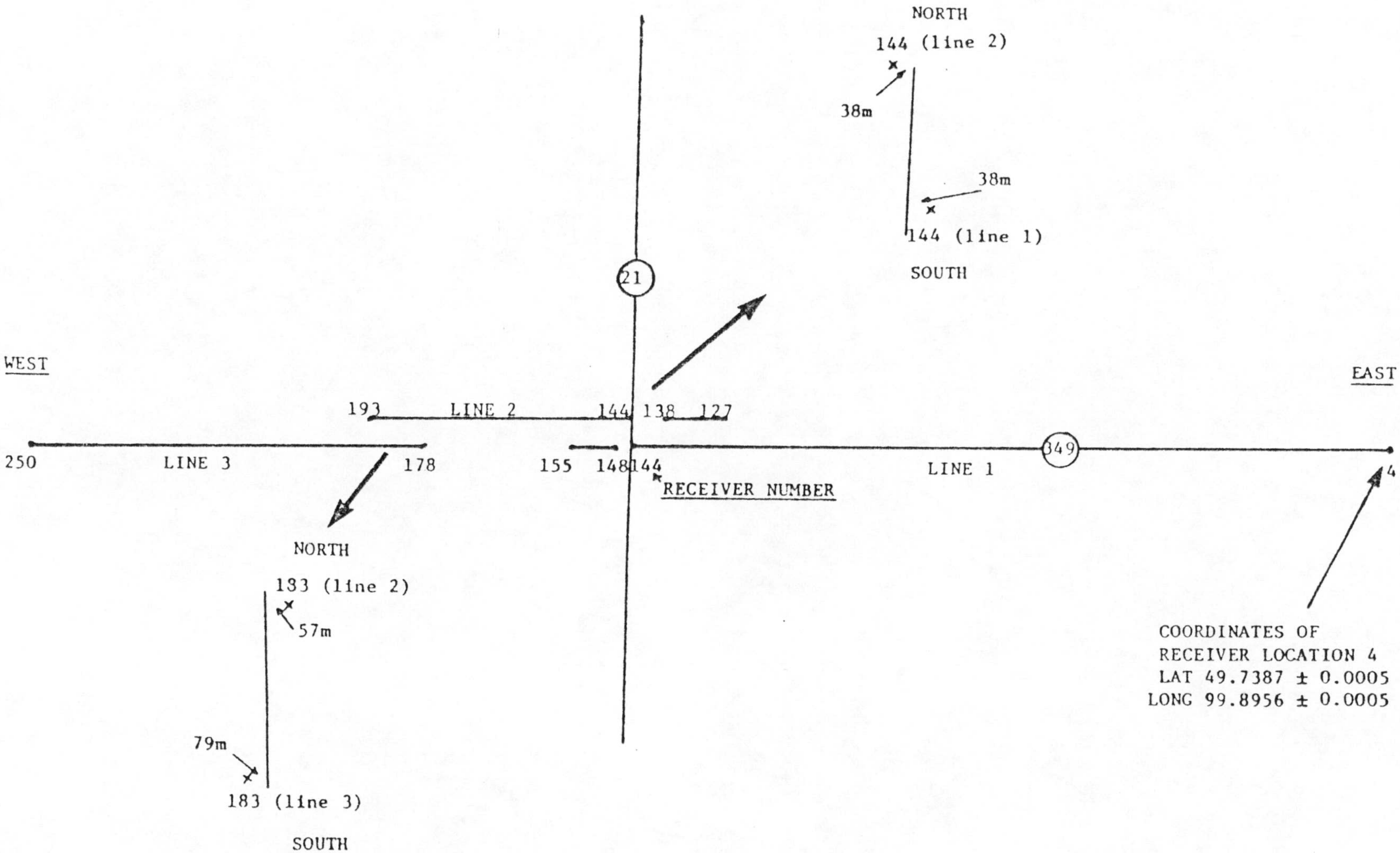


17


GMT 12 JULY
X 1
RECEIVER SPREAD
X
X 3
GMT 14 JULY
X 2
X
X 4
GMT 16 JULY
X
7 X
X 6
GMT 17 JULY
X
8 X
X 5


WEST
EAST
LINE 1
BRANDON 1977 REFLECTION SURVEY
SHOT/RECEIVER LOCATIONS
KM
M

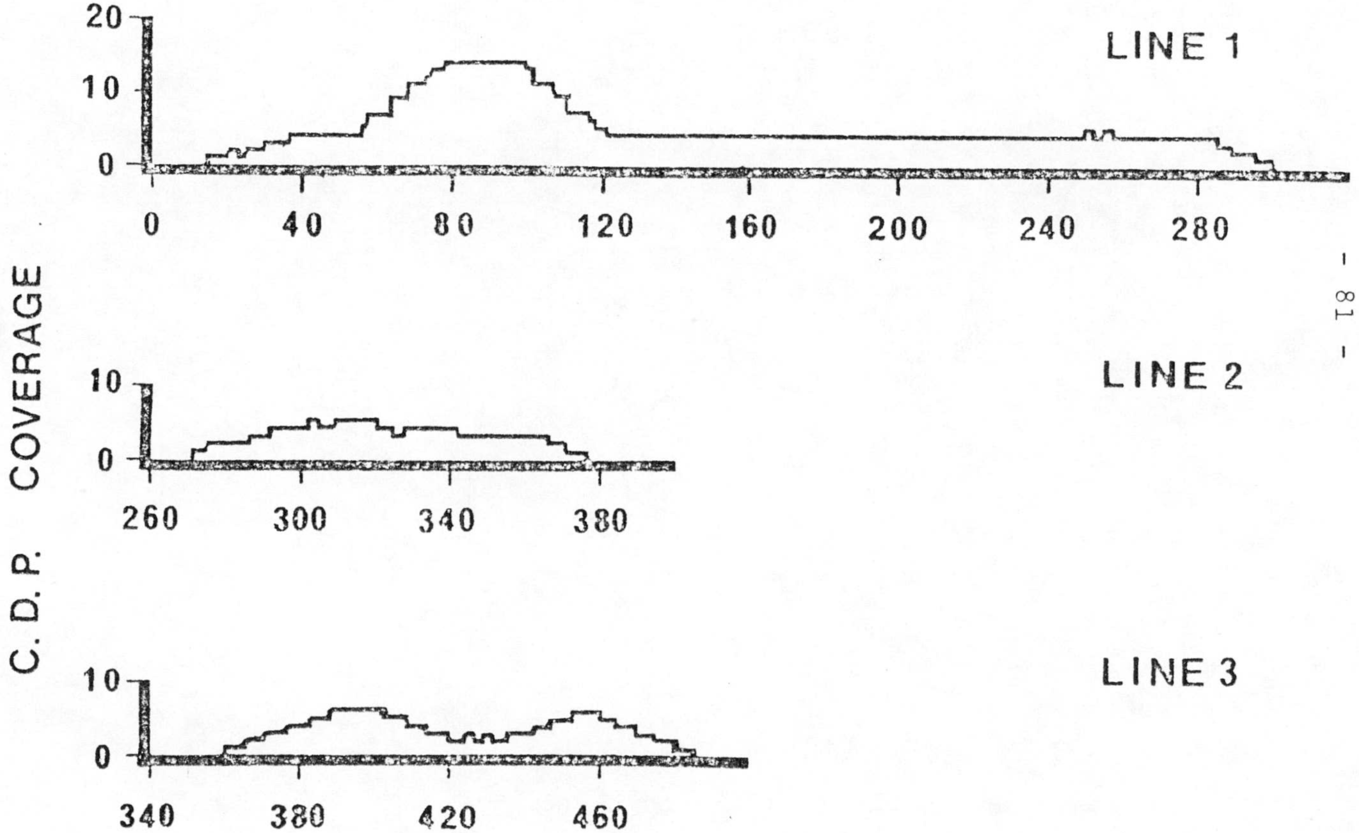
19



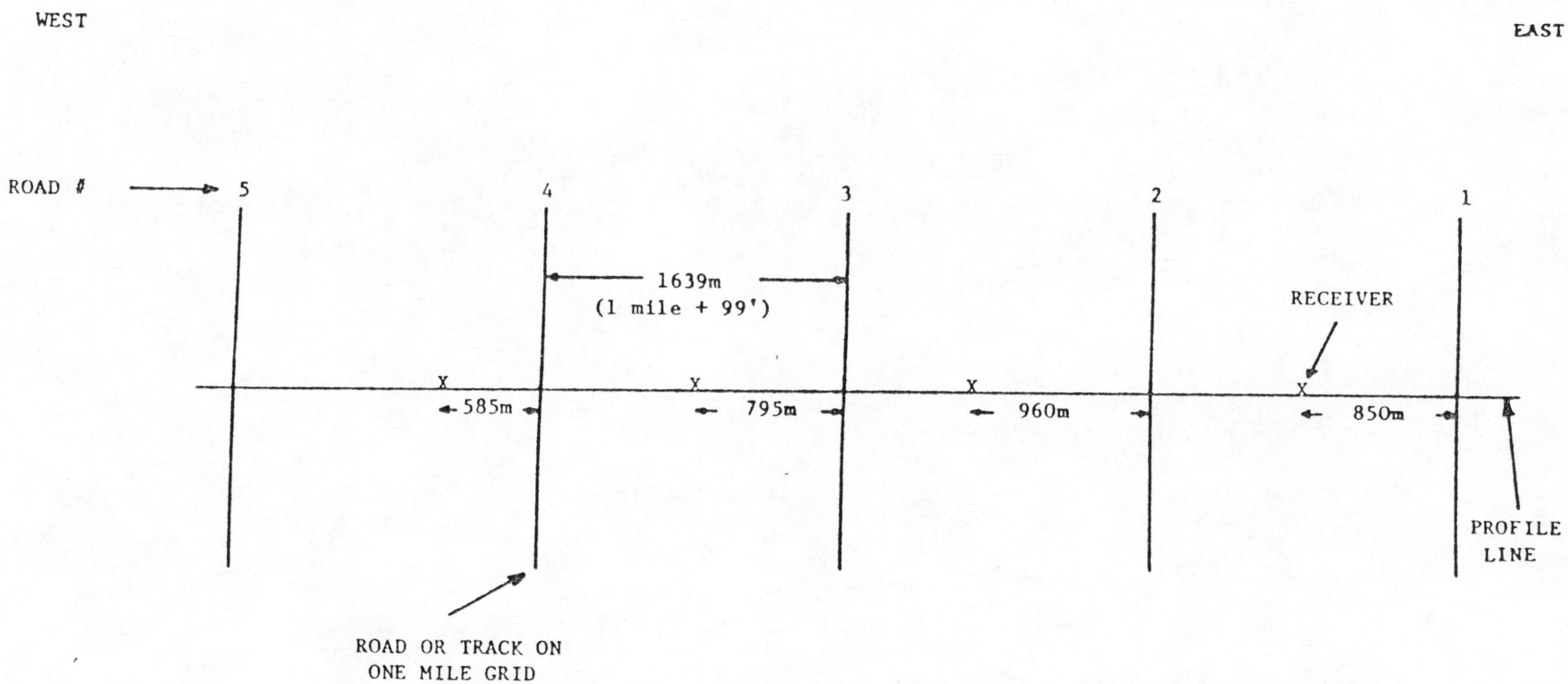
Distance between receivers = 292.5m

Overlap of lines - location 144 (line 2) is displaced 76m west relative to 144 (line 1)

location 183 (line 3) is displaced 136m west relative to 183 (line 2)

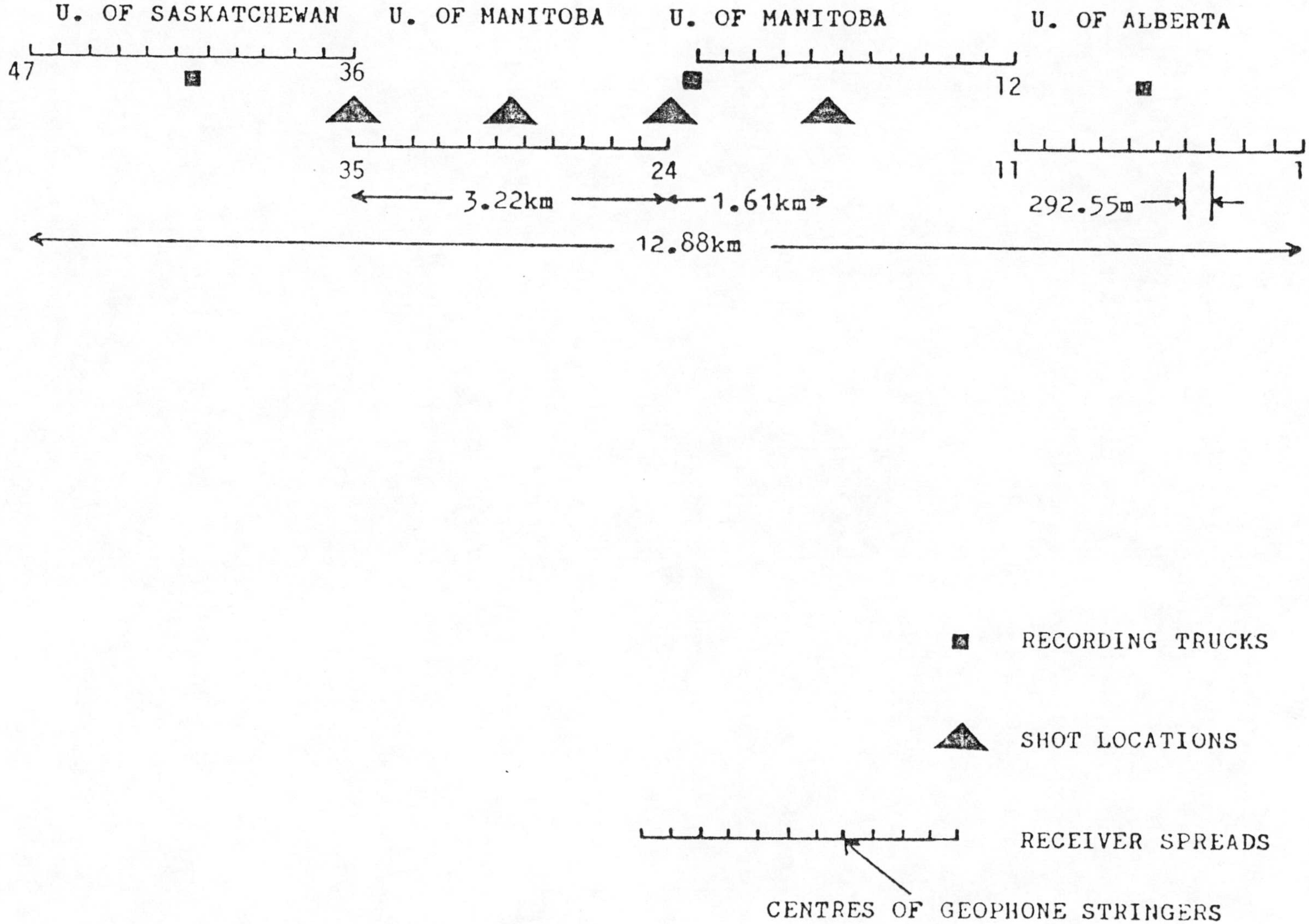

C. D. P. COVERAGE
LINE 1
20
10
0
0 40 80 120 160 200 240 280
LINE 2
10
0
260 300 340 380
LINE 3
10
0
340 380 420 460

22



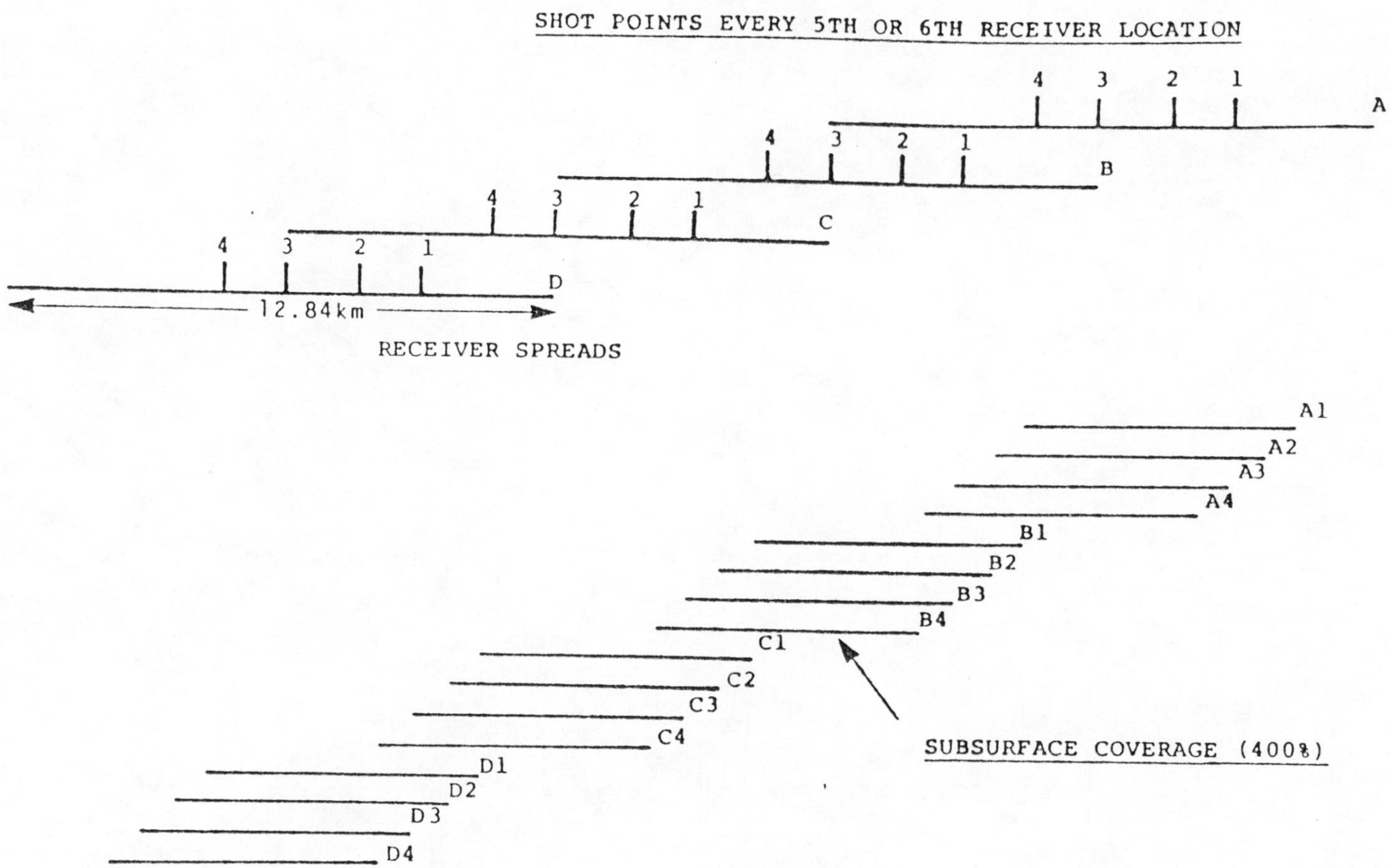
ROAD GRID IN S.W. MANITOBA IS ONE MILE (SECTION) PLUS 99' ROAD ALLOWANCE

24



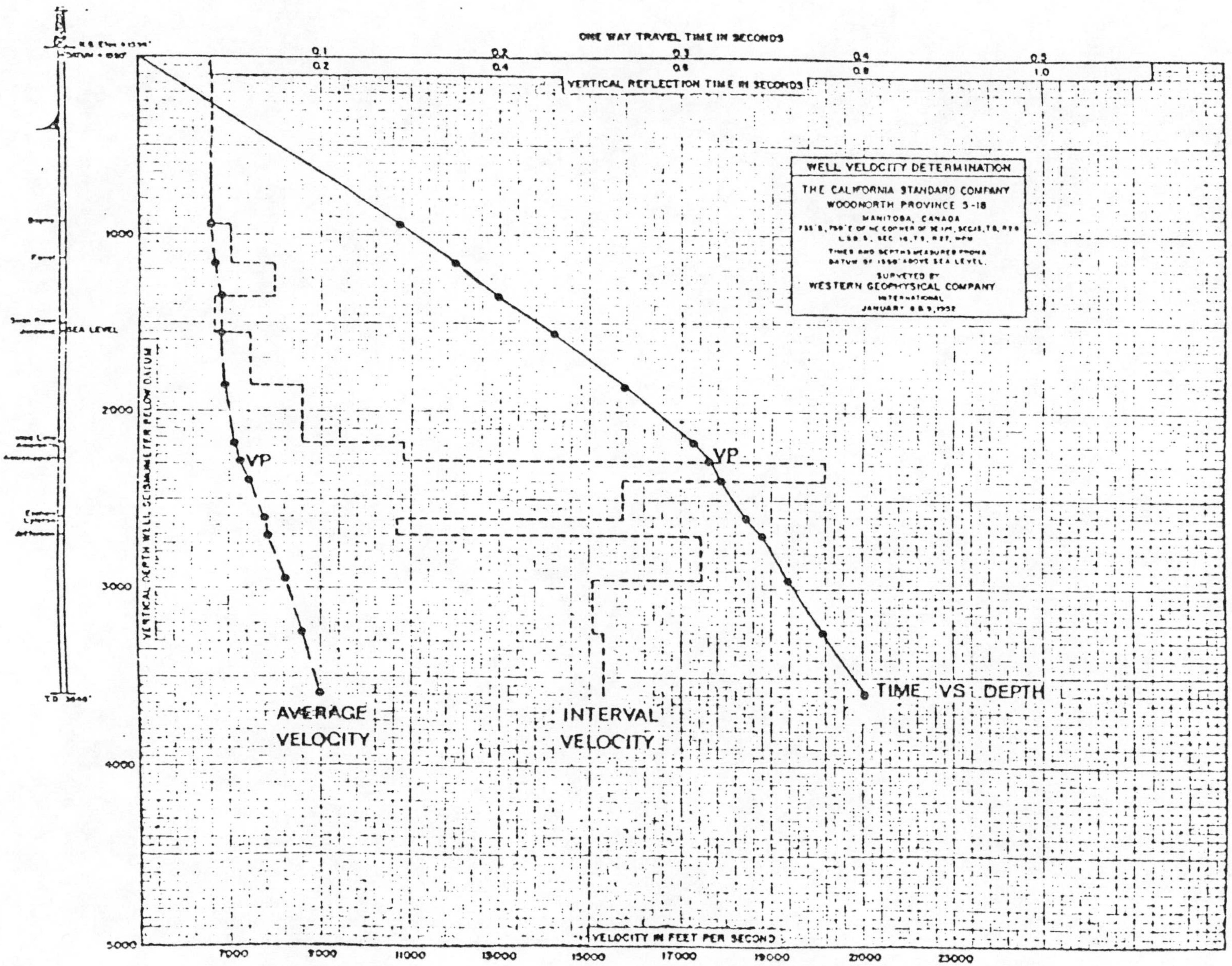
Shot - receiver configuration

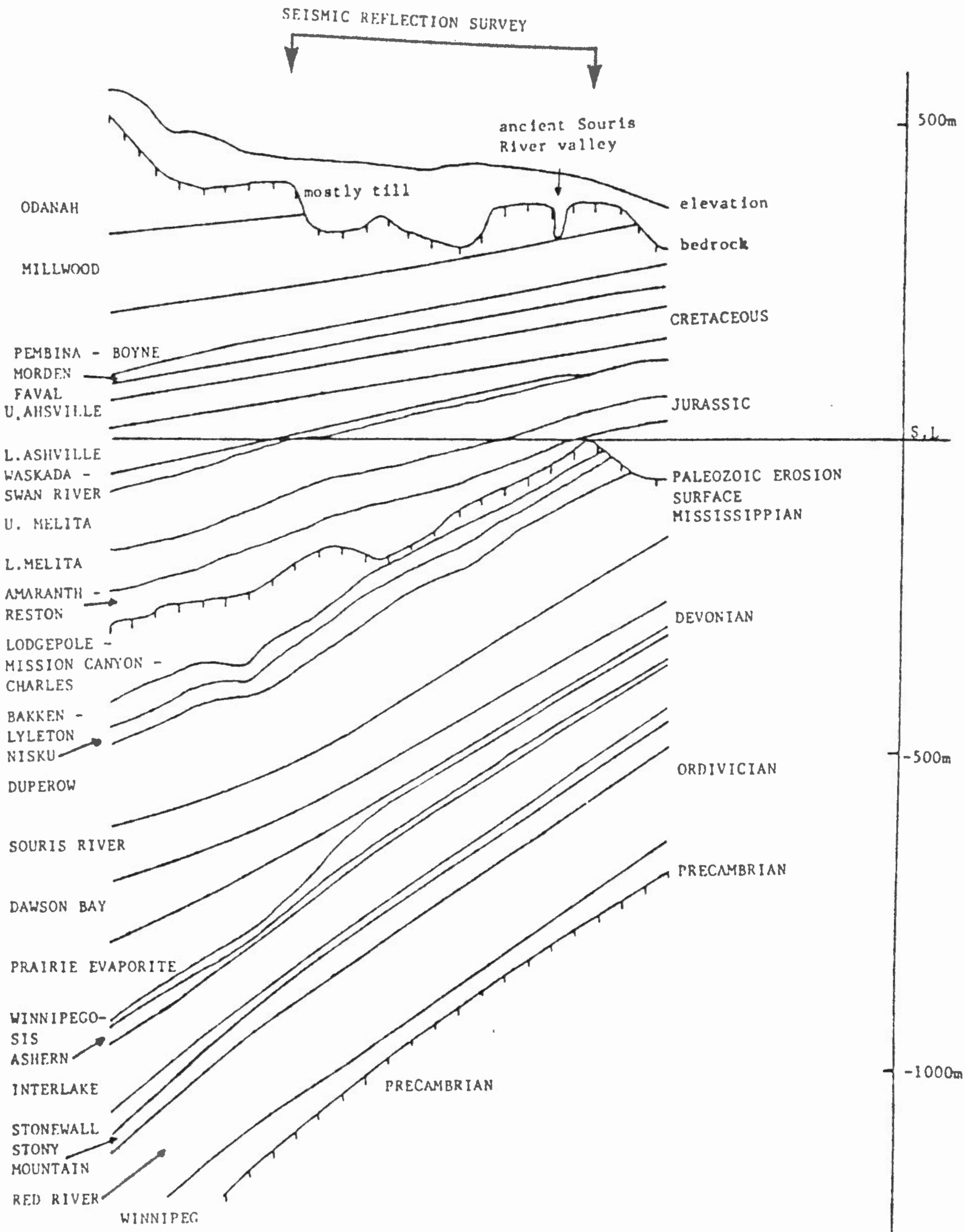
25



Shooting sequence. A shot is detonated at every 5th or 6th receiver location. At a few locations the shot point was moved one or more receiver positions from this ideal situation.

