ACTIVE FAULTS OF THE BAIKAL DEPRESSION

FAILLES ACTIVES DE LA DÉPRESSION DU BAÏKAL

Kirill G. LEVI, Andrei I. MIROSHNICHENKO, Vladimir A. SAN'KOV, Sergey M. BABUSHKIN, Gennady V. LARKIN, Alik A. BADARDINOV, How Kin WONG, Steven COLMAN and Damien DELVAUX

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La dépression du Baïkal occupe une position centrale dans le système des bassins de la zone du rift du Baïkal. Elle correspond au point de départ de l'ouverture de la lithosphère. Pour diverses raisons, la structure interne du bassin du lac Baïkal est longtemps restée inconnue. Dans cette publication, nous présentons pour la première fois des données concernant la structure de la série sédimentaire du fond du lac, données qui ont été obtenues en interprétant des sections sismiques et des données structurales acquises principalement de 1989 à 1992.

Une brève description des profils sismiques les plus intéressants fournit une idée générale de la série sédimentaire. Une interprétation structurale détaillée est présentée ; elle montre les relations entre les failles actives du lac, les anomalies du flux thermique et l'hydrothermalisme récent.

Kirill G. Levy, Andrei I. Miroshnichenko, Vladimir A. San'kov, Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences, Lermontova Street 128, 664033 Irkutsk, Russian Federation ; Sergey M. Babushkin, Gennady V. Larkin, United Institute of Geology, Geophysics and Mineralogy of the Russian Academy of Sciences, Universitetsky Av. 3, 630090, Novosibirsk, Russian Federation ; Alik A. Badardinov, Limnological Institute of the Russian Academy of Sciences, Ulan-Batorskaya Str., 3, 664033 Irkutsk, Russian Federation ; How Kin Wong, Institute of Biogeochemistry and Marine Chemistry, Hamburg University, Bundesstrasse 55, D-2000 Hamburg 13, Germany ; Steven Colman, US Geological Survey, Woods Hole, Massachusetts, MA 02543, USA ; Damien Delvaux, Royal Museum for Central Africa, Department of Geology and Mineralogy, Leuvensesteenweg, 13, B-3080 Tervuren, Belgium.— December 20, 1996.

Mots-clés : Levé sismique, Série sédimentaire, Faille active, Flux géothermique, Anomalie thermique, Région Baïkal.

ABSTRACT

The Baikal depression occupies a central position in the system of the basins of the Baikal Rift Zone and corresponds to the nucleus from which the continental lithosphere began to open. For different reasons, the internal structure of the Lake Baikal basin remained unknown for a long time. In this article, we present for the first time a synthesis of the data concerning the structure of the sedimentary section beneath Lake Baikal, which were obtained by complex seismic and structural investigations, conducted mainly from 1989 to 1992.

We make a brief description of the most interesting seismic profiles which provide a rough idea of a sedimentary unit structure, present a detailed structural interpretation and show the relationship between active faults in the lake, heat flow anomalies and recent hydrothermalism.

Keywords: Seismic surveys, Sedimentary section, Active Faults, Geothermal heat flow, Thermal anomalies, Baikal Region.

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INTRODUCTION

The geological and geophysical processes involved in the formation of the Baikal rift zone have been reviewed by LOGATCHEV (1993). For many years, investigations concentrated on the observation of the geological structure of the lake shores, its islands and peninsulas. Fault zones were extrapolated beneath the lake level from one shore to another. Kinematic models of the rift basin opening which were based on these interpretations of the fault pattern (e.g. BALLA *et al.*, 1991) are therefore questionable.

Single- and multi-channel seismic investigations in Lake Baikal provide a better insight into the tectonic structure of the underwater parts of the depression. These data allowed to trace active fault zones from one shore to another more precisely. This in turn better constrains the kinematic models of rift basin opening. This paper only deals with the results of single-channel seismic investigations. It describes the most important profiles and the results of detailed field structural investigations on the lake shores. It presents, for the first time, the map of active faults of the Baikal depression.

1. — SEISMIC REFLECTION EXPERIMENTS IN LAKE BAIKAL

Seismic reflection investigations of the upper sedimentary section of the Lake Baikal depression have been undertaken since 1977 by several research groups, using different methods and equipment.

The first seismic investigations of Lake Baikal were conducted in **1977-1982** by geophysicists from the Moscow University and the Institute of Oceanology, Russian Academy of Sciences (RAS). They were mostly concentrated at the north of Lake Baikal (Fig. 1A), using single-channel seismic profiling with a "Sparker" source, and "Aquamarine" analogue recording system. The seismic source had a frequency of 60 - 100 Hz, penetrating 1000-1500 metres of sediments. The profiles executed during these years are of poor quality, but they were the only ones before the new investigations of 1989. The first stratigraphic and structural interpretation of these seismic profiles was made by NIKOLAEV *et al.* (1985). The results were further used to highlight the Neogene history of development of the Baikal depression (NIKOLAEV, 1985; 1987; GARETSKY *et al.*, 1988; VASILYEV *et al.*, 1989).

In **1989**, a new series of seismic lines was shot on the initiative of the Limnological Institute, Siberian Branch, Russian Academy of Sciences (SB RAS), the Geological Institute RAS, and the Hamburg University (Germany). They investigated the southern and central basins of Lake Baikal, while the northern basin remained poorly known (Fig. 1B). A total of 1300 km of single channel reflection seismic profiles were acquired, using three air guns with a total of 4 litres and a spacing of one metre between adjacent guns. A single-channel two-sectional mini-streamer with a total length of 50 metres was used as a receiver. The depth of penetration was about 1500 metres. The description of the experiment and the preliminary results are given in WONG *et al.* (1990) and NIKOLAEV (1990).

In **1990-1992**, single-channel seismic surveys were performed by the United Institute of Geology, Geophysics and Mineralogy (UIGGM) SB RAS involving the Institute of the Earth's Crust SB RAS. Seismic lines were shot in order to fill the existing gaps and to cover the Northern Baikal basin by a more or less uniform grid (Fig. 1C). An air gun with an operating chamber of 3 litres and a frequency of 200 Hz was used in 1990 and 1991. In 1992, some of the profiles were acquired with the former source, and some with an impulse pneumatic

FIGURE 1