26


ONE WAY TRAVEL TIME IN SECONDS
VERTICAL REFLECTION TIME IN SECONDS
WELL VELOCITY DETERMINATION
THE CALIFORNIA STANDARD COMPANY
WOODNORTH PROVINCE 5-18
MANITOBA, CANADA
SURVEYED BY
WESTERN GEOPHYSICAL COMPANY
SEA LEVEL
VERTICAL DEPTH WELL SEISMOMETER BELOW DATUM
VP
VP
AVERAGE VELOCITY
INTERVAL VELOCITY
TIME VS DEPTH
VELOCITY IN FEET PER SECOND
1000
2000
3000
4000
5000
7000
9000
11000
13000
15000
17000
19000
21000
23000


SEISMIC REFLECTION SURVEY
ancient Souris River valley
mostly till
elevation
bedrock
500m
ODANAH
MILLWOOD
CRETACEOUS
PEMBINA - BOYNE
MORDEN
FAVAL
U.AHSVILLE
JURASSIC
S.L.
L.ASHVILLE
WASKADA -
SWAN RIVER
PALEOZOIC EROSION SURFACE
MISSISSIPPIAN
U. MELITA
L.MELITA
AMARANTH -
RESTON
DEVONIAN
LODGEPOLE -
MISSION CANYON -
CHARLES
BAKKEN -
LYLETON
NISKU
ORDIVICIAN
-500m
DUPEROW
SOURIS RIVER
PRECAMBRIAN
DAWSON BAY
PRAIRIE EVAPORITE
WINNIPEGO-
SIS
ASHERN
-1000m
INTERLAKE
PRECAMBRIAN
STONEWALL
STONY
MOUNTAIN
RED RIVER
WINNIPEG

REFERENCES

Bannatyne, B.B., 1970. The clays and shales of Manitoba. Manitoba Mines Branch Publication.

Bell, C.K., 1971a. History of the Superior-Churchill boundary in Manitoba. The Geological Association of Canada, Special Paper 9, p. 5.

Bell, C.K., 1971b. Boundary geology, Upper Nelson River Area, Manitoba and northwestern Ontario. The Geological Association of Canada, Special Paper 9, p. 11.

Cranstone, D.A. and Turek, A., 1976. Geological and geochronological relationships of the Thompson nickel belt, Manitoba. Canadian J. of Earth Sci. 13, p. 1058.

Gibb, R.A., 1968a. The densities of Precambrian rocks of northern Manitoba. Canadian J. of Earth Sci. 5, p. 433.

Gibb, R.A., 1968b. A geological interpretation of the Bouguer anomalies adjacent to the Churchill-Superior boundary in northern Manitoba. Canadian J. of Earth Sci. 5, p. 439.

Goldich, S.S., Lidiak, E.G., Hedge, C.E. and Walthall, F.G., 1965. Geochronology of the Midcontinent region, United States. J. Geophys. Res. 71, p. 5389.

Innes, M.J.S., 1960. Gravity and isostacy in northern Ontario and Manitoba. Publ. Dominion Observatory, Ottawa, vol. XXI, no. 6.

Hall, D.H., 1968. Regional magnetic anomalies, magnetic units, and crustal structure in the Kenora District of Ontario. Canadian J. of Earth Sci. 5, p. 1277.

Hall, D.H., 1971. Geophysical determination of deep crustal structure in Manitoba. The Geological Association of Canada, Special Paper 9, p. 83.

Hall, D.H., 1974. Long-wavelength aeromagnetic anomalies and deep crustal magnetization in Manitoba and northwestern Ontario, Canada. J. Geophys. 40, p. 403.

Kornik, L.J., 1969. An aeromagnetic study of the Moak Lake-Setting Lake structure in northern Manitoba. Canadian J. of Earth Sci. 6, p. 373.

Kornik, L.J., 1971. Magnetic subdivision of Precambrian rocks in Manitoba. The Geological Association of Canada, Special Paper 9, p. 51.

Kornik, L.J. and MacLaren, A.S., 1966. Aeromagnetic study of Churchill-Superior boundary in northern Manitoba. Canadian J. of Earth Sci. 3, p. 547.

McCabe, H.R., 1967. Tectonic framework of Paleozoic formations in Manitoba. Trans. Can. Inst. Mining Met., vol. LXX, p. 180.

McCabe, H.R., 1971. Stratigraphy of Manitoba, an introduction and review. The Geological Association of Canada, Special Paper 9, p. 167.

Meuhlberger, W.R., Denison, R.E. and Liliak, E.G., 1967. Basement rocks in the continental interior of the United States. The Am. Ass. of Petrol. Geol. Bull. 51, p. 2351.

Scoates, R.F.J. and Clark, G.S., 1978. Rb-Sr ages from the Churchill-Superior boundary zone in the Fox River area, northeastern Manitoba. (in preparation).

Weber, W. and Scoates, R.F.J., 1978. Archean and Proterozoic metamorphism in the northwestern Superior province and the Churchill-Superior boundary, Manitoba. (in press).

Wilson, H.D.B., 1971. The Superior province of Manitoba. The Geological Association of Canada, Special Paper 9, p. 41.

Wilson, H.D.B. and Brisbin, W.C., 1961. Regional structure of the Thompson-Moak Lake nickel belt. Bull. Can. Inst. Mining Met. 64, p. 815.

Wilson, H.D.B. and Brisbin, W.C., 1962. Tectonics of the Canadian Shield in northern Manitoba. The tectonics of the Canadian Shield, Roy. Soc. Can. Sp. Publ. No. 4, p. 60.

APPENDIX A

Refraction/wide angle reflection survey tape format.

Each seismic record consists of an alphanumeric header (10 card images), a six character (numeric) file identifier and 10799 data values for the EPB (Earth Physics Branch) data and 10799 data values for the UT (University of Toronto) data (with some padded zeros).

The alphanumeric header can be read as 10 card images (10 x 80 characters) with a 20A4 format:

Card #

1. title of experiment
2. line, date, shot time and shot size
3. shot location - number (specified on the supplied data sheets), latitude and longitude
4. shot elevation and depth, receiver elevation
5. receiver location - number (see code below), latitude and longitude
6. seismometer type, peak frequency and orientation. The orientation may be either vertical, N/S horizontal, E/W horizontal, remote vertical or radial horizontal.
7. recorder type, sampling interval and gain

Card images 8 to 10 contain additional information:-

EPB Records

Card #

8. blank
9. information about the file (specified above)
10. time of first data sample (may be up to 16 m.s. before shot time)

UT Records

Card #

8.

9.

10.

The six character identification tag and the data may be read with the following format (200A4). The identification tag contains the receiver and shot numbers and the instrument type.

Coded receiver numbers are field receiver numbers multiplied by 10:

field receiver number	new receiver number
1	010
2	020
3	030
⋮	⋮
16	160
16.5	165
⋮	⋮
31	310

Coded shot receiver numbers are the same as the field shot numbers 1 to 8, as described in the text.

Instrument types are coded - 1 vertical

2 remote vertical

3 N/S horizontal

4 E/W horizontal

5 additional local vertical

Example of coded identification tag:

receiver — shot # — instrument type

05041 — 5th receiver, shot number 4, vertical seismometer.

Seismic records (10799 values at 16.7 m.s., 180 sec. of data) are stored on the tape in the following sequence:

S. shot points locations 1 to 31

N. shot points locations 1 to 31

E. shot points locations 1 to 30

W. shot points locations 1 to 30

Each location has three records that are stored in order (eg. 1, 3, 4).

EPB data compression is down

UT data compression is up.

Records start approximately 10.0 seconds prior to shot time and extend for approximately 180.0 seconds. The submitted tape is unlabelled, the header is EBDIC coded, the identification tag and data are binary (A4).

One's complement

Odd parity

800 byte LRECL

1600 phase encoded BPS

There are a total of ? seismic records on the tape. Each seismic record has a header as described above. A computer program that reads all the header information and identification tags is given on the next page. The results of applying this program is given in Appendix B.

APPENDIX B

(see computer program folder)

TO FOLLOW LATER

APPENDIX C

Near vertical incidence reflection survey tape format

(a) Adjustments and information relative to the data

1. The University of Saskatchewan data were recorded in analogue form and digitized at 4 m.s. sampling interval in the laboratory.
2. The University of Alberta data were recorded with a 5.6 m.s. digital interval and subsequently interpolated to give a digital interval of 4 m.s.
3. The University of Manitoba data were recorded with a 1 m.s. digital interval and subsequently decimated to give a digital interval of 4 m.s.
4. Data on any individual trace have been adjusted to a single gain, except for the samples specified by bytes 19 to 22 in the trace header. These samples (usually data following first breaks) have been attenuated by a factor $\frac{1}{10}$ to keep the values within the dynamic range that can be specified by a 2 byte word.
5. A Butterworth band pass filter has been applied to all data; 3 to 55 Hz to the Manitoba and Alberta data and 0 to 55 Hz to the Saskatchewan data.
6. In most cases the null or useless traces have been included on the tape (packed with zeros if necessary) and weighted as described later. Traces that are not included on the submitted tapes are:

Shots	Traces
test shot 12B	1 to 47 (i.e. all traces)
test shot 12	1, 2 and 12 to 47
216, 221, 226, 232	1 to 11
237, 243	37 to 47.

7. Shot 12B, the first test shot, has not been included on the tape. Manitoba and Saskatchewan did not process shot 12, the second test shot, Alberta did not record shots 216, 221, 226, 232, 237 and 243.
8. Alberta recorded a trace at receiver location number 3. This receiver was approximately 292 m east of the first receiver location (number 4) that is shown in the tables and figures. In the text, receiver number 4 is taken as the first receiver of line 1.
9. Sample 451 on the tape is the first sample after zero time (from the time or tone break). Samples 1 to 450 are noise samples prior to shot instant (1.800s noise). Samples 451 to 5600 can be considered as signal samples (20.400s signal).

(b) Tape format

Header Logical Record - 11200 bytes of information that precedes the data logical records for each line (only 1 header logical record/line).

byte number

0-3 job identification - BN77

4-5 line number

- 1 for the main line stations 1 to 155

  2 for the northern line stations 127 to 193

  3 for the main line stations 178 to 250

6-7 number of shot points on the line

- 38 for line number 1 (includes the two test shots, the expanding spread and two reshots).

  N.B. shot 12B is not included

  N.B. other traces not included

byte number

6-7 (cont'd.)

- 8 for line number 2
- 12 for line number 3

8-9 number of traces/record

- 11 U of A (empty or useless traces have been included
- 24 U of M and weighted as described later)
- 12 U of S

10-11 sampling rate - 4 m.s.

12-13 number of samples/trace

- 5600 (2 bytes/sample - this number includes trace header information)

Total number of traces per line:-

line 1 - 1701
2 - 376
3 - 498

Additional information may be included in the remaining part of the block.

Data Logical Records

Trace Header

byte number

1-2 5 digit identifier - XXXXX

1st digit	2nd to 4th digits	5th digit
crew number	shot point number	shot number subscript

- crew numbers 1 - U of A
  2 - U of M
  3 - U of S

- shot point numbers 12 to 243

byte number

1-2 (cont'd.)

- shot subscript 0 - 1st shot

  1 - 2nd shot (A in the field)

  2 - 3rd shot (B in the field)

(e.g. 21440 - U of M record for shot 144;

10181 - U of A record for shot 18A)

3-4 trace number (see Appendices D and E)

- for most records the following applies:

  1 to 11 - U of A

  12 to 35 - U of M

  36 to 47 - U of S

- traces 11 and 12 overlap; traces 35 and 36 overlap

- traces 1 to 47 go from E. to W.

- for records from shot points (144, 149, 155, 160, 166):

  1 to 12 - U of S

  13 to 36 - U of M

  37 to 47 - U of A

- for records from shot points (237, 243):

  1 to 24 - U of M

  25 to 36 - U of S

  no record from U of A

- for a <u>poor</u> trace (one that has useful information but may/should not be included in a CDP stack) 100 is added to the trace number

- for a <u>useless or empty</u> trace 200 is added to the trace number

  e.g. good trace number 32 reads 032

byte number

3-4	(cont'd.)
	poor trace number 32 reads 132
	dead trace number 32 reads 232)
5-6	receiver number
7-8	ensemble sequence number
9-10	receiver elevation in meters
11-12	bottom of shot hole elevation
13-14	top of shot hole elevation
15-16	the north-south distance (meters) of the shot hole from the nearest surveyed location (north is positive, south is negative).
17-18	the east-west distance (meters) of the shot hole from the nearest surveyed location (east is positive, west is negative).
19-20	distance of receiver from shot point in meters
21-22	digital band pass filter characteristics XXXX 1st to 2nd digits — 3rd to 4th digits low pass filter — high pass filter (e.g. 0355 - 3 to 55 Hz band pass)
23-24	the first sample affected by an attenuation factor of $\frac{1}{10}$ (0 if no attenuation applied)
25-26	the last sample affected by an attenuation factor of $\frac{1}{10}$ (0 if no attenuation applied)
27-28	relative gain - lowest gain of all recordings is set to zero, and other gain values are relative

byte number

29-30 instrument band pass at recording (code as for digital band pass above)

31-32 line balance and/or notch filter in or out

XX

1st digit	2nd digit
0 - line balance out	0 - notch filter out
1 - line balance in	1 - notch filter in

33-34 shot size in kg

- all shots 38 kg except:

12	- 7 kg
23 and 28	- 76 kg
133	- 45 kg
139	- 15 kg
237,55A,62A,67A	- 30 kg
243	- 27 kg

35-100 any additional information or blank - see Appendix E

Data

101-1000 noise samples prior to shot instance (zero time)

- samples 1 to 450 noise time 1.800s

1001-11200 signal samples after and including the shot instance

- samples 451 to 5600 signal time - 20.400s

(sample 451 is the first sample closest to, but after the shot instance; total of 22.200s of information)

Header logical record	trace header	trace 1 from shot 1	trace header	trace 2 from shot 1

11200 bytes per logical record

APPENDIX D

Description of computer printout:

Sub	subscript	0 - no subscript in the field
		1 - subscript A in the field
		2 - subscript B in the field
except:	subscript	0 - shot 12, 2nd test shot
		1 - shot 12A, expanding spread shot
		2 - shot 12B, 1st test shot
		0 - 144 line 1, 182 line 2
		1 - 144 line 2, 182 line 3.

Except for shots 144 (lines 1 and 2) and 182 (lines 2 and 3), the subscripts for a given shot number refer to shots at essentially the same shot point (with the same receiver configuration).

Line	line number
Shot	shot number
Trace	trace or channel number
Receiver	number location of the receiver as shown on the surveyor's pickets and Fig.23 .
Ensembl	ensemble number for CDP
Elevr	elevation of receiver
Elevs1	bottom of shot point elevation
Elevs2	top of shot point elevation
Nssh	shot distance (metres) from numbered picket in N/S direction N → (+ve), S → (-ve).

<u>Ewsh</u> shot distance (metres) from numbered picket in E/W direction
$E \rightarrow (+ve)$, $W \rightarrow (-ve)$.

<u>Dist</u> distance (metres) of receiver from the shot point.

The following computer printout gives the above information for receivers 1 to 47 for successive shots. Appendix C gives essentially the same information for the ensemble sorted tape.

Some of the traces in the computer printout are not included on the final tape submitted (listed in Appendix C).

<u>COMPUTER PRINTOUT IS IN</u>

<u>COMPUTER FOLDER</u>

APPENDIX E

(see computer program folder)

COOPERATIVE NEAR VERTICAL INCIDENT
REFLECTION AND REFRACTION/WIDE ANGLE REFLECTION SEISMIC SURVEY
ACROSS THE SUPERIOR-CHURCHILL BOUNDARY ZONE IN SOUTHERN CANADA

PART II

DATA AND PRELIMINARY RESULTS

Report by A.G. Green[3] and O.G. Stephenson[3]

Principal participants - M. Berry[1], G. Cumming[2], D.H. Hall[3], Z. Hajnal[4], E. Kanasewich[2], A. Mair[1], I. Sereda[4], G. West[5], R. Young[5]

[1]Earth Physics Branch

[2]University of Alberta

[3]University of Manitoba

[4]University of Saskatchewan

[5]University of Toronto

INTRODUCTION

Part I of this report described the rationale, location, field procedures, field parameters and computer tape formats for the project. A number of minor revisions to these are outlined in the appropriate sections below.

In this part of the report the data are presented on a number of seismic sections. An interpretation of the refraction data, based mainly on first arrival times, is given in section (A). This preliminary analysis shows that a significant change in crustal structure (crustal layering and crustal thickness) occurs close to the transition from the Superior tectonic province to the boundary zone, as defined in Part I. To the east of the transition the crust is typical of the Superior province (with some minor refinements), while to the west the crust in the boundary zone is strikingly similar to the crust in Alberta and western Saskatchewan (i.e. the Churchill province).

Some of the data processing that is currently being applied to the near vertical incident reflection data are briefly described in section (B). An interpretation of these data should be possible when the static (preliminary static corrections are given in Part I) and normal moveout corrections are applied (Hajnal at the University of Saskatchewan is currently developing techniques for determining RMS and stacking velocities for the crustal section).

IA SEISMIC REFRACTION

(a) Revisions to Part I of this report

1. Table 4 should be replaced with the revised Table 4 (enclosed).
2. Table 1 requires the following modifications:

   N-S profile

18	UT	50.8360	50.8347	100.0140	100.0133	

   E-W profile

8	UT	49.6063	49.6063	100.7711	100.7711	1420' 433 m
20	UT	49.6310	49.6310	102.2089	102.2089	

3. Fig. 18 - shots 3 and 4 should be interchanged.
4. Appendix A

   Some of the submitted records from the University of Toronto are only provisional (the short records). Therefore, the records on the submitted tape have not been sorted as described in Part I of the report. All the record headers have now been placed together at the front of the tape, with the records following. Each record can be matched with its header by comparing the five character identification tags that are now included in the record header and at the beginning of each record.

Record Headers

Card images 1 to 7 as before.

University of Toronto and EPB data

8. ƀXXXXX - plus information about the first and last data point on the University of Toronto records.

   XXXXX - five character coded tag.

9. Blank or information that is not relevant.

10. The time of the first digital data value on the record (hr, min, sec). For either no record or a record without timing, the time of the first digital data value is set at 60 hr.

Originally it was proposed that exactly 600 'noise' samples would be included prior to the shot instant. Unfortunately, due to a mix up, the University of Toronto data has a variable number of data values prior to zero time (usually 1190 values). Relative timing should now be taken from the times given on card images 2 and 10.

The record headers are contained in logical records of size 800, with block sizes 8000. For a visual display they may be read with a (10 (40 A2)) format. The data are contained in blocks and logical records of size 21606 (10803 A2 values). These include the identification tag at the beginning of the record (3 A2) and 180 seconds of data (10800 digital values - 60 samples/sec). A (250 (250 A2)) format will allow these data to be read.

The order of the records is the same as the order of the record headers. A listing of the record headers is given in Appendix B.

(b) The Refraction data

Computer plots of the raw field records are shown in Figs. 1 to 16. The data are plotted on reduced (T-X/6.5) travel time graphs. Events with apparent velocities less than 6.5 km/s slope down to the right, while events with apparent velocities greater than 6.5 km/s slope down to the left. The coded identification is shown to the right of each trace. Each trace is normalized to give a common maximum amplitude.

Comments

(1) The provisional University of Toronto records are short (often less than 3 sec) and some contain bit errors associated with overloading.

(2) Data quality (signal to noise ratio) varies from excellent to poor. Generally, all records from the southern shot point, along the N/S profile, have good signal (first arrivals) to noise ratios, while records from the other shot points only have good signal to noise ratios to a distance ~ 200 km. However, the signal to noise ratio is a function of site location, as can be seen by comparing the 3 most distance stations from the western shot point with the neighbouring nearer stations.

(3) The timing and polarity on some of the University of Toronto data need to be rechecked. Most of the records that require rechecking are listed below.

(4) There is good correspondence (signal character, etc.) between neighbouring records.

(5) Most of the first breaks can be read to better than 0.05 sec on the larger scale plots (see later).

(c) Horizontal Plane Layer Interpretation of the Seismic Refraction Data

This interpretation is based mainly on the first breaks read from the local vertical seismomèters. When the onset of a first break was difficult to read on any record the corresponding remote vertical and horizontal records were scrutinized.

The following tables and figures show:

(i) Local vertical seismometer traces with elevation corrections applied (Figs. 17 to 24). Two plots of each trace, with different amplitude factors, are shown.

(ii) Number of successful recordings of each component (Tables 1, 3, 5, 7).

(iii) Records used in the linear least squares analysis (Tables 1, 3, 5, 7).

(iv) Apparent velocities and intercepts obtained from the least squares analysis (Tables 1, 3, 5, 7).

(v) Dipping model apparent velocities and intercepts (see (d) Dipping Plane Interface Models; Tables 1, 3, 5, 7).

(vi) Parameters of the horizontal plane layered models that fit the linear least squares velocities and intercepts (i.e. neglects the reverse profile information and the dip of the Precambrian basement; Tables 2, 4, 6, 8). The 'average' velocity of the sediments beneath each shot point was computed to give the correct depth (to $\sim \pm$ 20 m) to the Precambrian basement via the intercept time of the Pg arrival with the origin.

(vii) Some comments on the reliability etc. of the data.

N SHOT POINT - SHOTS 1 AND 2

Number of local vertical records - 31

Number of remote vertical records - 16

Number of N/S horizontal records - 29

Number of E/W horizontal records - 11

Least Squares and Model Apparent Velocities, and Intercepts

Layer number	Records used in least sqs	Number of records	Least sqs velocities (km/s)	Dipping model velocities (km/s)	Least sqs intercept (sec)	Dipping model intercept (sec)	Comments
1	-	-	3.55	3.55	0	0	velocity taken to give known depth to Precambrian basement
2	20.5, 21 23 to 30	8	5.93±.01	5.93	0.19±.02	0.19	reliable
3	12 - 16 19	6	6.20±.02	6.24	0.83±.09	0.95	reliable
4	7, 9, 10	3	6.65±.04	6.68	2.62±.16	2.74	poorly defined
5	1, 3 to 7	6	7.96±.07	7.96	7.44±.24	7.44	low signal to noise ratio

Table 1.

N. Shot Points

Horizontal Plane Layered Model from the Least Squares Velocities and Intercepts (neglects reverse profile information and dip of the Pre-cambrian basement)

Layer number	Velocity (km/s)	Thickness (km)	Depth to bottom of layer (km)
1	3.55	0.41	0.41
2	5.94	6.54	6.95
3	6.20	12.27	19.22
4	6.65	19.92	39.14
5	7.95		

Table 2.

Comments

Record 11 with shot to receiver distance ~ 164 km is very early (~ 0.25 sec). Although this is probably a timing error, similar early events are recorded from the southern shot point at distances 156 to 161 km (receivers 20.5 and 21).

Records 5 to 7 have an early event with low apparent velocity (~ 6.5 km/s).

Record 17 - a little early (0.1 sec).

Record 18 - first arrival is delayed by 0.4 sec - possibly a timing error.

Records 16521 and 16511 - should be coincident, but ~ 0.04 sec difference between first arrivals.

Records 15, 16, 21 - check polarity.

S SHOT POINT - SHOTS 3 AND 4

Number of local vertical records - 31

Number of remote vertical records - 17

Number of N/S horizontal records - 29

Number of E/W horizontal records - 10

Least Squares and Model Apparent Velocities and Intercepts

Layer number	Records used in least sqs	Number of records	Least sqs velocities (km/s)	Dipping model velocities (km/s)	Least sqs intercept (sec)	Dipping model intercept (sec)	Comments
1	-	-	3.55	3.55	0.00	0.00	velocity taken to give known depth to Precambrian basement
2	2 to 5	4	5.98±.04	5.98	0.51±.02	0.50	reliable
3	6 to 9, 11 to 18	12	6.21±.01	6.19	0.61±.03	0.60	reliable
4	16.5 to 19.5, 22 to 26	9	6.45±.02	6.44	1.41±.07	1.37	reliable
5	26 to 31	5	8.11±.08	8.11	7.80±.26	7.80	reliable

Table 3.

S. Shot Points

Horizontal Plane Layered Model from the Least Squares Velocities and Intercepts (neglects reverse profile information and dip of the Precambrian basement)

Layer number	Velocity (km/s)	Thickness (km)	Depth to bottom of layer (km)
1	3.55	1.13	1.13
2	5.98	0.99	2.12
3	6.21	8.56	10.68
4	6.45	27.88	38.58
5	8.11		

Table 4.

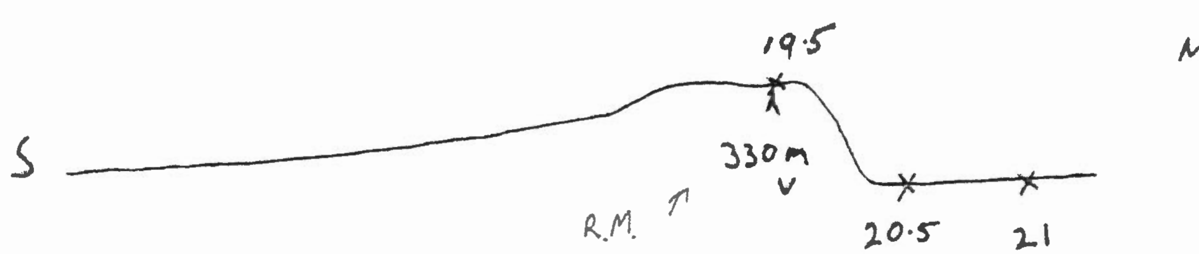
Comments

Record 10 is late by 0.2 sec, possibly a timing error.

Records 16531 and 16532 should be coincident, but ~ 0.04 sec difference between first arrivals.

Records 20.5 and 21 have an early event (0.04 sec and 0.14 sec respectively) that may be due to timing errors. However, a similar early event is observed from the northern shot point at receiver 11. In addition, receiver stations 20.5 and 21 were situated at the base of the northern 'escarpment' that defines Riding Mountain. So, these early events may be due to poor static corrections (similar effects are not observed from the northern shot point at these receivers).

Records 14 and 15 - check polarity.



E SHOT POINT - SHOTS 5 AND 6

Number of local vertical records - 25

Number of remote vertical records - 12

Number of N/S horizontal records - 10

Number of E/W horizontal records - 23

Least Squares and Model Apparent Velocities and Intercepts

Layer number	Records used in least sqs	Number of records	Least sqs velocities (km/s)	Dipping model velocities (km/s)	Least sqs intercept (sec)	Dipping model intercept (sec)	Comments
1	-	-	3.43	3.43	0.00	0.00	velocity taken to give known depth to Precambrian basement
2A	2 to 5	4	6.04±.03	6.04	0.53±.02	0.53	reliable
2B	6 to 13	6	6.22±.01	6.22	0.68±.02	0.68	poorly defined
3	12 to 15.5	5	6.55±.02	6.52	1.79±.05	1.76	reliable
4	20 to 23, 25 to 30	8	7.00	7.00	4.99	4.99	reliable
5	26, 27, 30	3	7.92	7.92	8.28	8.28	very low reliability

Table 5.

E. Shot Points

Horizontal Plane Layered Model from the Least Squares Velocities and Intercepts (neglects reverse profile information and dip of the Precambrian basement)

Layer number	Velocity (km/s)	Thickness (km)	Depth to bottom of layer (km)
1	3.43	1.11	1.11
2A	6.04	1.80	2.90
2B	6.22	10.04	12.94
3	6.55	24.62	37.56
4	7.00	8.10	45.67
5	7.92		

Table 6.

Comments

Arrivals defining the 6.22 km/s event often have very low signal to noise ratios.

Prominent trough on records 12 to 15.5 (immediately following the first arrivals - as picked here!) is displaced by ~ 0.15 sec on records 9 to 11.

Most of records 20 to 30 seem to have reasonable first arrivals, but they do not lie on or close to a straight line. The timing seems okay (except below) as the prominent ~7 km/sec event lines up well. The possible curved character of these times may be an indication of a high positive velocity gradient (pure speculation).

Records 12 to 15.5 have a slow (~ 6.3 km/s) late event that needs explaining.

Records 26, 27, 30 first arrivals poorly define the Pn phase. We may be imagining this arrival.

Record 24 is distinctly slow - both the first arrival and the 7 km/s events are delayed by ~ 0.2 sec.

Record 22 - check polarity.

Records 15561 and 15551 - is there a phase shift here?

W SHOT POINT - SHOTS 7 AND 8

Number of local vertical records - 24

Number of remote vertical records - 11

Number of N/S horizontal records - 11

Number of E/W horizontal records - 22

Least Squares and Model Apparent Velocities and Intercepts

Layer number	Records used in least sqs	Number of records	Least sqs velocities (km/s)	Dipping model velocities (km/s)	Least sqs intercept (sec)	Dipping model intercept (sec)	Comments
1	-	-	3.64	3.64	0.00	0.00	velocity taken to give known depth to Precambrian basement
2	20 to 27	8	6.18±.01	6.18	1.06±.02	1.06	reliable
3	9 to 12, 14 to 15.5	7	6.59±.03	6.64	2.27±.06	2.44	reliable - but with scattered events
4	1 to 5	5	7.24	7.24	6.18	6.18	reliable
5	2 to 5	4	8.21±.08	8.21	9.27±.19	9.27	reliable

Table 7.

W. Shot Points

Horizontal Plane Layered Model from the Least Squares Velocities and Intercepts (neglects reverse profile information and dip of the Precambrian basement)

Layer number	Velocity (km/s)	Thickness (km)	Depth to bottom of layer (km)
1	3.64	2.39	2.39
2	6.18	10.50	12.89
3	6.59	26.15	39.04
4	7.24	8.73	47.77
5	8.21		

Table 8.

Comments

Records 29 and 39 first arrivals from the sediment section.

Record 15.5 first arrival can be read from change of character.

Records 6 and 7 have first arrivals that probably belong to the 6.59 km/sec layer.

Records 1 to 5 (possibly to 12) have a very strong $\sim$ 7.24 km/sec event as a secondary arrival. This has been included in the model. The prominent events with similar velocities, which follow this arrival, may be reflected refractions or converted waves.

Records 5 to 12 have an additional strong secondary arrival (apparent velocity $<$ 7.2 km/s) that should be accounted for in any refinement of the proposed model. It does not fit in simply as an additional high velocity layer (calculations give negative thickness).

(d) The Dipping Plane Interface Models

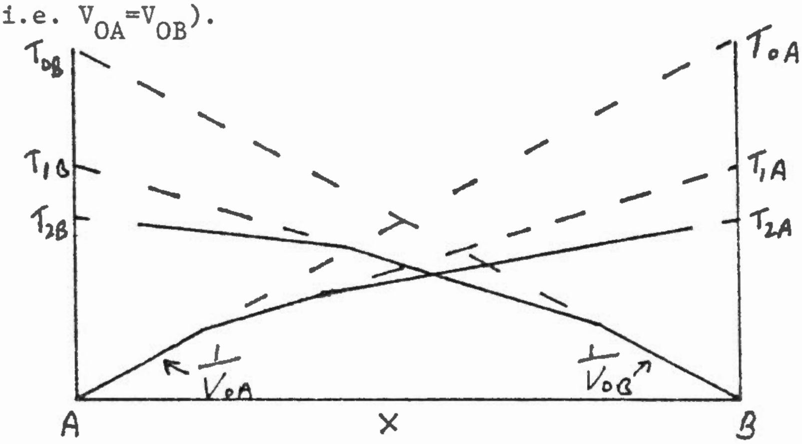
The lengths of subsurface that are sampled from the forward and reverse shot points are sufficiently close to each (overlap in some cases) that conventional reverse refraction profile techniques may be used for an improved inversion. In this section, the crust is assumed to be composed of a number of plane dipping interfaces that separate homogeneous layers. For this technique to be applied to first arrival analyses the following are required:

(a) The velocity must not decrease with depth.

(b) The velocity must not vary appreciably between two defined interfaces.

(c) The extrapolated arrival time of each forward travel time branch at the reverse shot point must equal the reversed extrapolated arrival time at the forward shot point (i.e. in the figure below, $T_{OA}=T_{OB}$, $T_{1A}=T_{1B}$, $T_{2A}=T_{2B}$, etc.).

(d) The near surface velocities must equal at each end of the profile (i.e. $V_{OA}=V_{OB}$).



Further ray tracing and seismogram simulation should show how realistic assumptions (a) and (b) are. There is good evidence for a low velocity channel in the records from the eastern shot points at locations 9 to 15.5. The processed seismic reflection data should also be an aid in this regard.

The extrapolated travel times from the linear least fits (unrounded values) are shown in Table 9.

Layer number	N (sec)	S (sec)	Difference (sec)	Layer number	E (sec)	W (sec)	Difference (sec)
2	41.63	41.69	0.02	2	40.07	40.93	0.14
				2A	40.31	-	-
3	40.50	40.25	0.25	3	39.36	39.59	0.23
4	39.61	39.51	0.10	4	40.15	40.15	0.00
5	38.34	38.14	0.20	5	39.35	39.25	0.10

Table 9.

Although the extrapolated reversed times look similar they are sufficiently different to cause inconsistencies in the inversion. The slopes and intercepts of most of the travel time branches have been adjusted, marginally, to give equal reverse intercept times, subject to the constraint that the modified travel time branches closely fit the data. Most of the changes required adjusting the velocities and intercepts by less than twice the standard errors (error limits quoted) of the least squares fits. These modified velocities and intercepts, the model values, are compared to the least squares values in Tables 1, 3, 5 and 7. The derived models are shown in Figs. 25 and 26, and Table 10. It should be noted that the presumed Pn travel time branches have not been adjusted, as the velocity and depth to the mantle does affect any of the other crustal parameters. The goodness of fit between the model travel time branches and the first arrivals may be judged in Figs. 17, 19, 21, and 23.

Interface number	Velocity above interface (km/s)	Dip (°)	Depth to interface from N shot point (km)	Depth to interface from S shot point (km)
1	3.55	-.16	0.42	1.11
2	5.95	1.47	8.32	2.03
3	6.21	3.12	22.72	9.10
4	6.55	-1.18*	37.39	40.95
5	8.02			

Interface number	Velocity above interface (km/s)	Dip (°)	Depth to interface from W shot point (km)	Depth to interface from E shot point (km)
1	3.64	0.30	2.40	1.11
2A	6.09+	-	-	2.90
2B	6.27+	-	-	
2	6.14	0.48	13.86	11.80
3	6.58	1.40	41.26	35.26
4	7.11	0.72*	48.26	45.95
5	8.06			

* Dip obtained from Pn velocities does not match exactly the dip estimated from the depth estimates (the travel time branches for Pn were not modified).
+ The Pg velocities do not match at the ends of the E-W profile. The eastern shot point records have an additional travel time branch.

Table 10.

(e) Comments on the Models

N-S Model

(i) The subsurface sampled by the N-S profile lies within the Superior province. However, it is not possible to state definitely whether the profile crosses a predominantly granite/greenstone or a granite/gneiss terrain. In the south, there is a major change in the magnetic anomaly pattern in a westerly direction from the exposed Precambrian Shield to the boundary zone. The magnetic pattern of the English River gneissic belt in the east changes in the west to a magnetic pattern that is typical of a greenstone terrain. This may be evidence that the relatively minor Bird River greenstone formation, which lies within the English River gneissic belt adjacent to the Paleozoic cover, expands to become the dominant structural feature to the west.

In the north, at approximately 51°N, the profile seems to cross from an area of greenstone type magnetic anomalies to an area of gneissic type anomalies.

(ii) The fit of the simple dipping model to the N and S travel time branches is very good.

(iii) The model (data) demonstrate that there is considerable relief on the various interfaces throughout the depth of the western Superior Province crust.

(iv) The velocities and depths computed from the unreversed data (centre of circles shown in Figs. 25 and 26) are close to the dipping model estimates. Except for the Mohorovicic discontinuity, the differences in the depths from the N and S shot points are in the same sense and have similar magnitudes for the horizontal and dipping models. The dip of the Mohorovicic discontinuity computed from the Pn velocities (-1.2°) is close to the value computed from the depths (0.8°).

(v) The 'average' velocity of the sediments was chosen to give the correct depth to the Precambrian basement using the origin intercept time of Pg at the N shot point. This same velocity also yielded the correct depth to the basement at the S shot point.

(vi) Compared to published western Superior Shield models, there are some notable <u>differences</u>:

(1) There is a distinct layer with P-wave velocity ~ 6.2 km/s underlying the usual upper crustal layer of ~ 6.0 km/sec. This layer approaches the sediment-basement contact at the southern shot point. (Upper crustal velocities of ~ 6.2 km/s have been reported from the Geotraverse corridor in NW Ontario by Wright and West, 1976).

(2) The ~ 6.6 km/s P-wave velocity of the lower crustal layer is lower than the usual value of 6.8 to 7.2 km/sec.

and <u>similarities</u>:

(1) The 9 to 23 km depth to the Riel discontinuity and the 37 to 41 km depth to the Mohorovicic discontinuity are comparable to the depths obtained in other parts of Manitoba and NW Ontario (Mereu and Hunter, 1969; Hall and Hajnal, 1969, 1973; Wright and West, 1976; Green, Hall and Stephenson, 1978).

(2) The amount of relief on the various interfaces is similar to that obtained previously (eg. Hall and Hajnal, 1973).

<u>E-W Model</u>

(i) Except for the uppermost crust (from the Pg data), the subsurface that is sampled by the E/W profile lies mostly within the boundary zone (Fig. 26)

(ii) First arrivals from the E and W shot points at distances less than 100 km cannot be used for a reversed refraction inversion. There are two travel time branches from the E shot point (apparent velocities of 6.04 and 6.22 km/s) and only one branch from the W shot point (apparent velocity 6.18 km/s).

There are a number of plausible interpretations of the E shot point data. The two travel time branches could define two near horizontal layers. Beneath the shot point, the layers would have velocities of 6.09 km/sec (accounting for the dip of the basement) and 6.27 km/s (assuming the interface is horizontal) and depths of 1.1 and 2.9 km respectively. These model parameters are similar, with higher velocities and a greater depth to the second layer, to that derived from the N/S profile (Fig. 25).

As the 6.04 km/s event is recorded from receivers within the Superior province, while the 6.22 km/s events are mostly recorded within the boundary zone, it is feasible that the change in velocity delineates a change in subcrop basement material; i.e. the change may define the start of the boundary zone. Without reverse profile constraints or a study of reflections it is not possible to discriminate between these or a number of other models.

(iii) The deeper intra-crustal interfaces are clearly observed on records from both shot points. Depths to these interfaces were computed by using the uppermost crustal model derived from the western shot point and its linear extrapolation eastwards.

(iv) Events with apparent velocities of 7.0 to 7.2 km/s on both record sections are strong secondary arrivals that could not be reasonably excluded from the inversion.

(v) As mentioned previously, there is evidence for either a low velocity zone or some lateral complexity on E shot point records 20 to 25. Further interpretation of these data will undoubtedly modify the models presented here.

(vi) The high amplitude trough, immediately following the first breaks on records 12 to 15.5 are displaced to earlier times on records 9 to 11. On Fig. 26 this break is represented by a fault at the appropriate subsurface position. However, the first arrival travel time branch on records 6 to 10 (possibly 11) suddenly disappears at the same receivers. Perhaps a more complex model, with pods of low velocity material, will be required to explain these peculiar records.

(vii) Although Pn is emergent, it is reasonably well defined on the W shot point records. The picks of the Pn arrivals on the E shot point records are highly speculative.

(viii) The fit of the dipping model travel time branches to the observed data (Figs. 21 and 23) are generally good, except for the problem areas mentioned in (v) and (vi).

(ix) Velocities and depths derived from the unreversed profiles (depths shown by the centres of the circles in Fig. 26) are close to those derived using the reversal information.

(x) The E/W dipping model of Fig. 26 is remarkably similar to the refraction derived crustal structure for the region to the west of Swift Current, Saskatchewan (Chandra and Cumming, 1972; Fig. 27).

Swift Current model (Churchill Province)		Boundary Zone model	
km	km/s	km	km/s
~2		2.4	
	6.12		6.14
~15		13.9	
	6.50		6.58

~36 ————————	
	41.3 ————————
7.17	7.11
~47 ————————	48.3 ————————
8.10	8.06
taken from Fig. 6 of Chandra and Cumming (1972)	E/W profile - depths beneath the western shot point from the dipping interface model

Fig. 27

Clearly the similarities of the models in Fig.27 are too striking to be coincidence. Swift Current is less than 150 km from the western end of the E/W profiles so the similarity may not be too surprising. However, there are two important conclusions to be derived from these similarities:

(1) The crust in the boundary zone is closer to that of the Churchill province than the Superior province. This conclusion may influence the current debate on the nature of the boundary zone (Thompson Nickel Belt) in northern Manitoba. Most government geologists claim that the boundary zone is altered Superior province terrain. INCO research geologists dispute this.

(2) Churchillian type crust seems to cross the southern extension of the Wollaston fold belt (as defined by aeromagnetic anomalies, conductivity anomalies and possibly seismicity).

(f) Comparison of the N/S and E/W Profiles

Relative to the N/S profile the E/W profile shows:

(1) broadly similar velocities.

(2) distinctly different P-wave characteristics - compare the records from the common E and S shot points (first arrivals and coda).

(3) thicker crust, by 5 km (a thicker crust is required even if the 7.0 to 7.22 km/s event is ignored).

(4) a 7 to 7.22 km/s layer - a $\sim$ 7 km/s arrival is not observed as a strong event on the N/S profiles (but see the discussion by Hall and Hajnal, 1973).

In addition:

(5) the Pg velocity at the western end of the E/W profile is 6.14 km/s, (similar throughout the western Prairies - Chandra and Cumming, 1972) which compares to the 5.95 km/s observed on the N/S profile and the 6.09 km/s observed at the eastern end of the E/W profile.

(6) the top three interfaces (includes the upfaulted interface near 10 km) at the E end of the E/W profile in Fig. 26 can be compared with the upper crustal model in the southern region of the N/S profile:

E/W km	E/W (km/s)	N/S km	N/S (km/s)
	3.43		3.55
1.11		1.11	
	5.95		6.09
2.90		2.03	
	6.21		6.27
		9.10	
10.3			6.55
	6.58		

It is not possible to state definitely which of the similarities and differences are significant.

(7) The Riel discontinuity in the Churchill province (and its extension into the boundary zone) is a different interface to that defined in the Superior province.

(8) Surprisingly, there is less relief on the interfaces in the boundary zone than is observed in the Superior province.

(g) General Conclusions

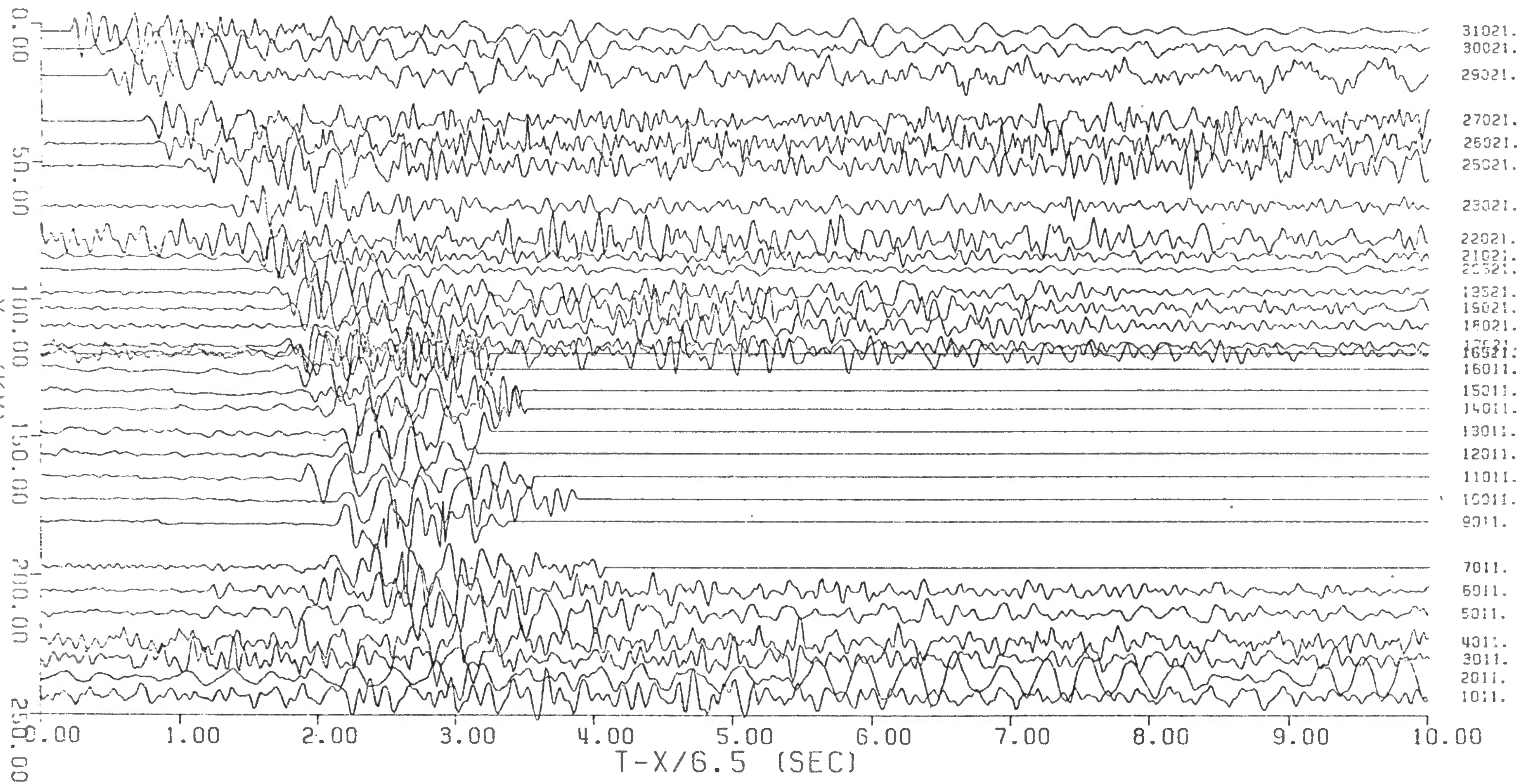
The crustal structure derived from the N/S profile is similar to published crustal models of the Superior province. Depths to the Riel (Man.) and Moho vary from 9 to 23 km and from 41 to 37 km respectively in a south to north direction. An additional interface, which has not been previously defined in the Superior province, separates the sub-crop basement material with a velocity of 6.0 km/s from an underlying layer with a velocity of 6.2 km/s. This interface varies from a depth of 2 km in the south to 8 km in the north.

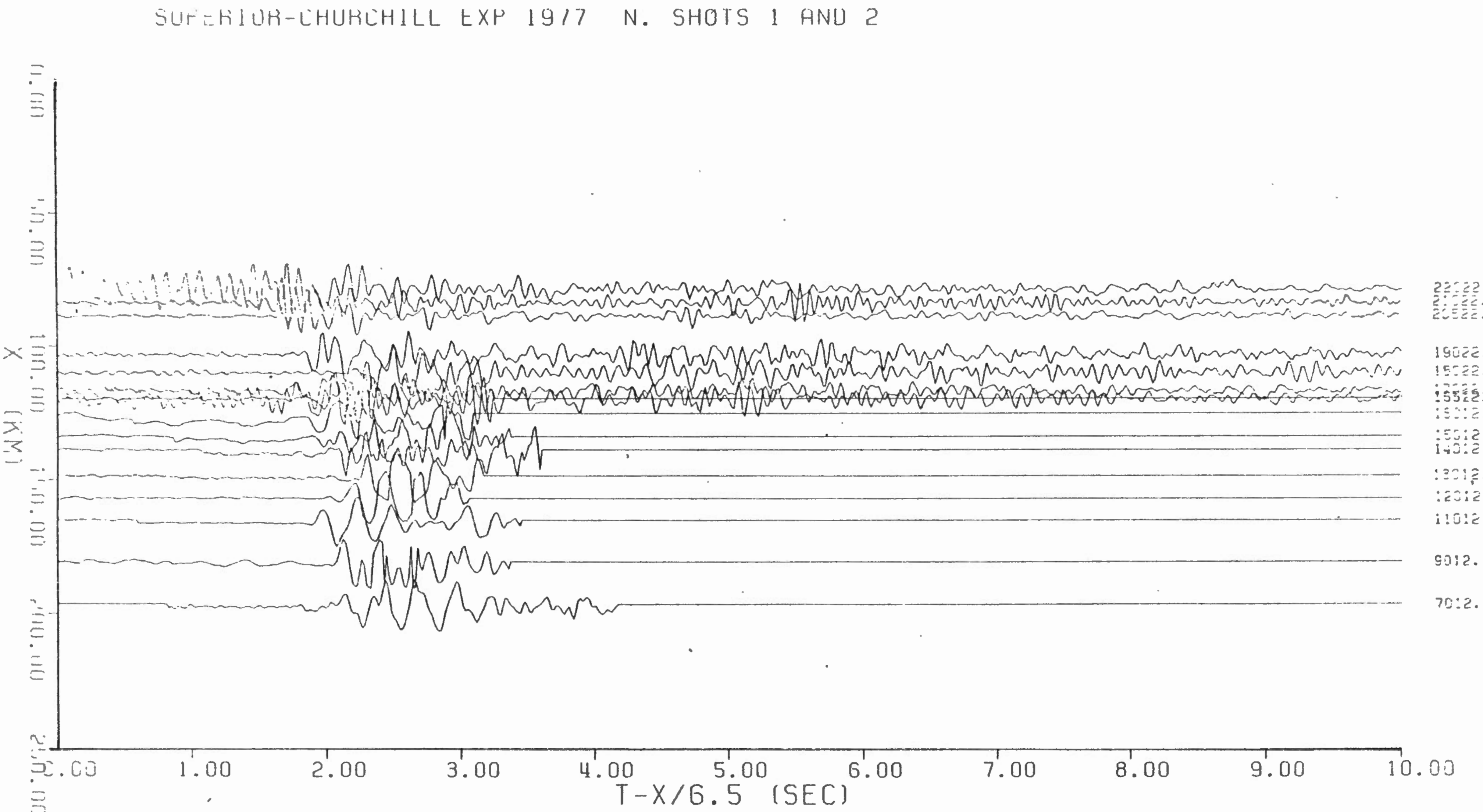
A comparison of the two models in Figs. 25 and 26 shows that there is a relatively sharp (the data does not preclude a discontinuous change that could be coincident with the 'fault' on the 6.58 km/s interface in Fig. 26) thickening of the crust across the boundary zone. If the depth to the Moho $\sim$ 41 km, taken from the N/S profile, represents the crustal thickness beneath the common S and E shot points, then over a distance $\lesssim$ 72 km the crust thickens in a westward direction to $\sim$ 47 km. A similar phenomenon has been observed across the boundary zone in northern Manitoba (Mereu and Hunter, 1969; Hall and Hajnal, 1973).

There is a significant correlation between the crustal section in the boundary zone and the crust described for the Churchill province in western Saskatchewan and Alberta. Present data seem to show that a Churchill province type crust extends eastwards from the foothills in Alberta to the western limit of the Superior magnetic fabric. Further east the typical Superior province crustal structure dominates. The major characteristics of the crust that distinguish the Churchill province from the Superior province are the 7 to 7.2 km/s lower crustal layer and the relatively thicker crust ($\gtrsim$ 43 km for the Churchill province, $\lesssim$ 41 km for the Superior province). The upper crustal section in the Churchill province looks quite similar to the complete crustal section of the Superior province. Pn velocities in the two provinces are also similar.

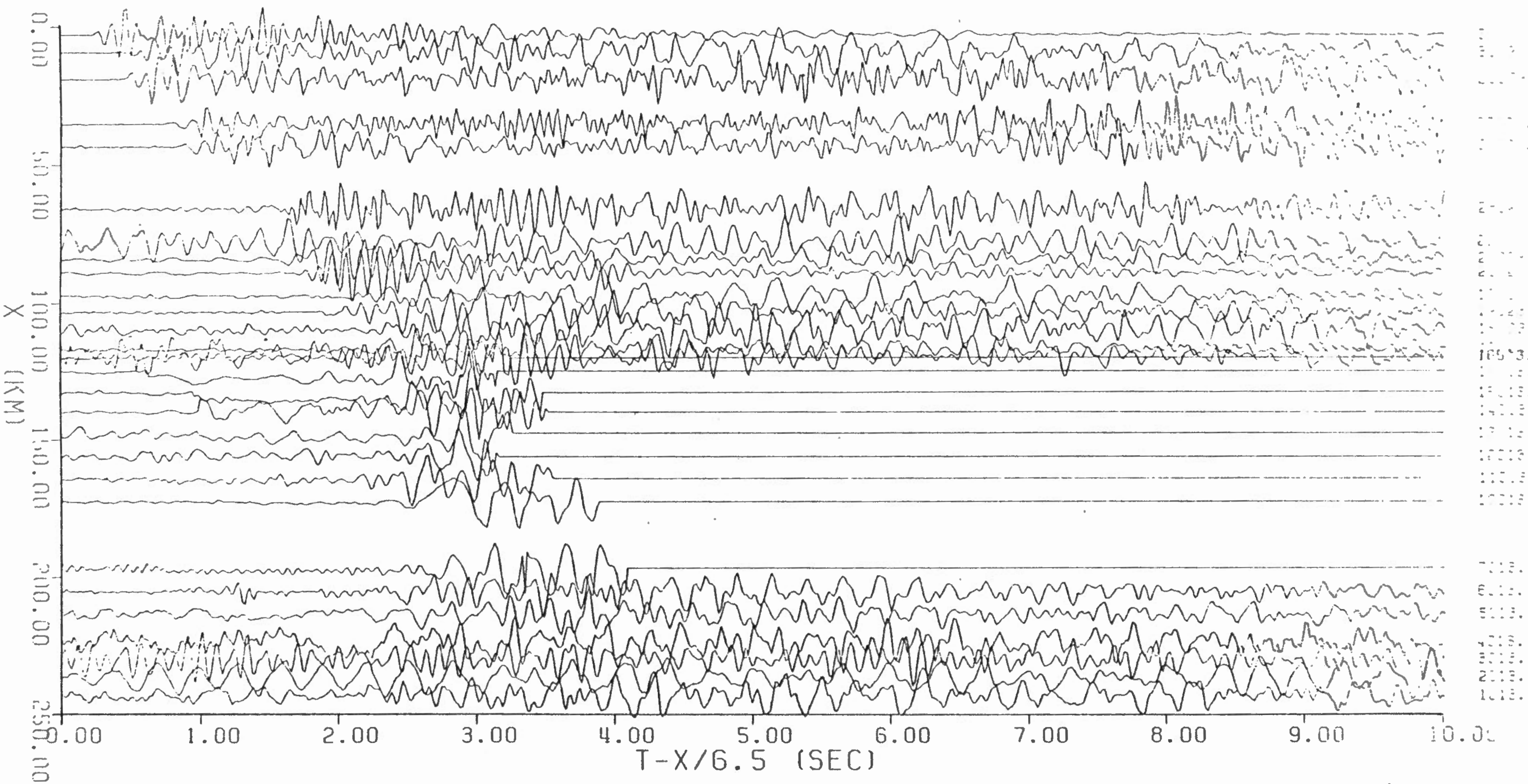
Further refinement to these models will incorporate (i) interpretations of the wide angle reflections and converted phases, (ii) results of the near vertical incident reflection survey, and (iii) available gravity data.

SUPERIOR-CHURCHILL EXP 1977 N. SHOTS 1 AND 2

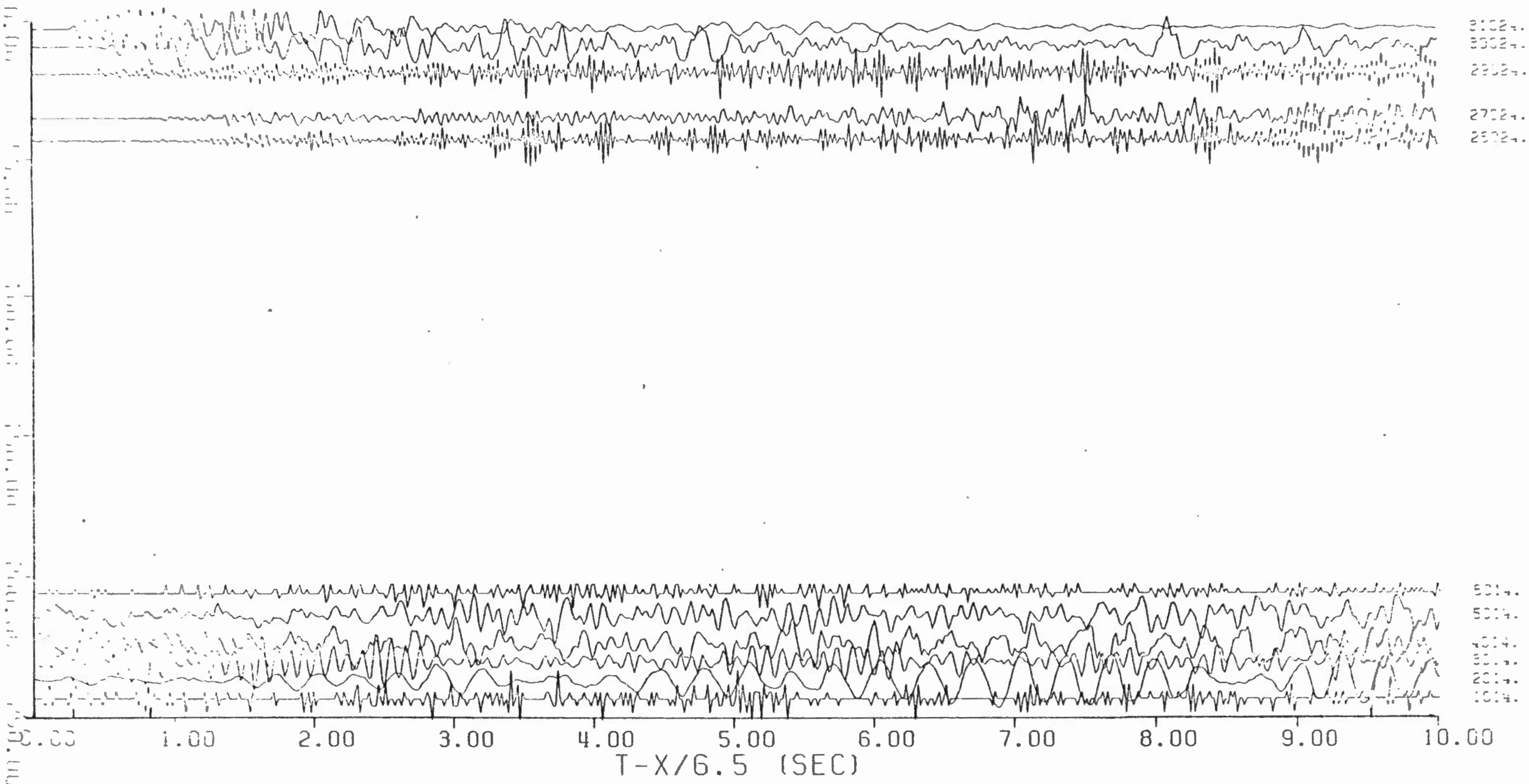



SUPERIOR-CHURCHILL EXP 1977 N. SHOTS 1 AND 2
X (KM)
T-X/6.5 (SEC)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
22022.
19022.
9012.
7012.

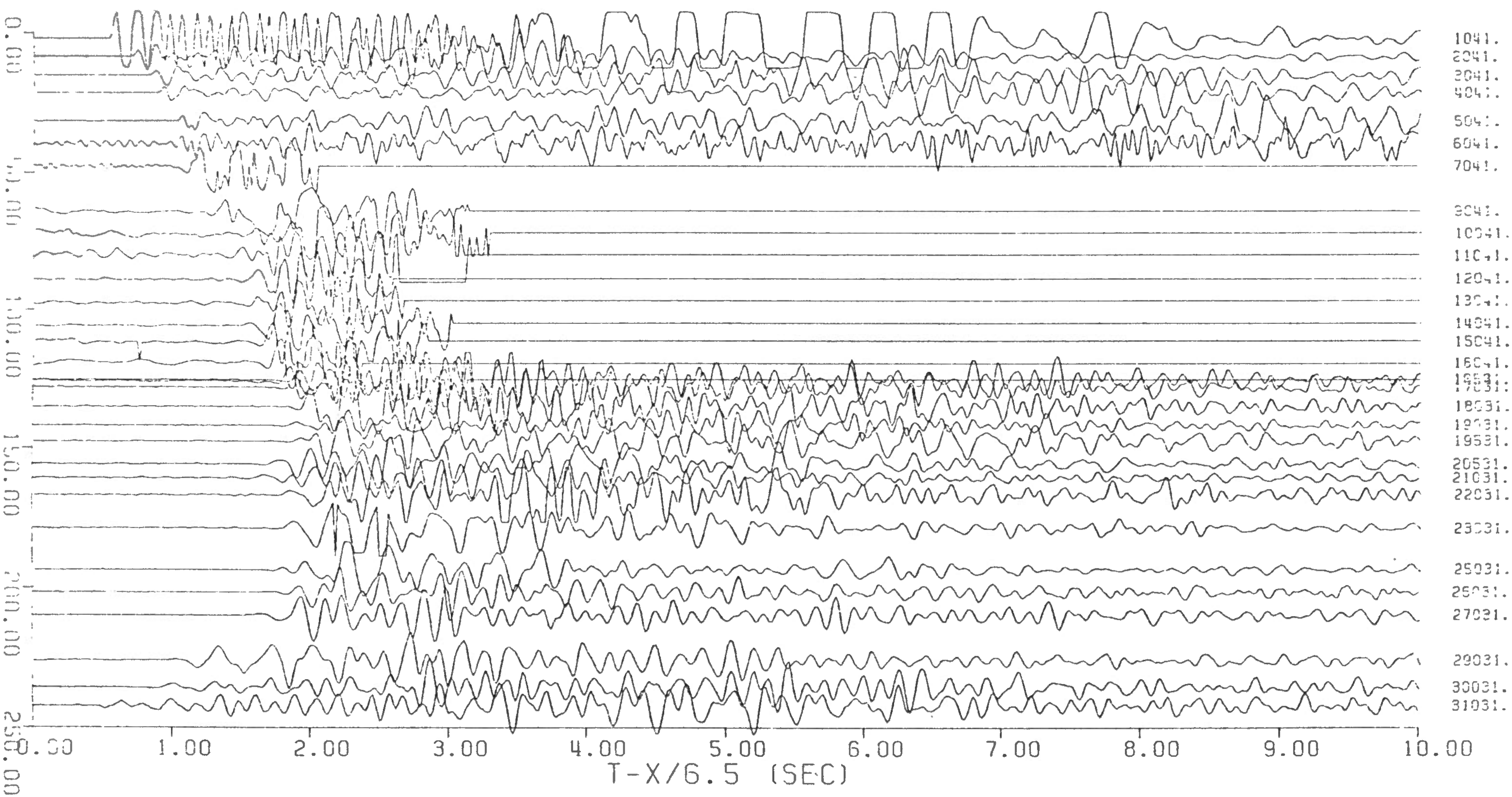
SUPERIOR-CHURCHILL EXP 1977 N. SHOTS 1 AND 2

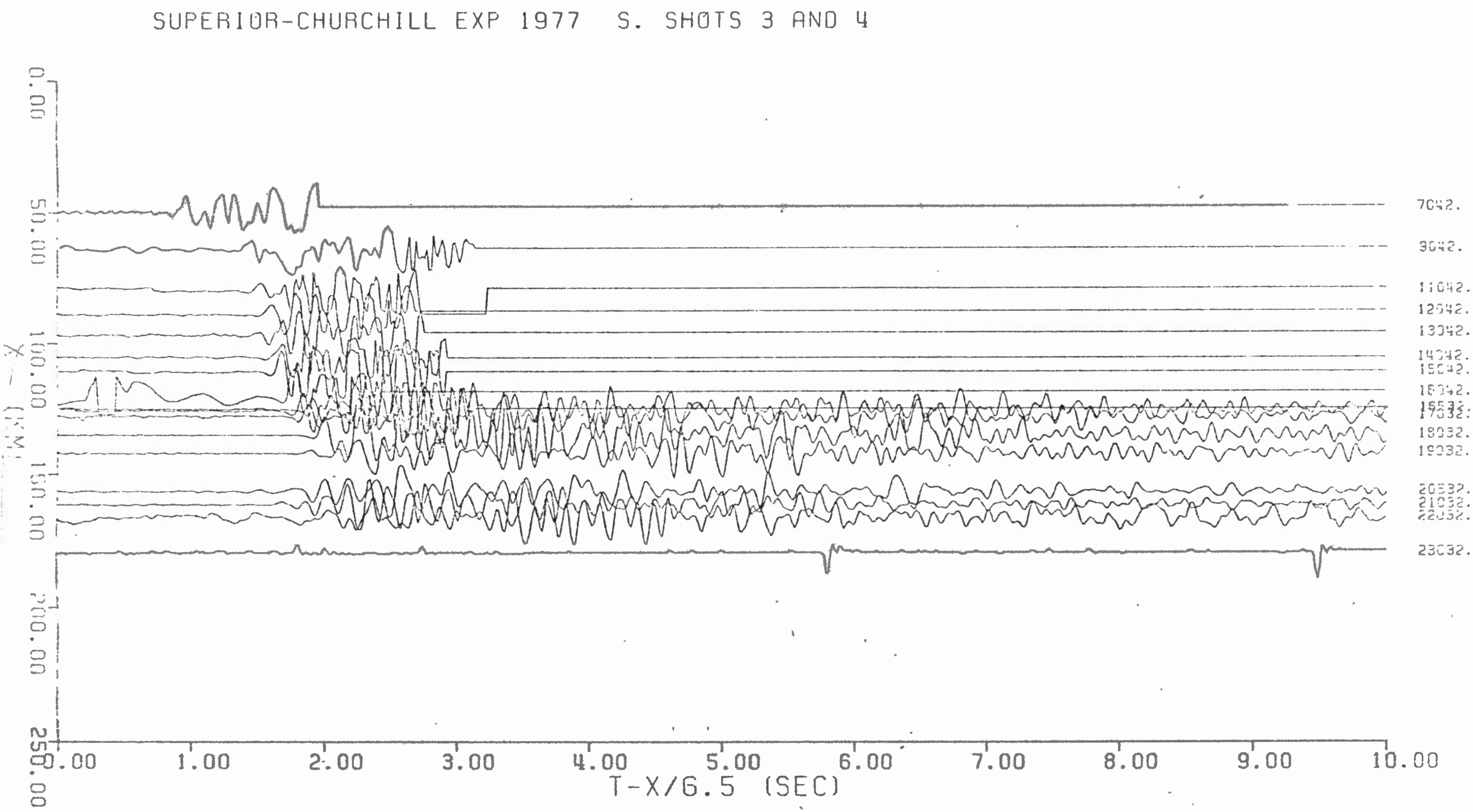


SUPERIOR-CHURCHILL EXP 1977 N. SHOTS 1 AND 2

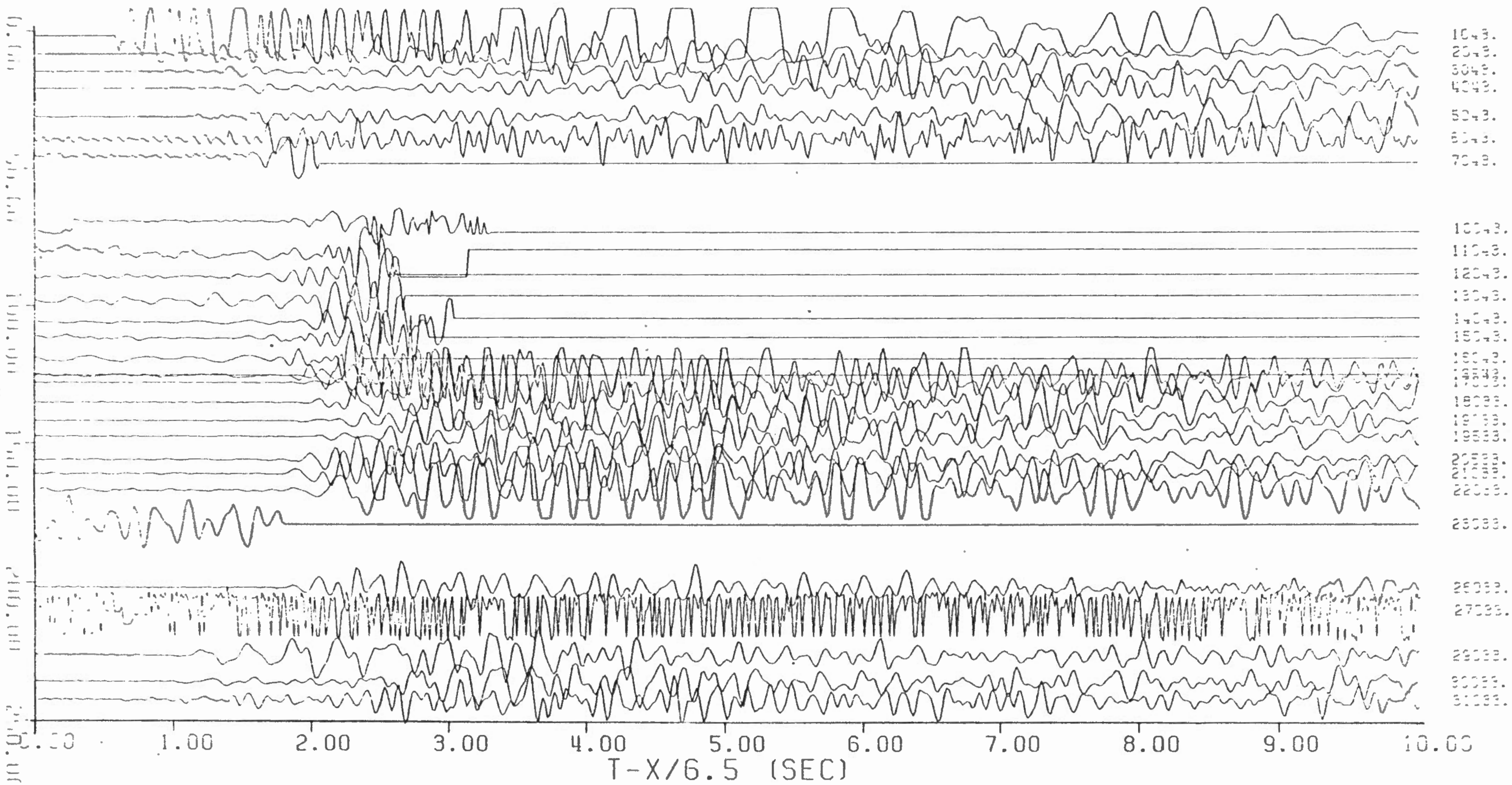


SUPERIOR-CHURCHILL EXP 1977   S SHOTS 3 AND 4

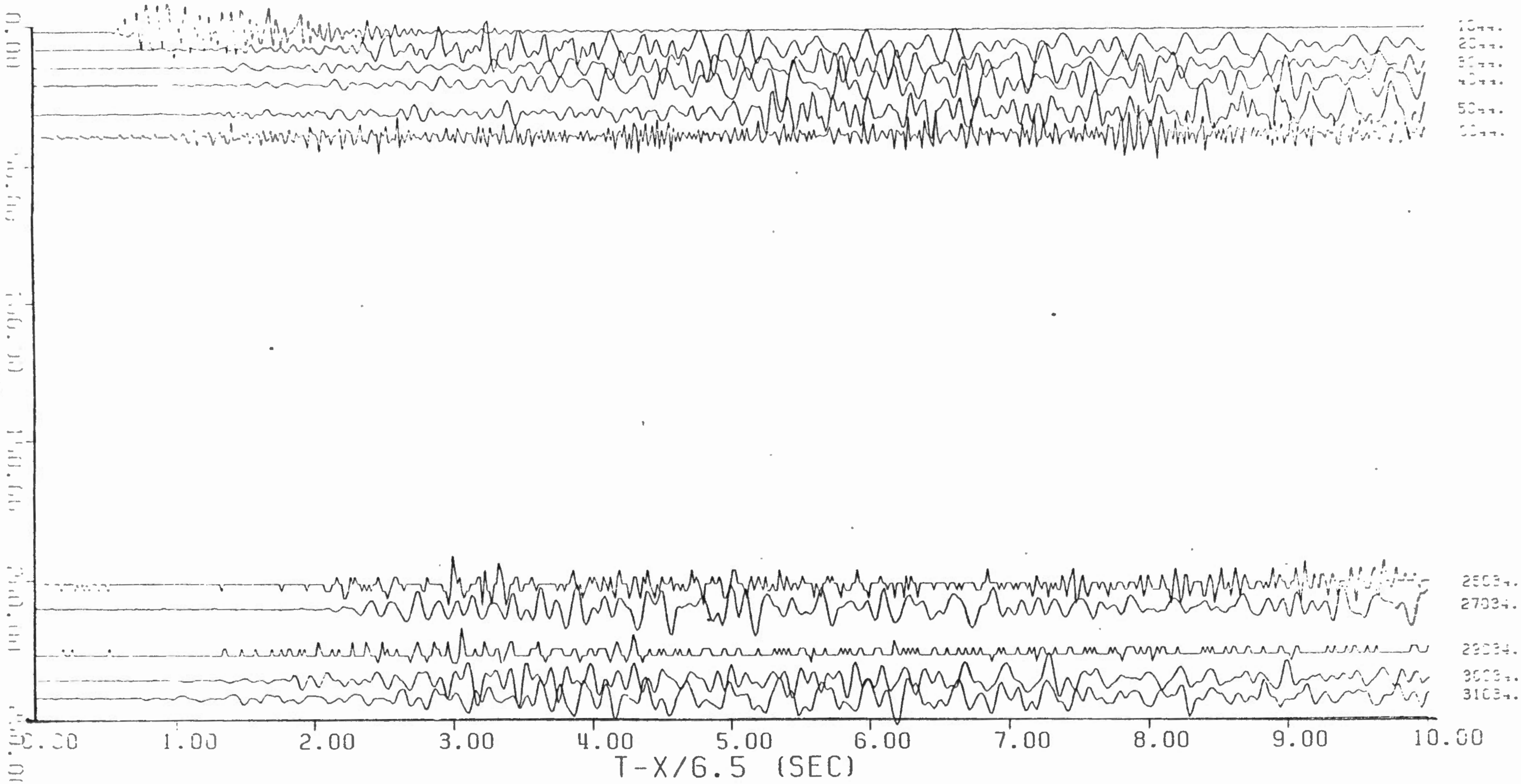


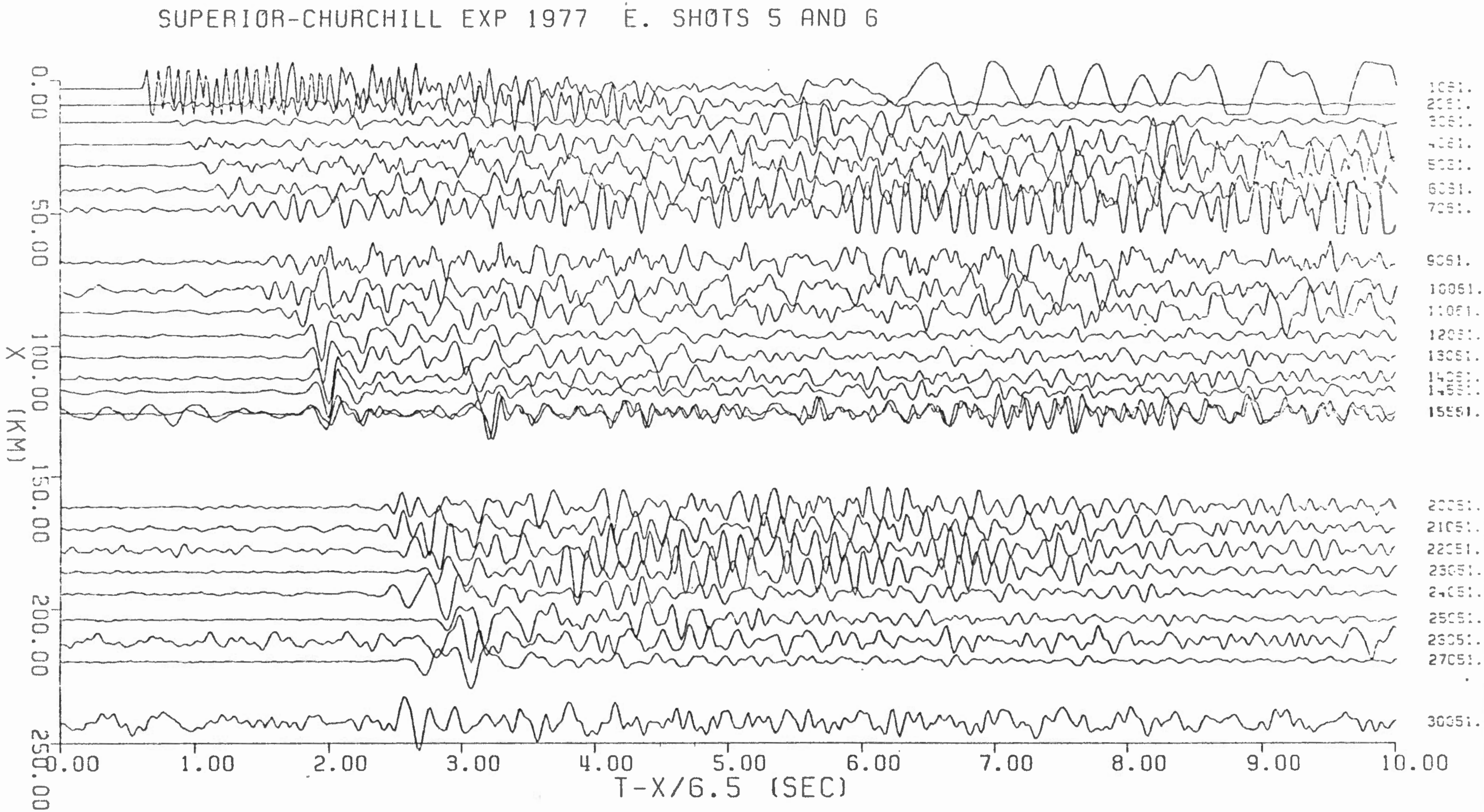

SUPERIOR-CHURCHILL EXP 1977 S. SHOTS 3 AND 4
0.00
50.00
100.00
150.00
200.00
250.00
X - (KM)
7042.
9042.
11042.
12042.
13042.
14042.
15042.
16042.
16532.
17032.
18032.
19032.
20532.
21032.
22032.
23032.
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
T-X/6.5 (SEC)

SUPERIOR-CHURCHILL EXP 1977 S. SHOTS 3 AND 4



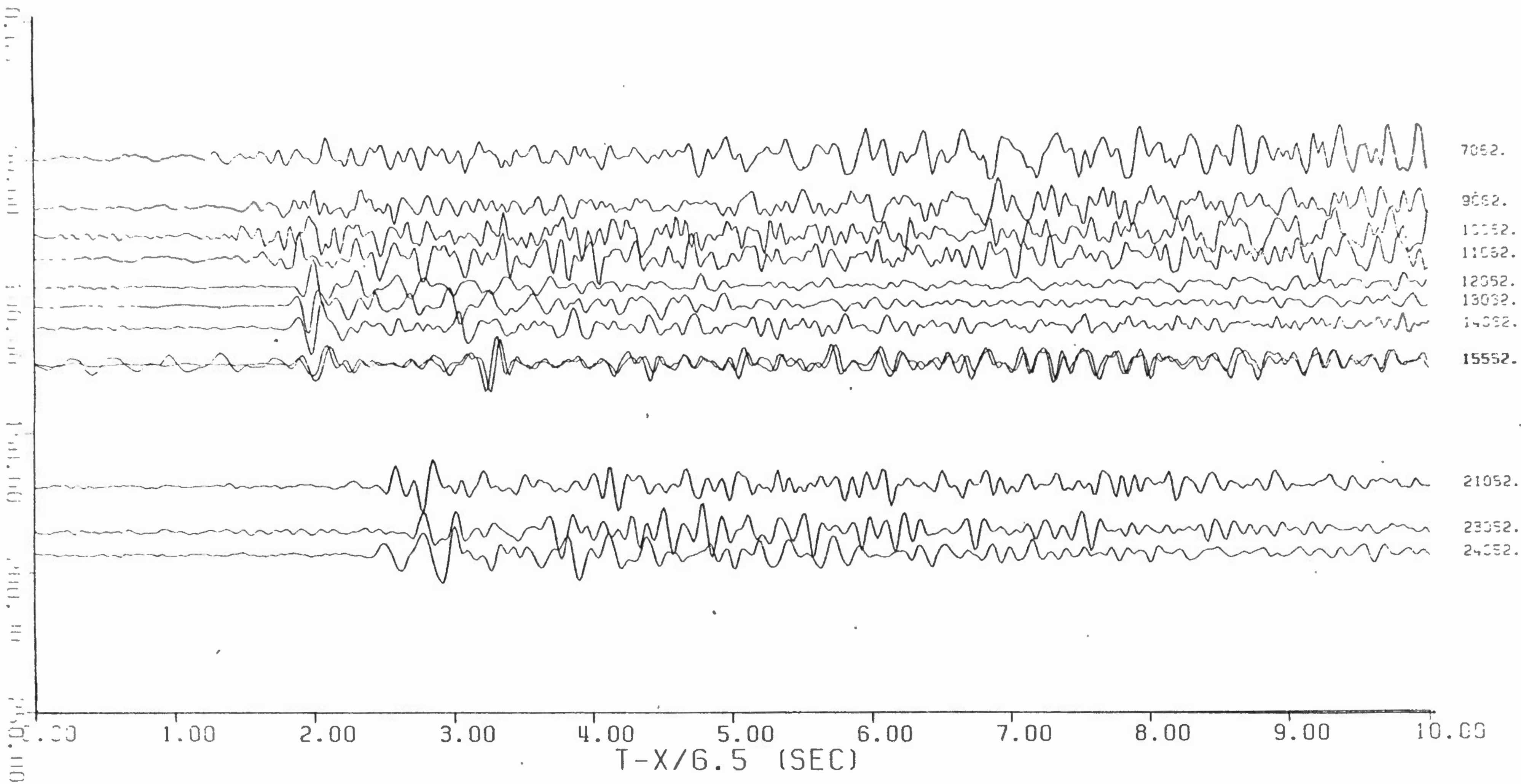
SUPERIOR-CHURCHILL EXP 1977 S. SHOTS 3 AND 4



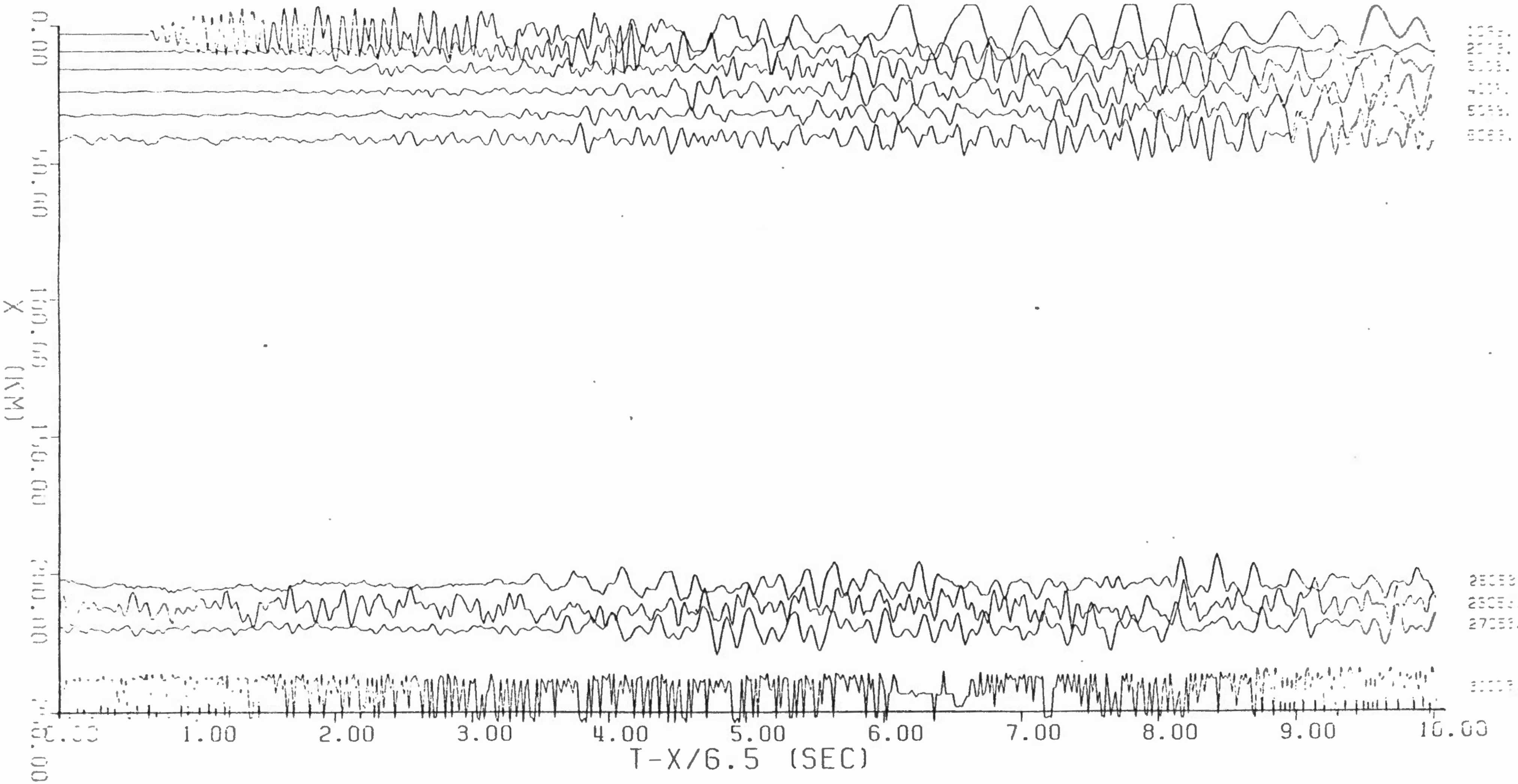


SUPERIOR-CHURCHILL EXP 1977 E. SHOTS 5 AND 6
X (KM)
T-X/6.5 (SEC)

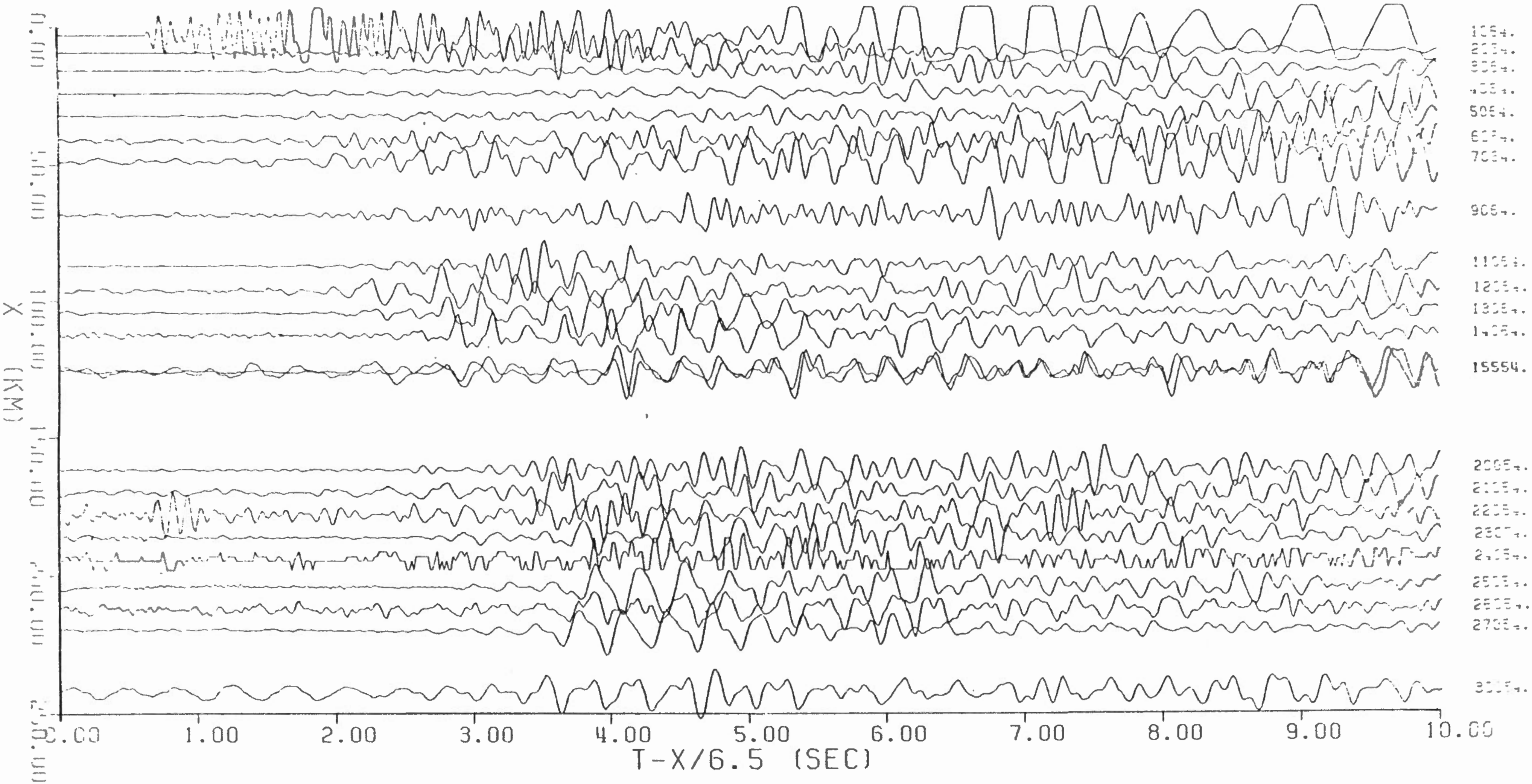
SUPERIOR-CHURCHILL EXP 1977 E. SHOTS 5 AND 6



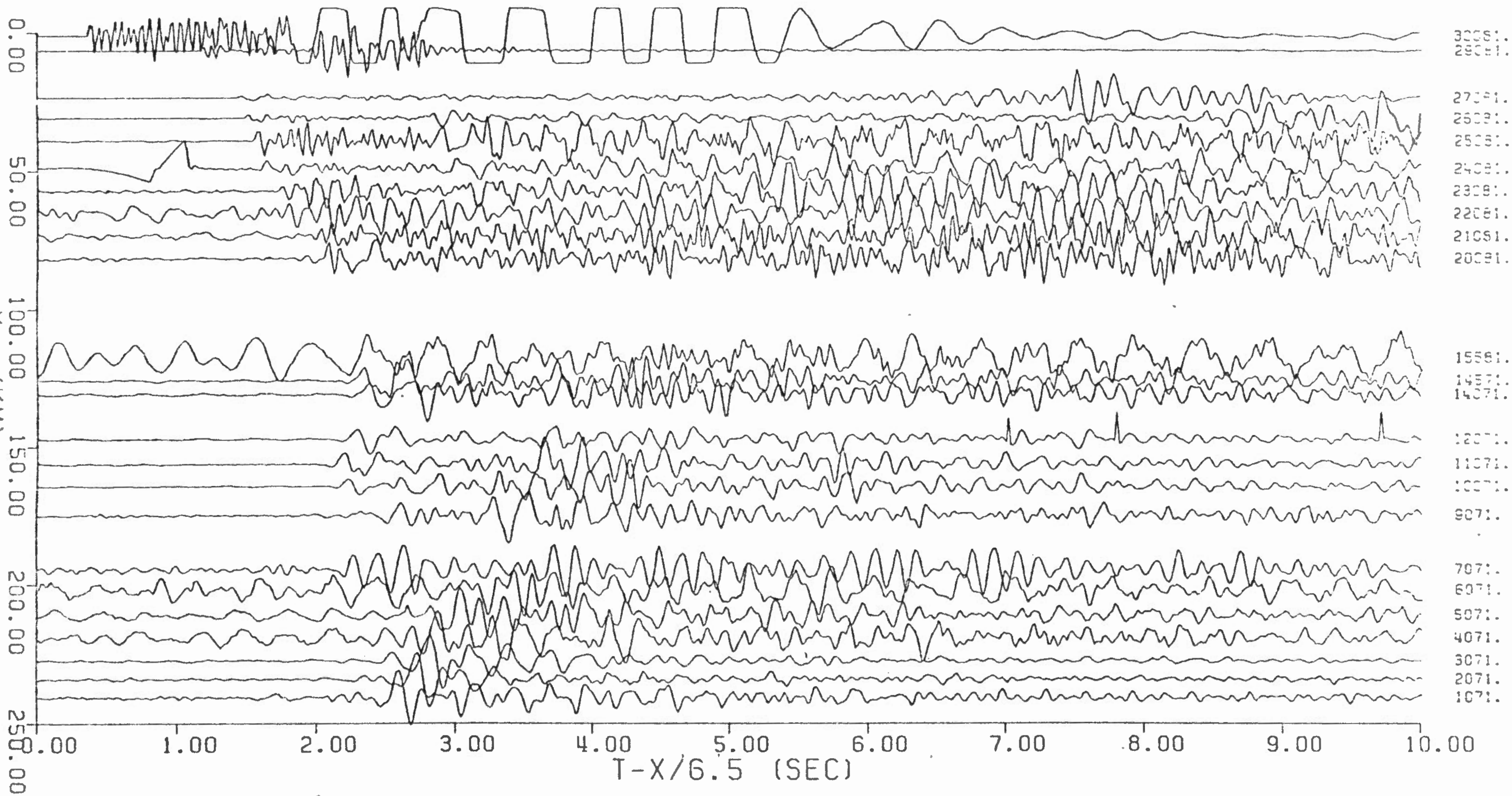
SUPERIOR-CHURCHILL EXP 1977 E. SHOTS 5 AND 6



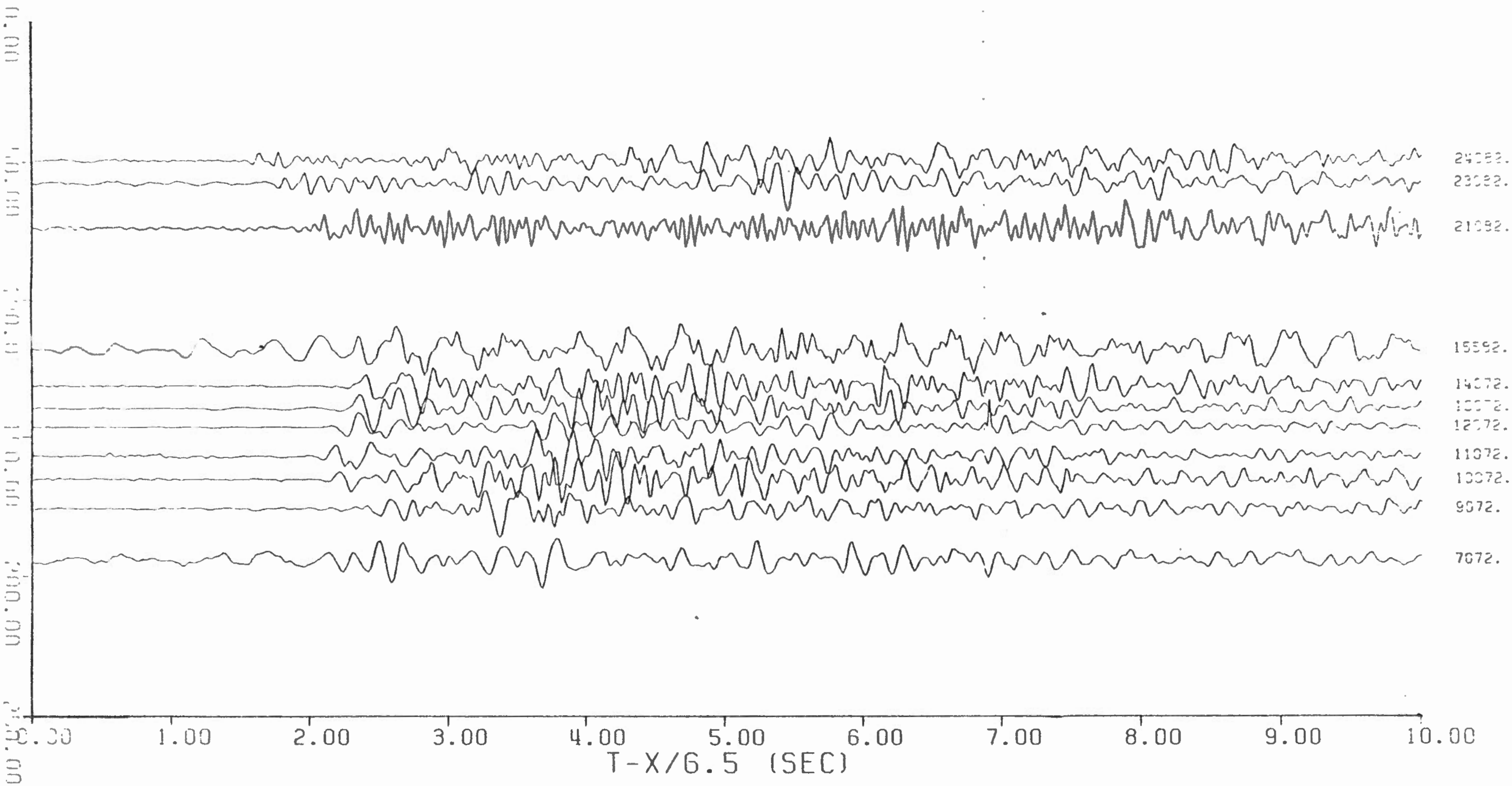
SUPERIOR-CHURCHILL EXP 1977 E. SHOTS 5 AND 6



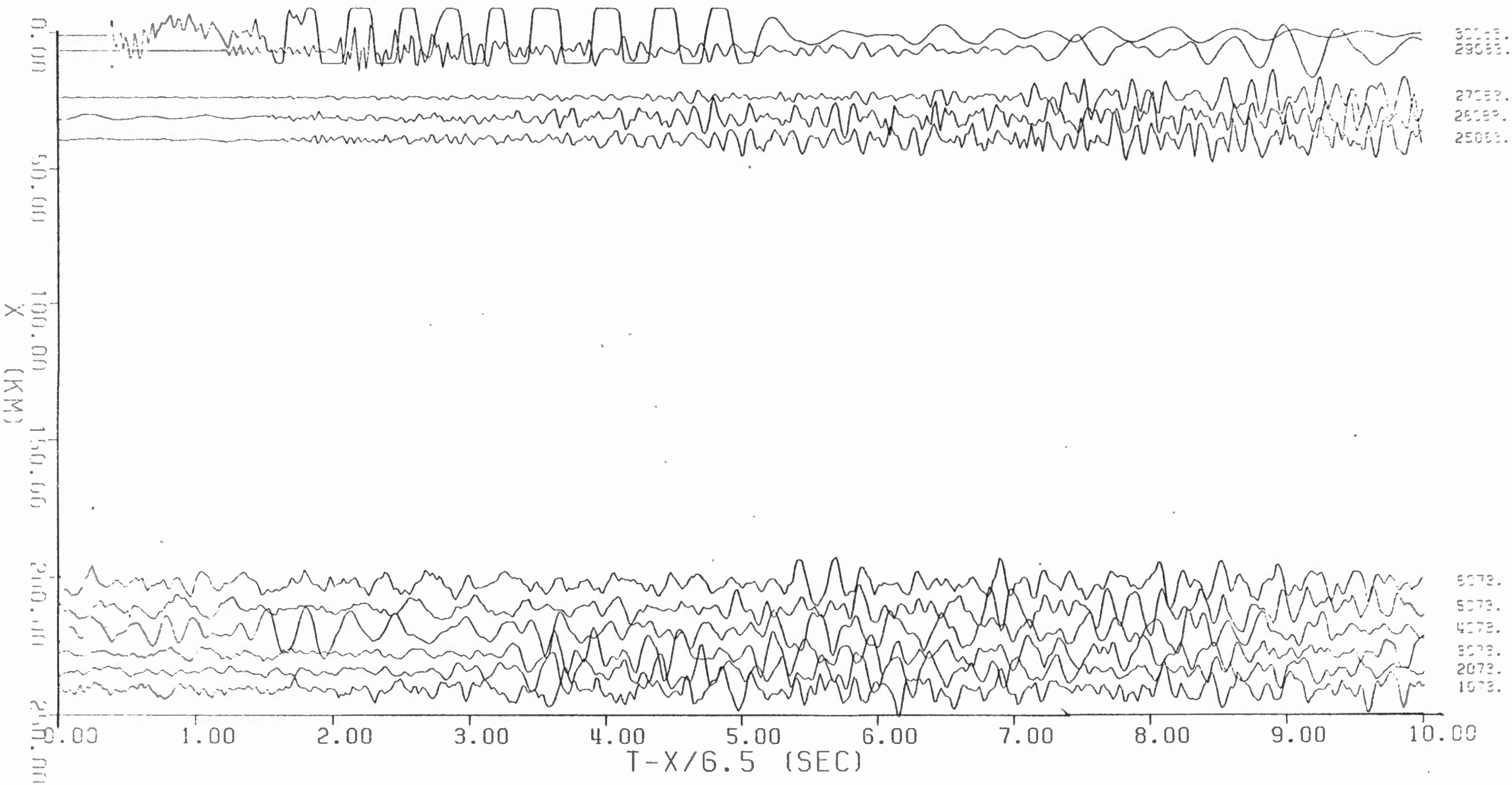
SUPERIOR-CHURCHILL EXP 1977 W. SHOTS 7 AND 8



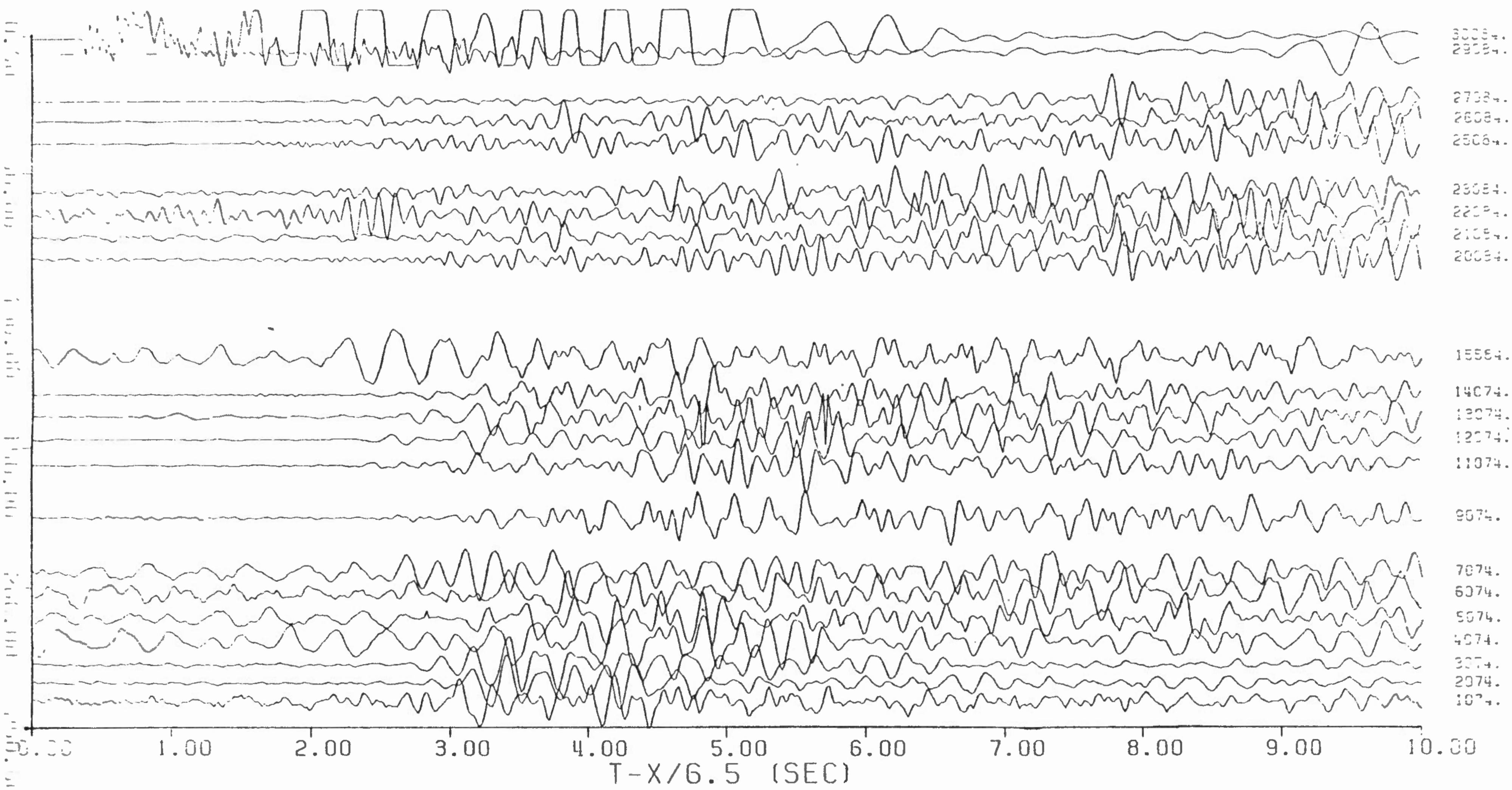
SUPERIOR-CHURCHILL EXP 1977 W. SHOTS 7 AND 8

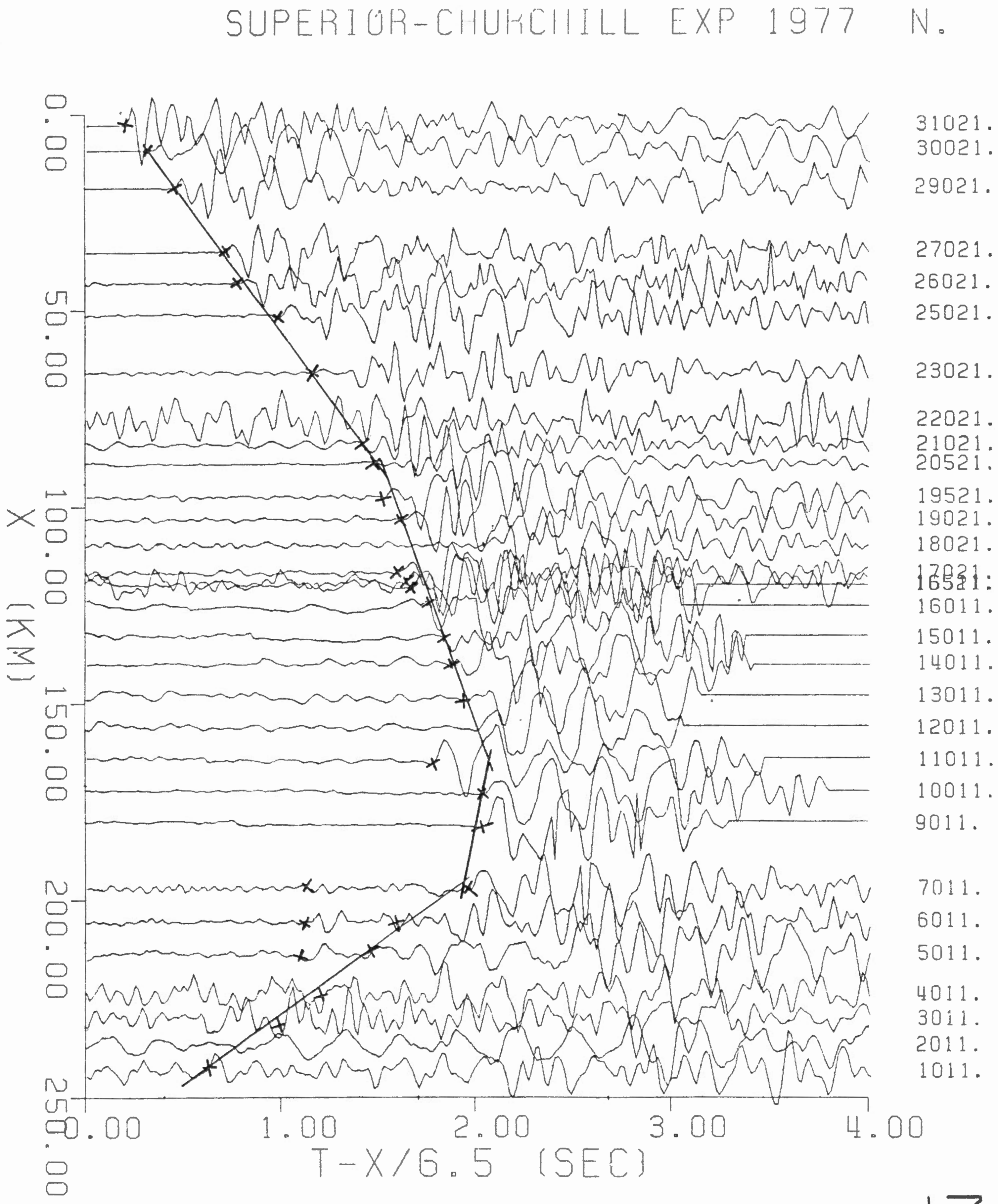


SUPERIOR-CHURCHILL EXP 1977 W. SHOTS 7 AND 8

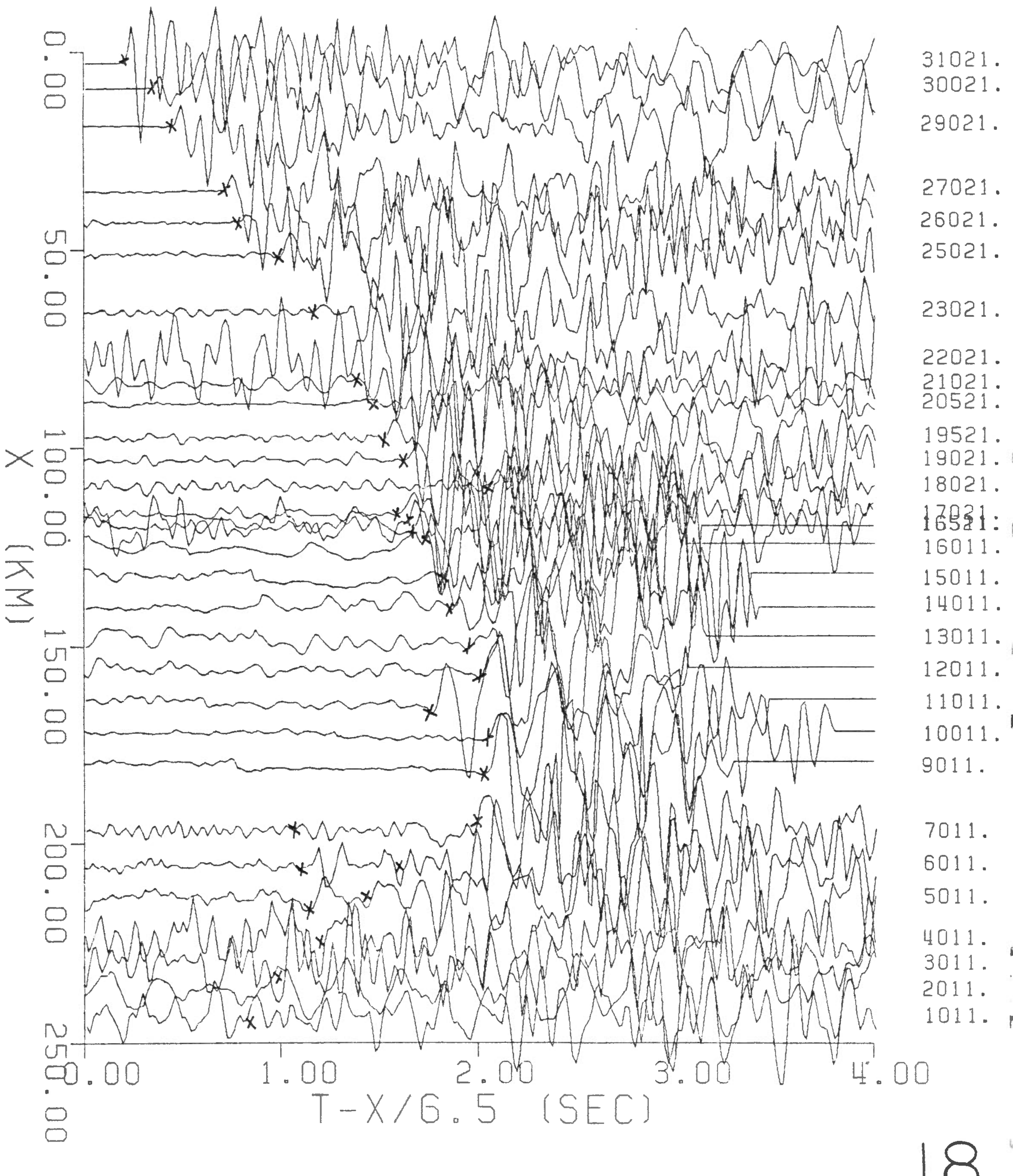


SUPERIOR-CHURCHILL EXP 1977 W. SHOTS 7 AND 8

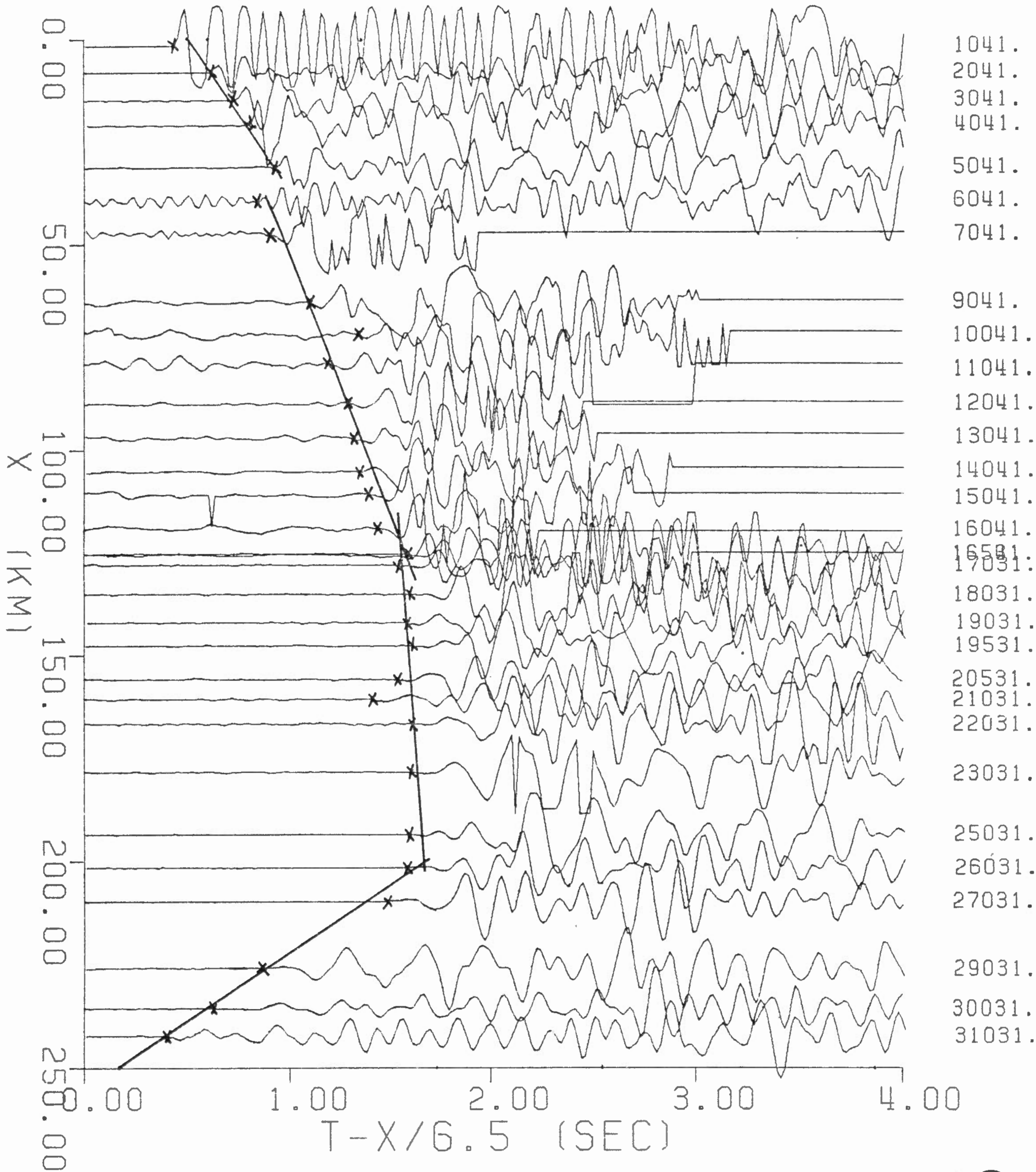


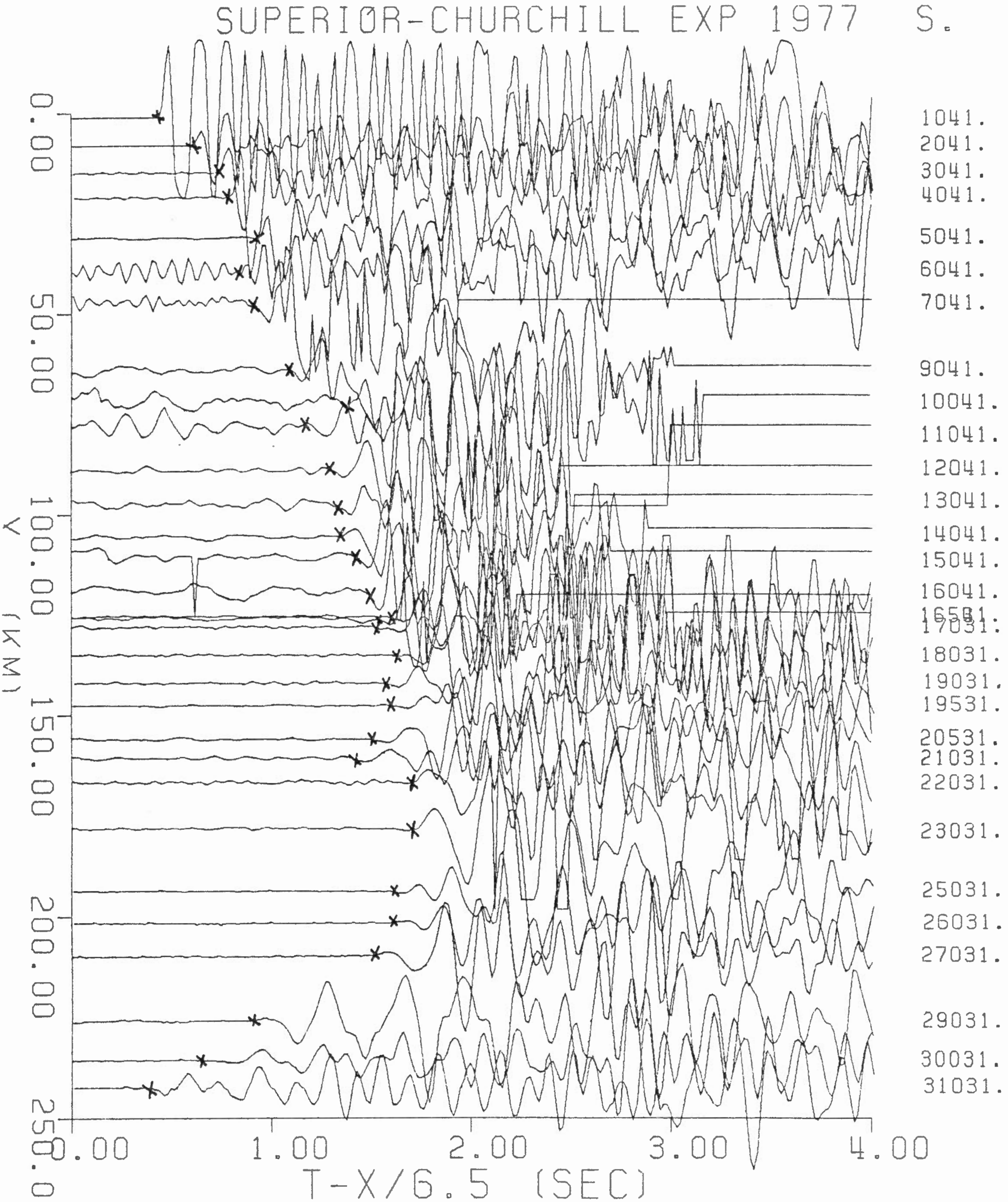

SUPERIOR-CHURCHILL EXP 1977 N.
X (KM)
0.00
50.00
100.00
150.00
200.00
250.00
T-X/6.5 (SEC)
0.00
1.00
2.00
3.00
4.00
31021.
30021.
29021.
27021.
26021.
25021.
23021.
22021.
21021.
20521.
19521.
19021.
18021.
17021.
16521.
16011.
15011.
14011.
13011.
12011.
11011.
10011.
9011.
7011.
6011.
5011.
4011.
3011.
2011.
1011.

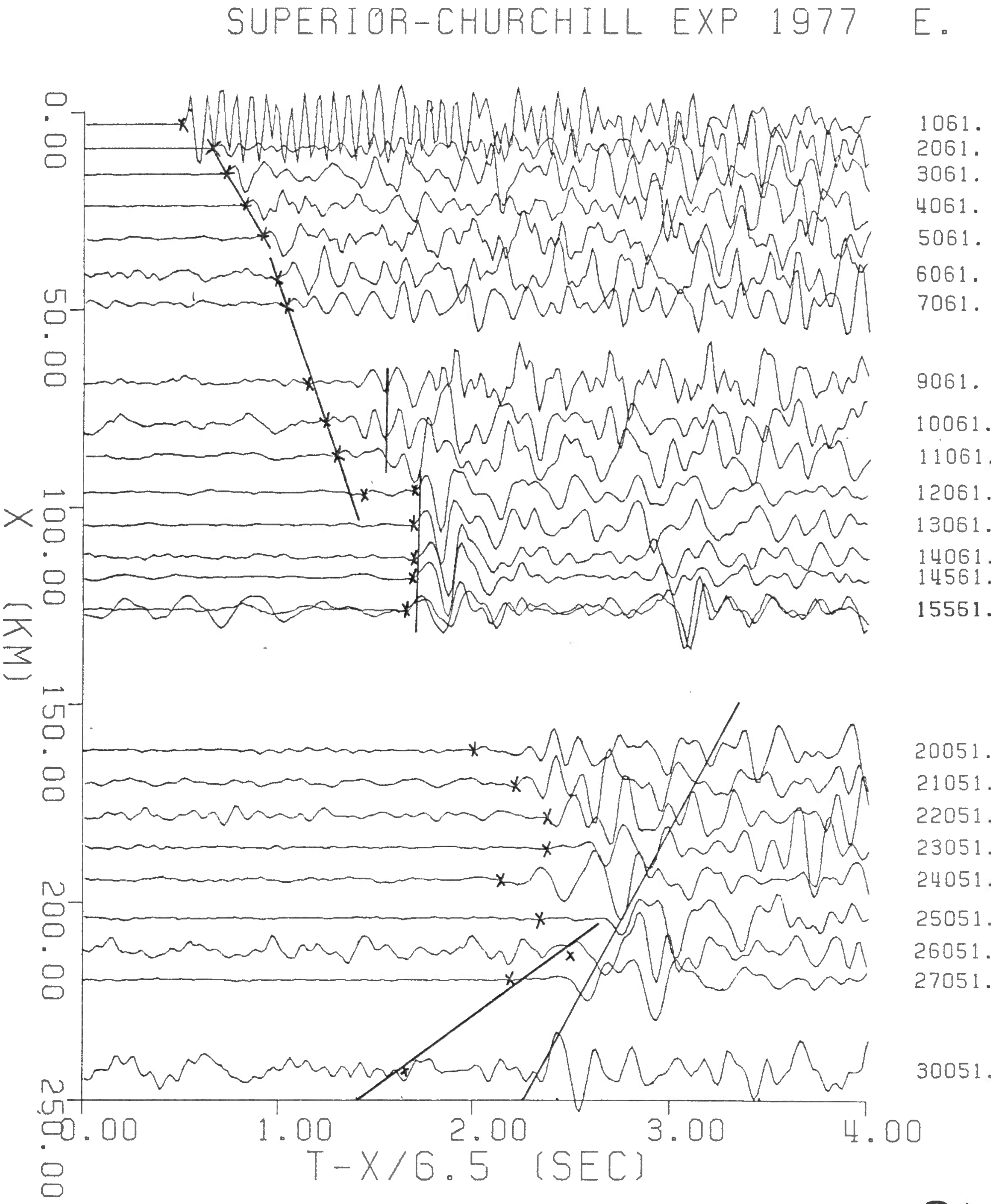
SUPERIØR-CHURCHILL EXP 1977 N.



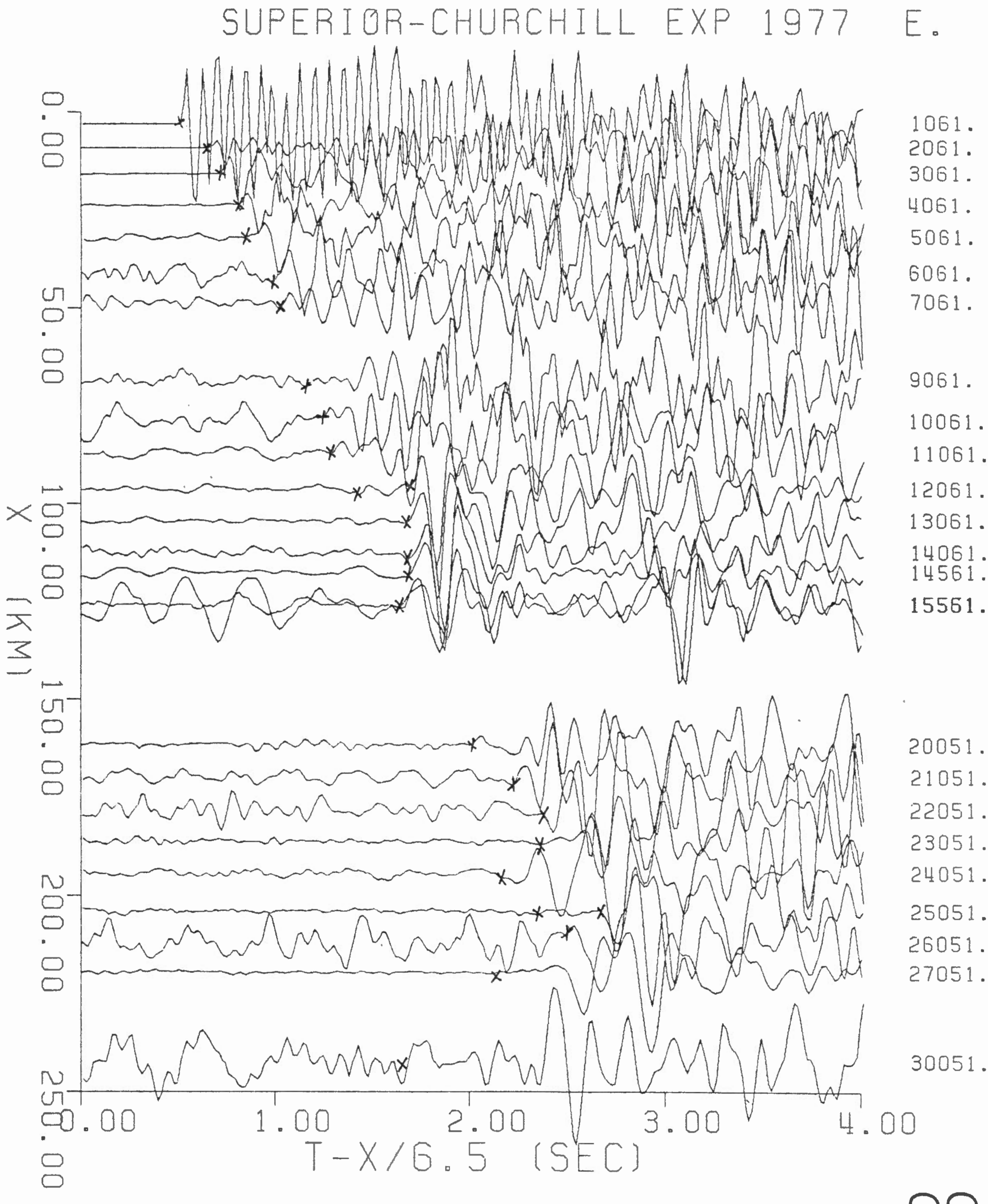
SUPERIØR-CHURCHILL EXP 1977 S.

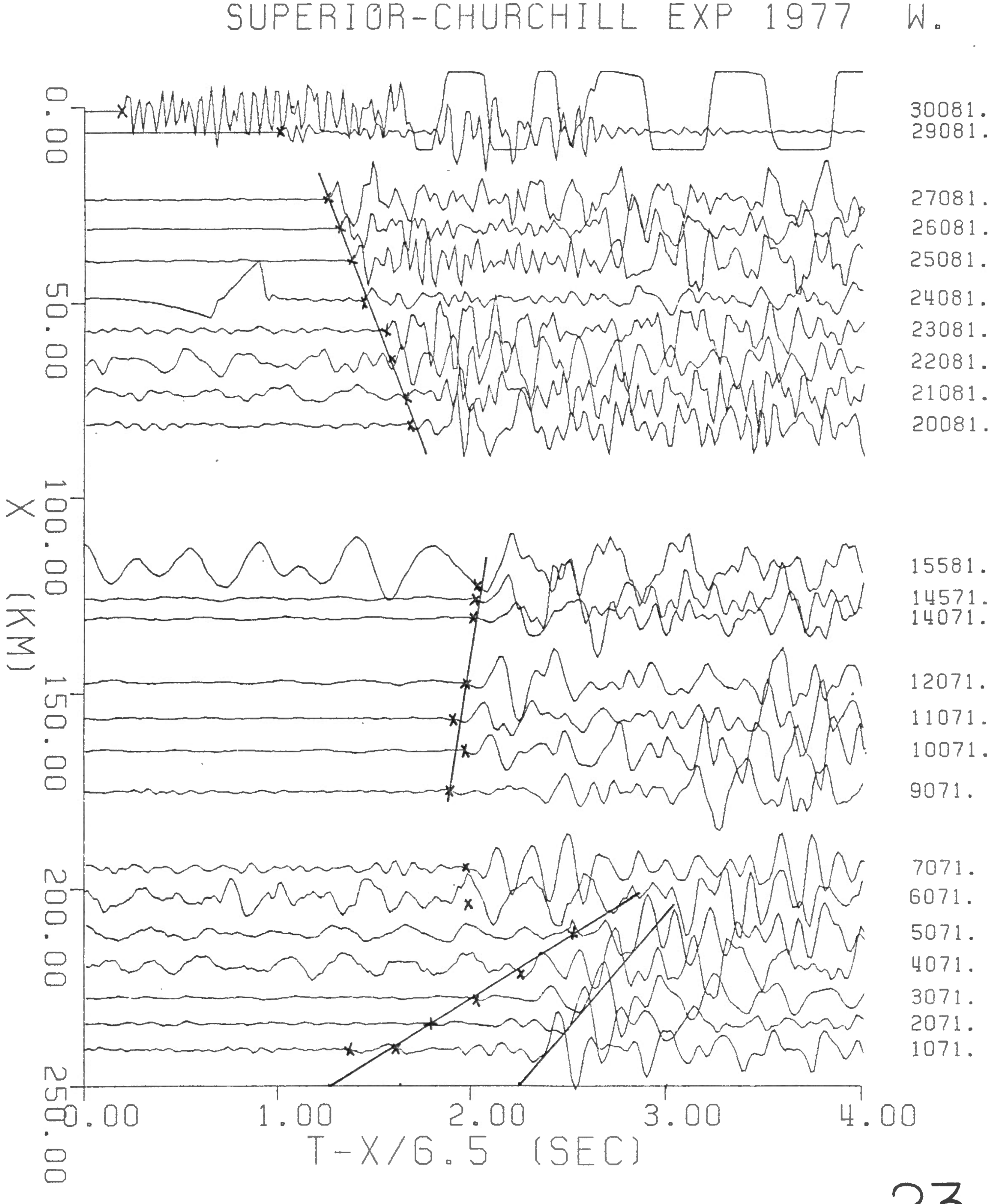


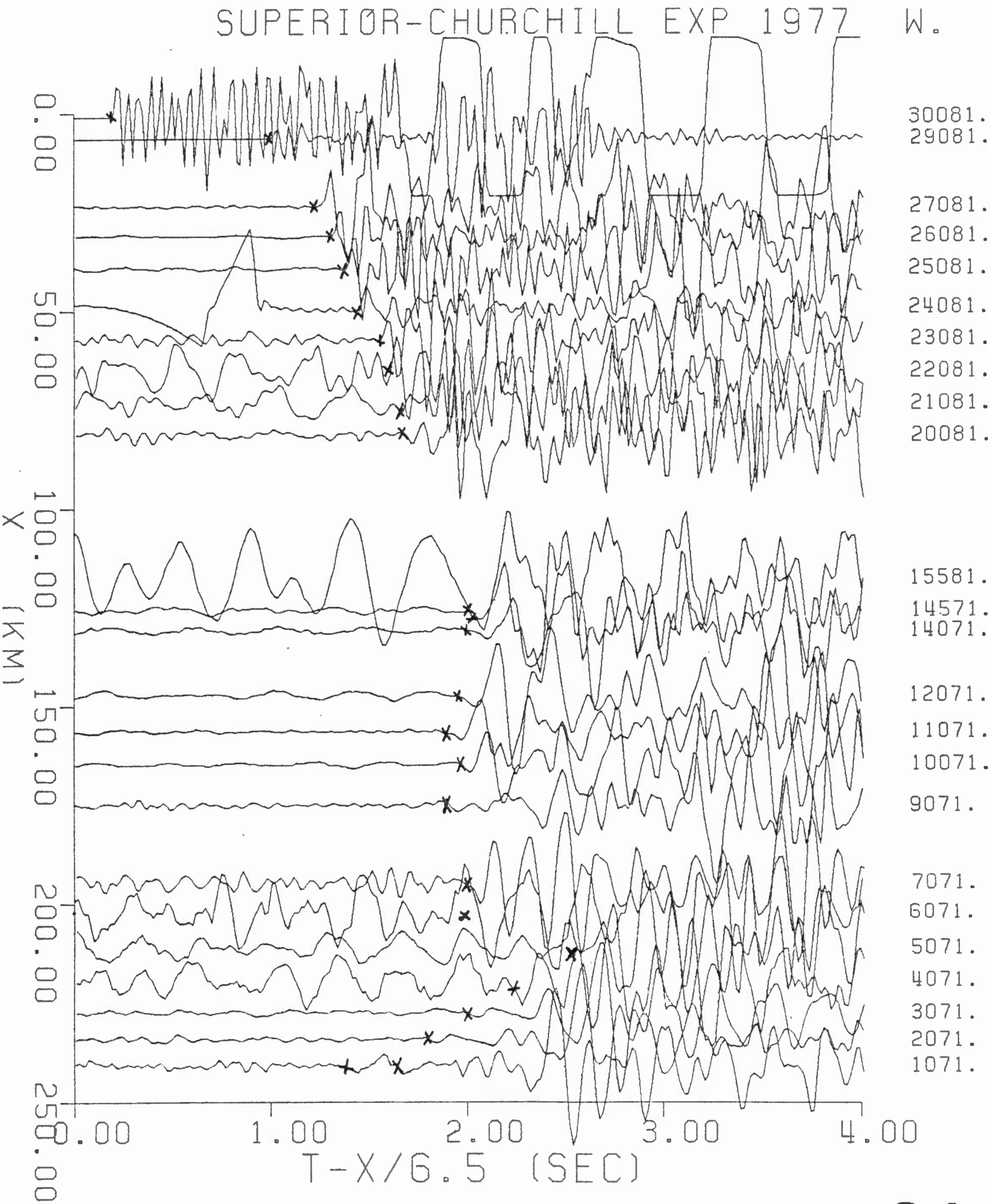

SUPERIØR-CHURCHILL EXP 1977 S.
0.00
50.00
100.00
150.00
200.00
250.00
Y (KM)
1041.
2041.
3041.
4041.
5041.
6041.
7041.
9041.
10041.
11041.
12041.
13041.
14041.
15041.
16041.
16531.
17031.
18031.
19031.
19531.
20531.
21031.
22031.
23031.
25031.
26031.
27031.
29031.
30031.
31031.
0.00
1.00
2.00
3.00
4.00
T-X/6.5 (SEC)



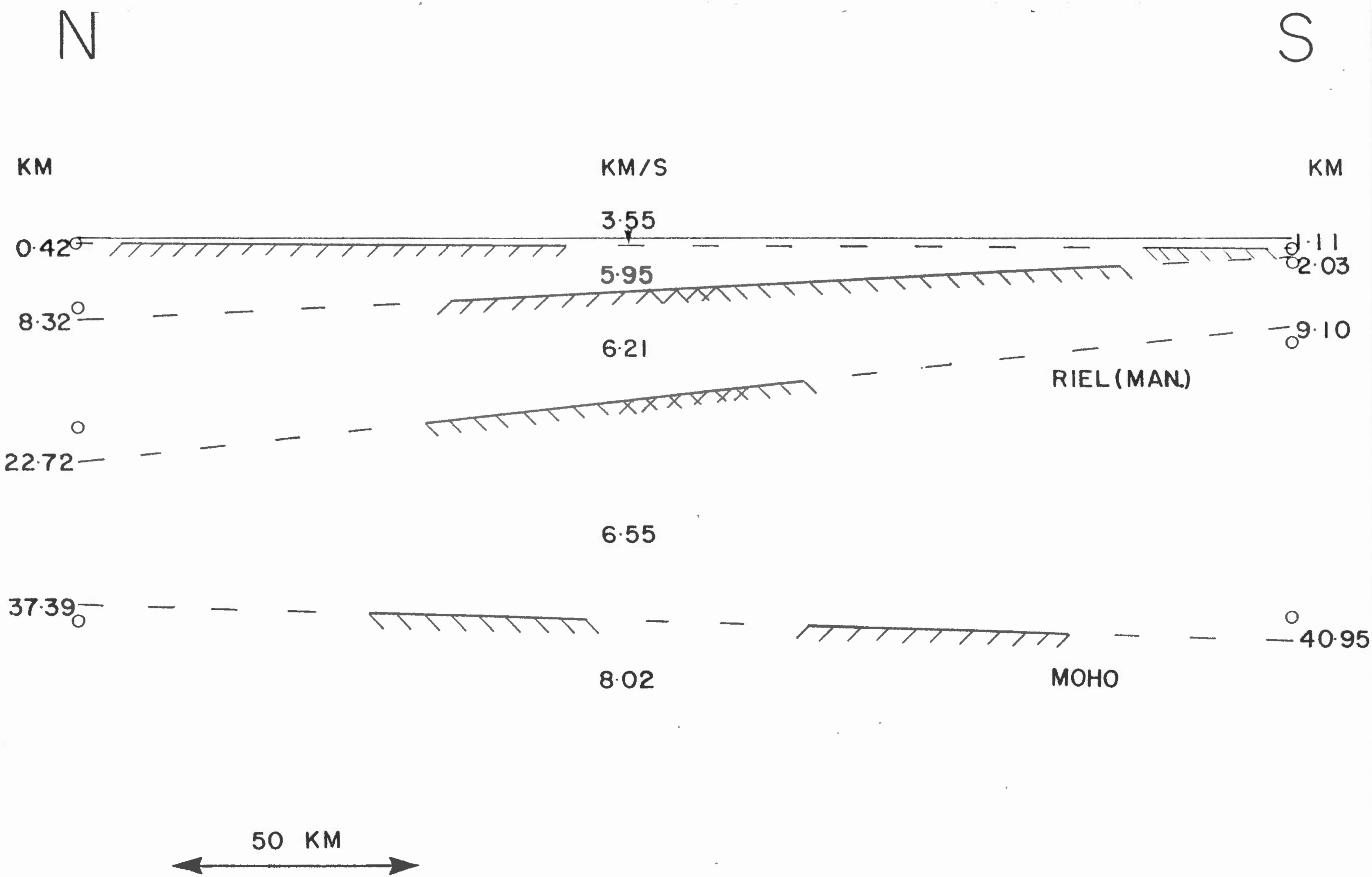
SUPERIØR-CHURCHILL EXP 1977 E.
0.00
50.00
100.00
150.00
200.00
250.00
X (KM)
0.00
1.00
2.00
3.00
4.00
T-X/6.5 (SEC)
1061.
2061.
3061.
4061.
5061.
6061.
7061.
9061.
10061.
11061.
12061.
13061.
14061.
14561.
15561.
20051.
21051.
22051.
23051.
24051.
25051.
26051.
27051.
30051.


SUPERIØR-CHURCHILL EXP 1977 E.
1061.
2061.
3061.
4061.
5061.
6061.
7061.
9061.
10061.
11061.
12061.
13061.
14061.
14561.
15561.
20051.
21051.
22051.
23051.
24051.
25051.
26051.
27051.
30051.
0.00
50.00
100.00
150.00
200.00
250.00
X (KM)
0.00
1.00
2.00
3.00
4.00
T-X/6.5 (SEC)


SUPERIOR-CHURCHILL EXP 1977 W.
X (KM)
0.00
50.00
100.00
150.00
200.00
250.00
T-X/6.5 (SEC)
0.00
1.00
2.00
3.00
4.00
30081.
29081.
27081.
26081.
25081.
24081.
23081.
22081.
21081.
20081.
15581.
14571.
14071.
12071.
11071.
10071.
9071.
7071.
6071.
5071.
4071.
3071.
2071.
1071.

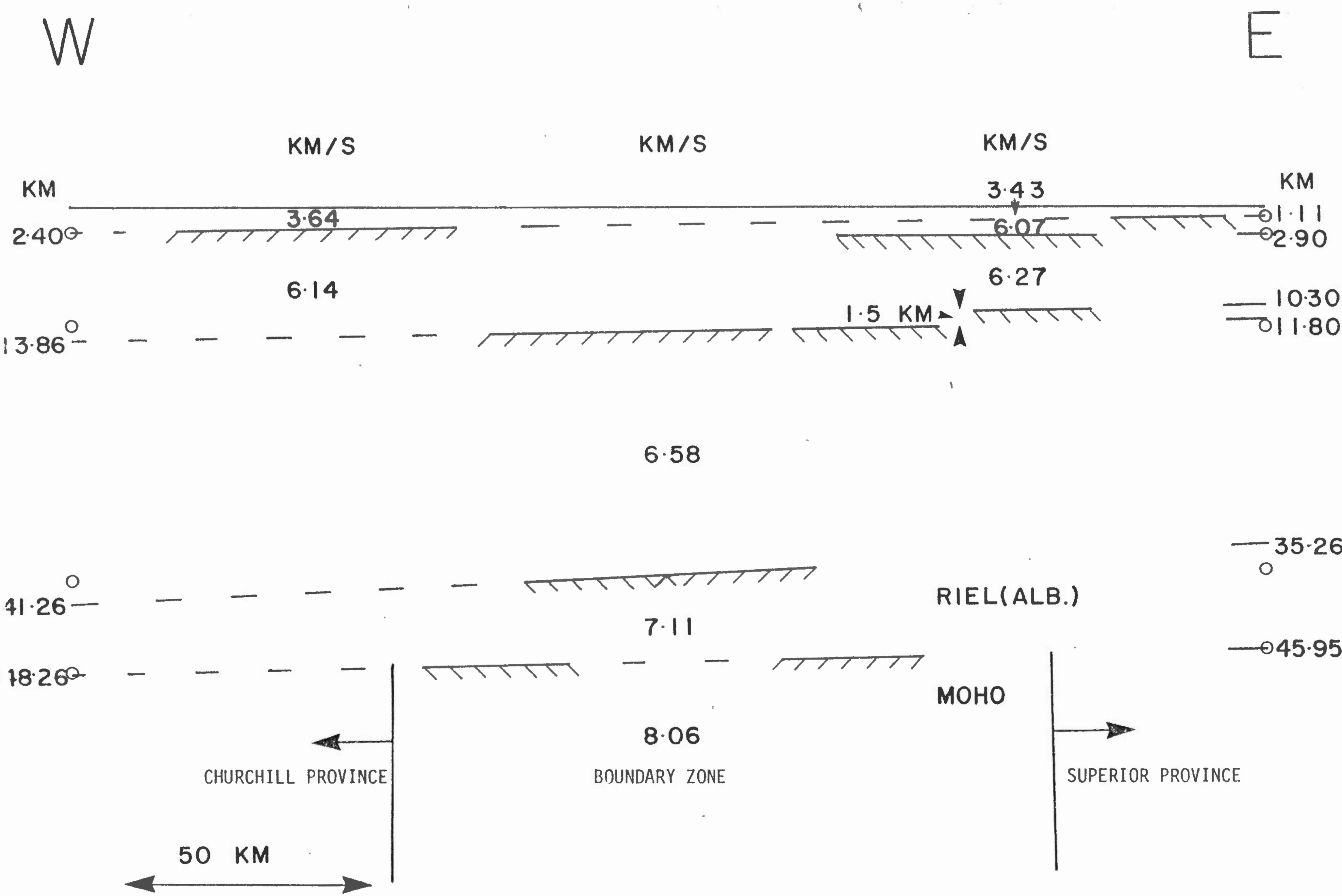


SUPERIØR-CHURCHILL EXP 1977 W.
0.00
50.00
100.00
150.00
200.00
250.00
X (KM)
0.00
1.00
2.00
3.00
4.00
T-X/6.5 (SEC)
30081.
29081.
27081.
26081.
25081.
24081.
23081.
22081.
21081.
20081.
15581.
14571.
14071.
12071.
11071.
10071.
9071.
7071.
6071.
5071.
4071.
3071.
2071.
1071.



Vertical exaggeration of two

25



Vertical exaggeration of two

(B) SEISMIC REFLECTION

(a) Revisions to Part I of this report

1. The shot point elevation corrections should be ignored (as given, these corrections would place all shots 15 m below the datum). The equivalent receiver elevation corrections may be taken as reasonable estimates of the shot elevation corrections (i.e. receiver elevation correction at location 18 = shot elevation correction at location 18).
2. In Table 11a, replace 49 with 45 in column 1.

(b) The Reflection Data

Copies of sections produced by Petty Ray geophysical are available from the University of Manitoba for the cost of reproduction (copies have been sent as part of the agreement to the Earth Physics Branch and the universities of Alberta and Saskatchewan). These sections were plotted by Petty Ray from computer tapes provided by the University of Manitoba.

Comments on the sections

1. Two band pass filters were applied to the plotted data. Recursive Butterworth band pass filters (Kanasewich, 1975), with eight poles, was applied in the forward and reverse directions (written and supplied by David Ganely, University of Alberta). Records submitted as the basic data were filtered with the following characteristics:

   3 - 55 Hz (Universities of Alberta and Manitoba)

   0 - 55 Hz (University of Saskatchewan).

   Several additional filters with various bandwidths (low pass - 8, 10, 12 Hz; high pass 30, 35, 40, 50 Hz) were then tested on an assortment of records with the object of reducing the high amplitude, low frequency ground roll and high frequency random noise. A band pass filter of 8-35 Hz was found to produce satisfactory results (compare Fig. 27 to the submitted sections). Thus, the records sections have been filtered twice:

0
\- 55 Hz (only this filter is mentioned on the label)
3

and 8 - 35 Hz.

3. An automatic gain function was applied to the data shown in the sections (program written and supplied by Ivan Sereda, University of Saskatchewan). On the true amplitude plots, where individual traces were normalized to a final maximum value, most of the data after 2 or 3 seconds were impossible to read due to the relatively low amplitudes (i.e. amplitudes of signal after 3 seconds are very low relative to the earlier arrivals; this effect is particularly noticable on the University of Manitoba records which have a wide dynamic range). The automatic gain accounts for most of the 'noise' prior to the first breaks. Other techniques of increasing the amplitudes of the later arrivals will be tested later.
4. No static or normal moveout corrections have been applied.
5. There is fair to very good correspondence between the records that were recorded at the common locations (mostly University of Manitoba traces 12 and University of Alberta traces 11, and University of Manitoba traces 35 and University of Saskatchewan traces 36). See Figs. 28 to 31 for comparisons of some raw (non-AGC) records and the autocorrelations of some adjacent records. The similarity between overlapping and adjacent records is higher for the University of Manitoba and

University of Alberta data than for the University of Manitoba and University of Saskatchewan data. Many of the events on the University of Saskatchewan records have a 'ringing' character that may be associated with a marginally higher dominant frequency range.

6. The relative timing between adjacent recording systems needs to be adjusted by up to several sample intervals. The largest discrepancies occur when the WWV radio signal was used as the principal timing information for one or more of the recording units. Except for shots 28A and 67A (Table 7, Part I), at least one of the recording units obtained a good time break or tone break signal. Records from the three recording trucks may be synchronized to the most reliable timing channel via cross-correlation of the overlapping traces. Fig. 32 shows that this technique can align the traces to within 1 sample interval.

7. Most of the garbage or noice traces were inadvertently plotted by Petty Ray (they ignored their own weighting system).

8. Recording channels that were not operational for any shot are documented in the text and Appendices of Part I.

9. Receivers that were adjacent to the shot holes were not connected; the nearest take-out was often used for the uphole geophone. Overloading on the lines adjacent to the uphole line was frequently observed in the early part of some records.

10. <u>Line 1</u>

Record 12 - only the U of A processed the test shot recordings.

34A- a neighbouring charge that was primed for shot 34B was sympathetically detonated ~ 13½ s after the main shot.

67 - U of M recorded only ~ 18.3 s

123A- U of A channels are subscripted 0 instead of 1 on the tape; therefore they were not plotted.

U of M did not record channels 12 to 23 (locations 99 to 110). The traces shown on the sections should read 35 to 24:

12 - 35

13 - 34

|

|

|

23 - 24

These traces are also in the wrong order on the tapes. (Use traces from shot 123 for U of A and U of M data and traces from shot 123A for U of S data; 123A was specifically shot for U of S, as a train passed by during the recording of 123).

Record 23A - field filter, notch/line balance and charge size parameters on the tape are displaced by 2 locations (has the effect of multiplying the above parameters by 100 - U of M data only).

Record 67A - as for 28A except that the field filters are not involved.

Line 2

Records 144A to 166 - missing some of the traces. For unknown reasons Petty Ray missed the first 74 traces on the line 2 tape. We have checked these records and they are good.

Records 172 to 182 - the six traces 30 to 35 on these records were not recorded (short line). Traces 36 to 48 should be in the positions of the traces 30 to 42.

Line 3

Record 193 - U of M traces 12 to 21 were not automatically gain controlled. They are listed with a "1" weighting factor as the first 2 seconds of information was accidentally erased during playback.

Record 210 - for unknown reasons trace 1 has been placed on its own.

Records 216 to 243 - U of A system was not operational.

12. There may be some problems with persistent multiples from the sedimentary section (eg. record 40).

13. The many prominent refracted arrivals will be useful for outlining sedimentary discontinuities with high velocity contrasts (note the basement refractor on the wide angle shots).

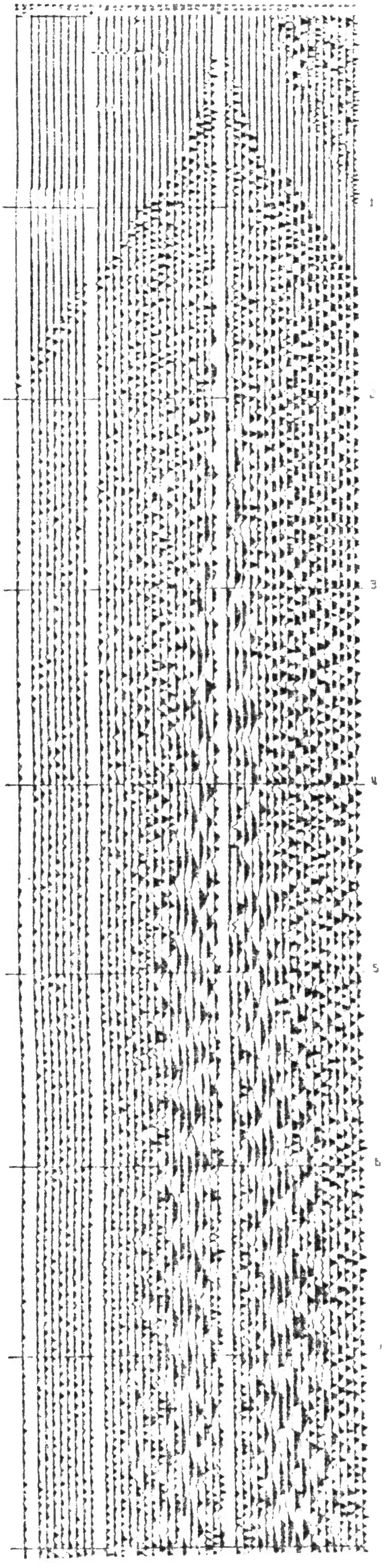
14. As the sections are uncorrected it is not surprising that deep crustal reflections cannot be traced over the ~72 km of the survey. With this type of display (variable area/wiggly trace) it is difficult to see events with large moveouts and reflections from as deep as the Mohorovicic discontinuity may be expected to have moveouts of 0.1 to 0.3 s over the 12.8 km spreads. A number of events can be correlated over at least single record sections. If these events are from the deep crust, then the reflector must be continuous for > 6 km; [redacted] After applying the static and normal moveout corrections and stacking the data about their common depth points some clear results should emerge. We have not attempted to correlate events between neighbouring record sections.

15. There are two problem areas related to the three different recording systems that have to be tackled:

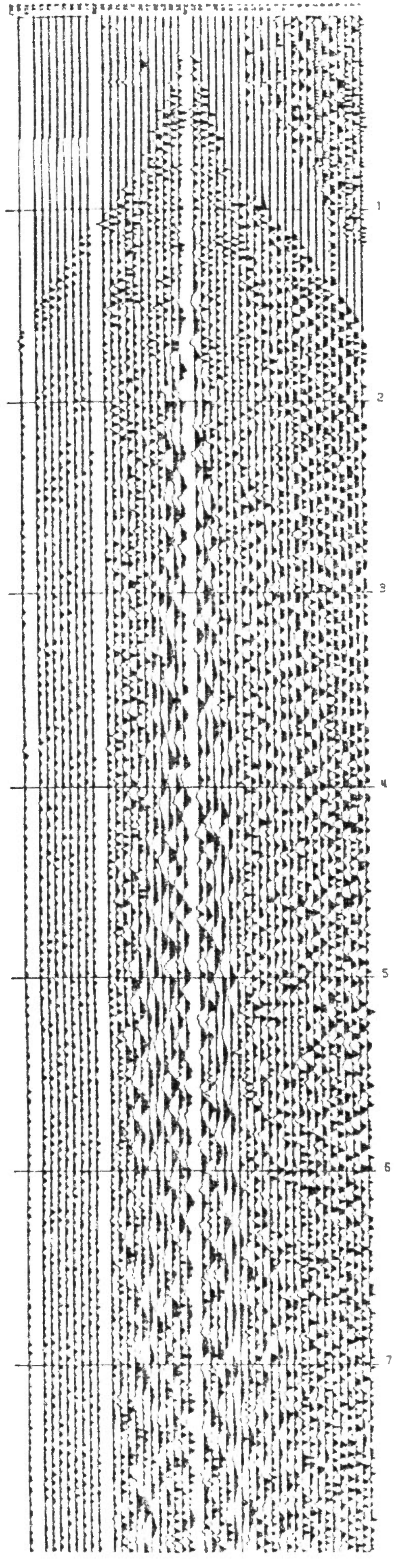
    (i) We must detect and remove any phase differences between the three systems.

    (ii) A modified velocity analysis program must account for the large variations in amplitude with time of the U of M and U of S data relative to the U of A data; the U of A data have a relatively constant amplitude with time (some clipping at the beginning of a trace), while the other systems allow a large decrease in amplitude with time. As the AGC computer program produces distortion it should not be applied prior to the velocity analysis. Multiplying the U of M and U of S data by a simple function that increases with time may solve this problem.

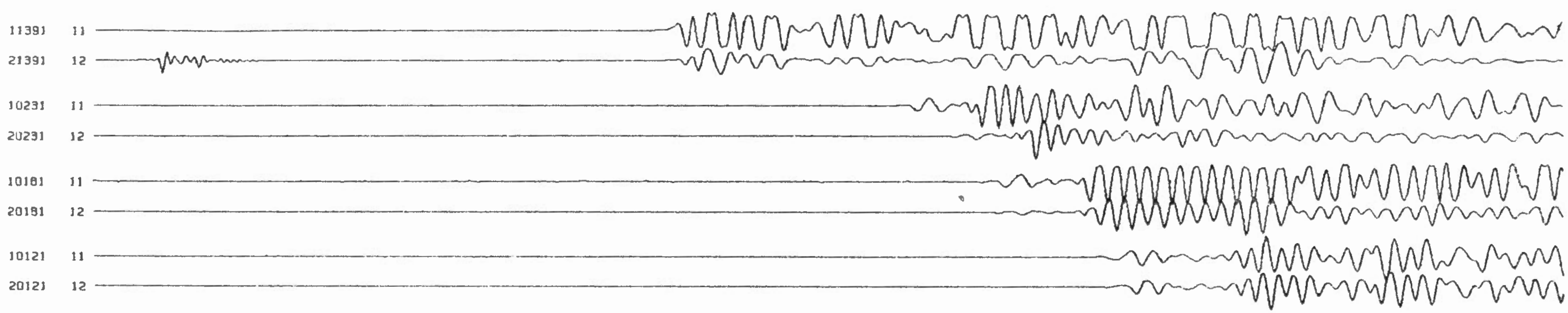
RECORD NO.10400



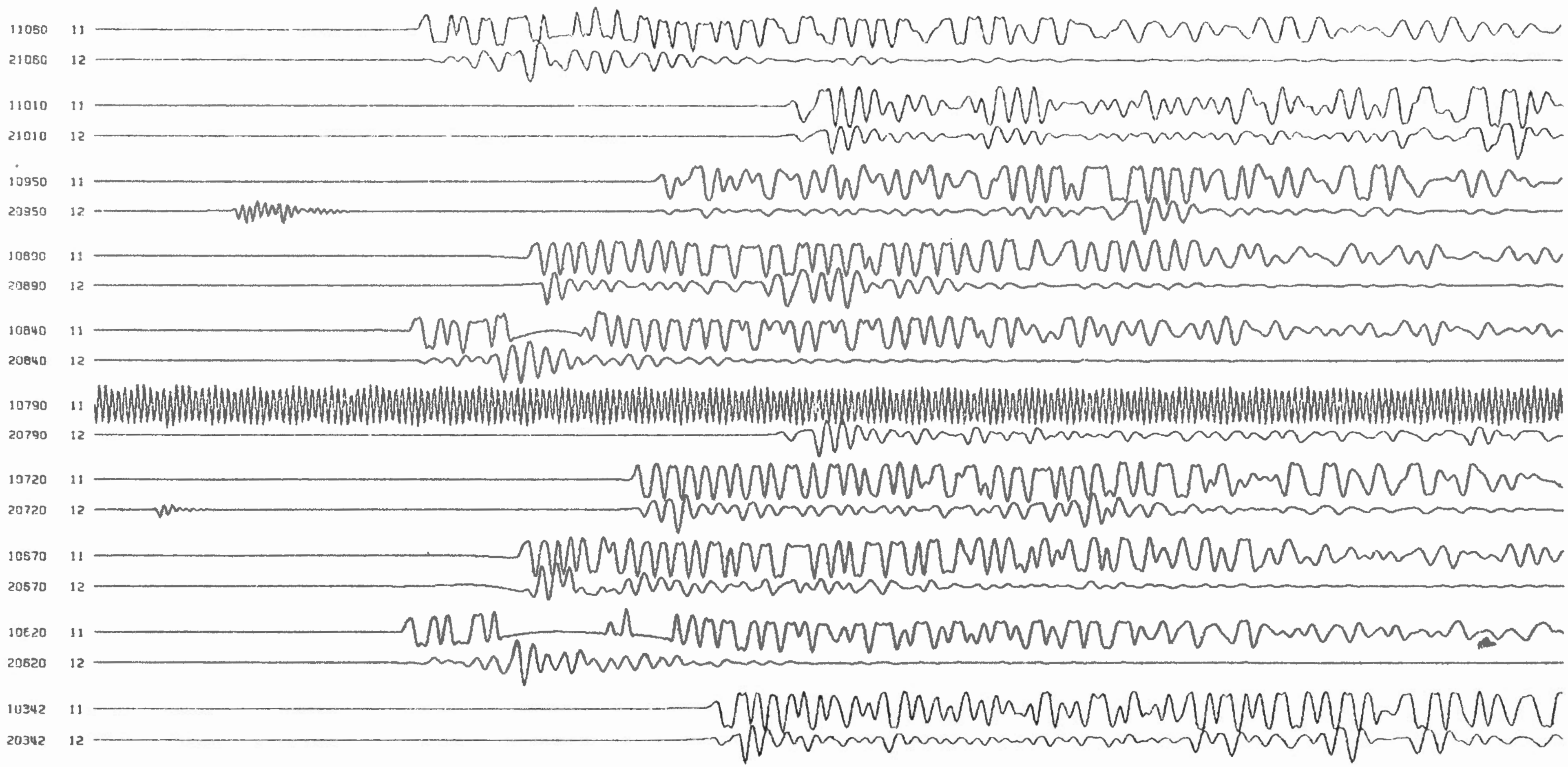
RECORD NO.10450

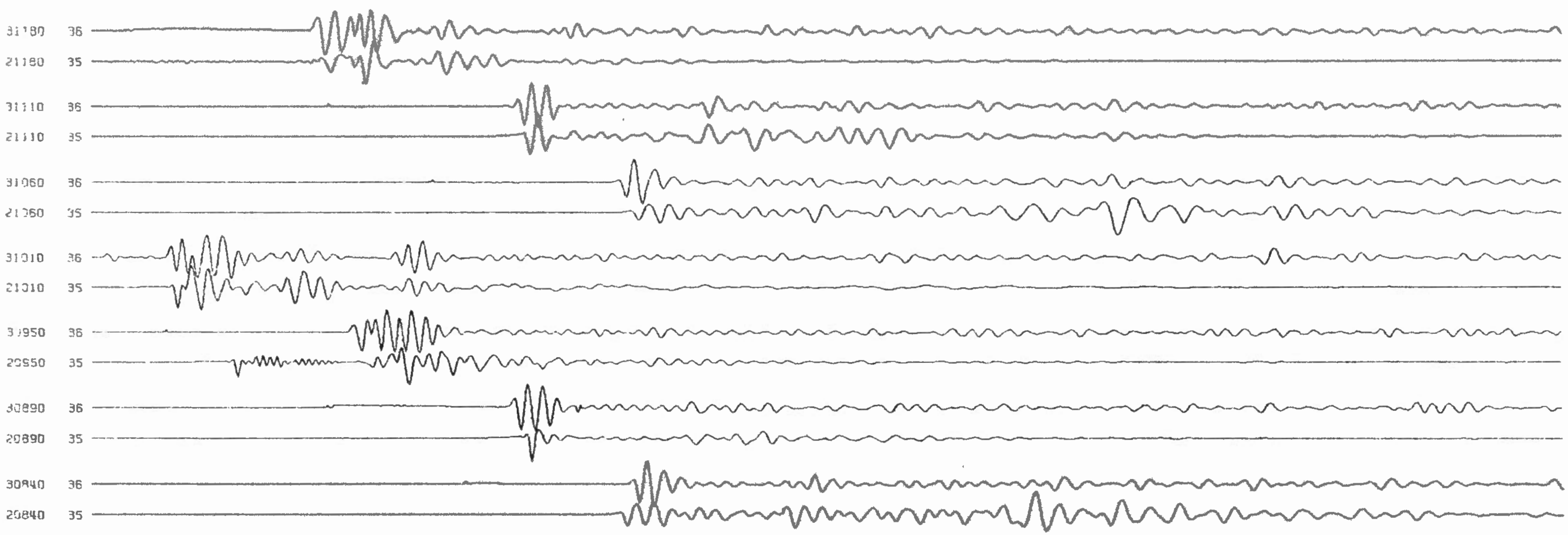


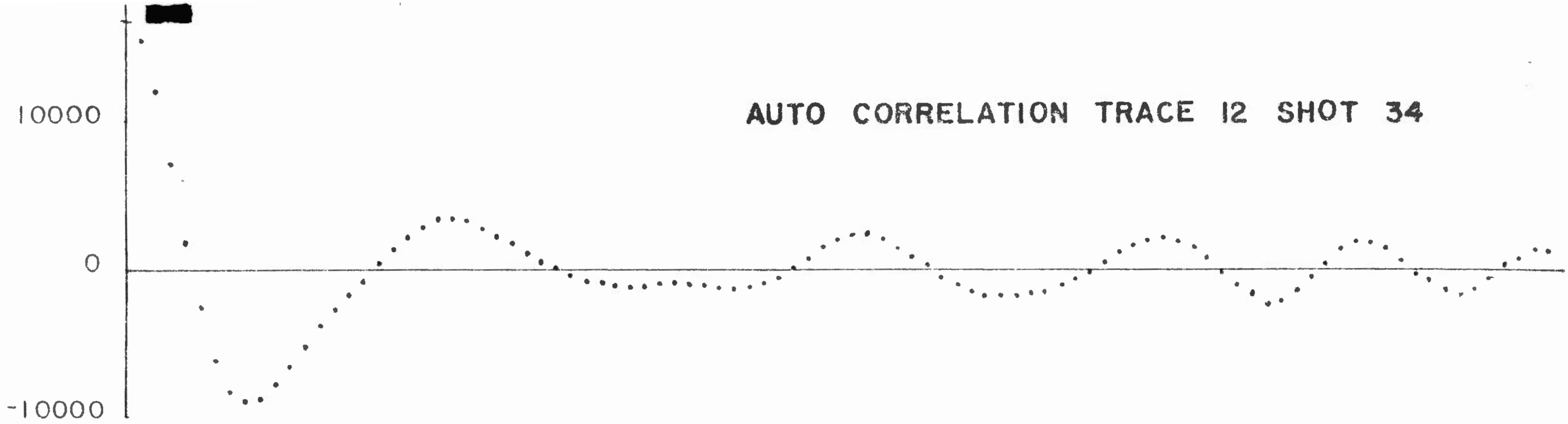
[redacted]

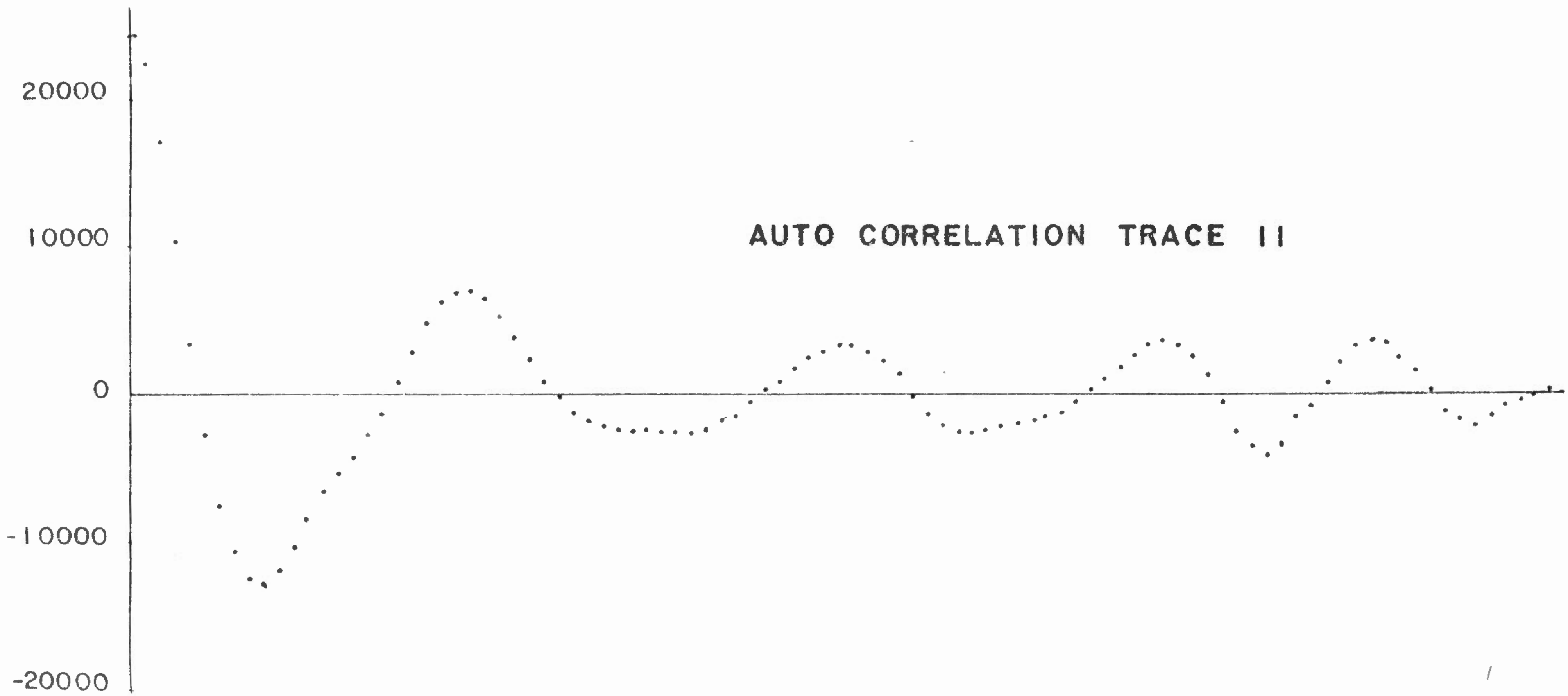

11391 11
21391 12
10231 11
20231 12
10181 11
20181 12
10121 11
20121 12

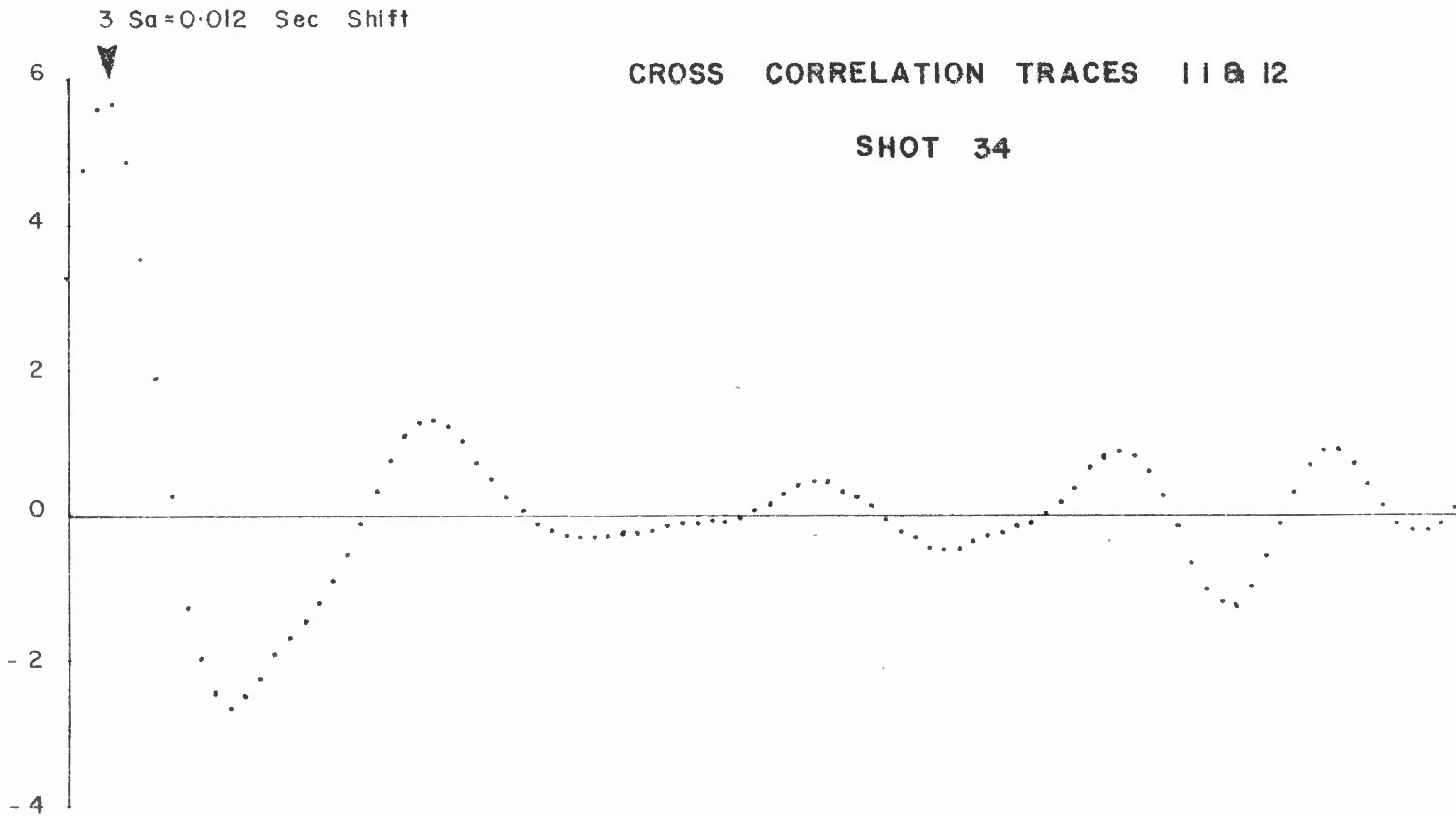
[redacted]


11060 11
21060 12
11010 11
21010 12
10950 11
20950 12
10890 11
20890 12
10840 11
20840 12
10790 11
20790 12
10720 11
20720 12
10670 11
20670 12
10620 11
20620 12
10342 11
20342 12


31180 36
21180 35
31110 36
21110 35
31060 36
21060 35
31010 36
21010 35
30950 36
20950 35
30890 36
20890 35
30840 36
20840 35


AUTO CORRELATION TRACE 12 SHOT 34
10000
0
-10000


AUTO CORRELATION TRACE 11
20000
10000
0
-10000
-20000


3 Sa=0·012 Sec Shift
CROSS CORRELATION TRACES 11 & 12
SHOT 34
6
4
2
0
- 2
- 4

REFERENCES

Chandra, N. N. and Cumming, G. L., 1972. Seismic refraction studies in western Canada. Can. J. Earth Sci., 9, 1099.

Green, A. G., Hall, D. H. and Stephenson, O. G., 1978. A sub-critical seismic reflection survey over the Aulneau batholith, Kenora region, Ontario. Can. J. Earth Sci., 15, 301.

Hall, D. H., and Hajnal, Z., 1969. Crustal structure of northwestern Ontario, refraction seismology. Can. J. Earth Sci., 6, pp. 81-99.

___________ 1973. Deep seismic crustal studies in Manitoba. B. S. S. A., 63, pp. 885-950.

Mereu, R. F. and Hunter, J. A., 1969. Crustal and upper mantle structure under the Canadian Shield from Project Early Rise data. B. S. S. A., 59, 147.

Wright, J., and West, G. F., 1976. Seismic studies in the southern Geotraverse. University of Toronto, Geotraverse Workshop, 1976, pp. 47-55.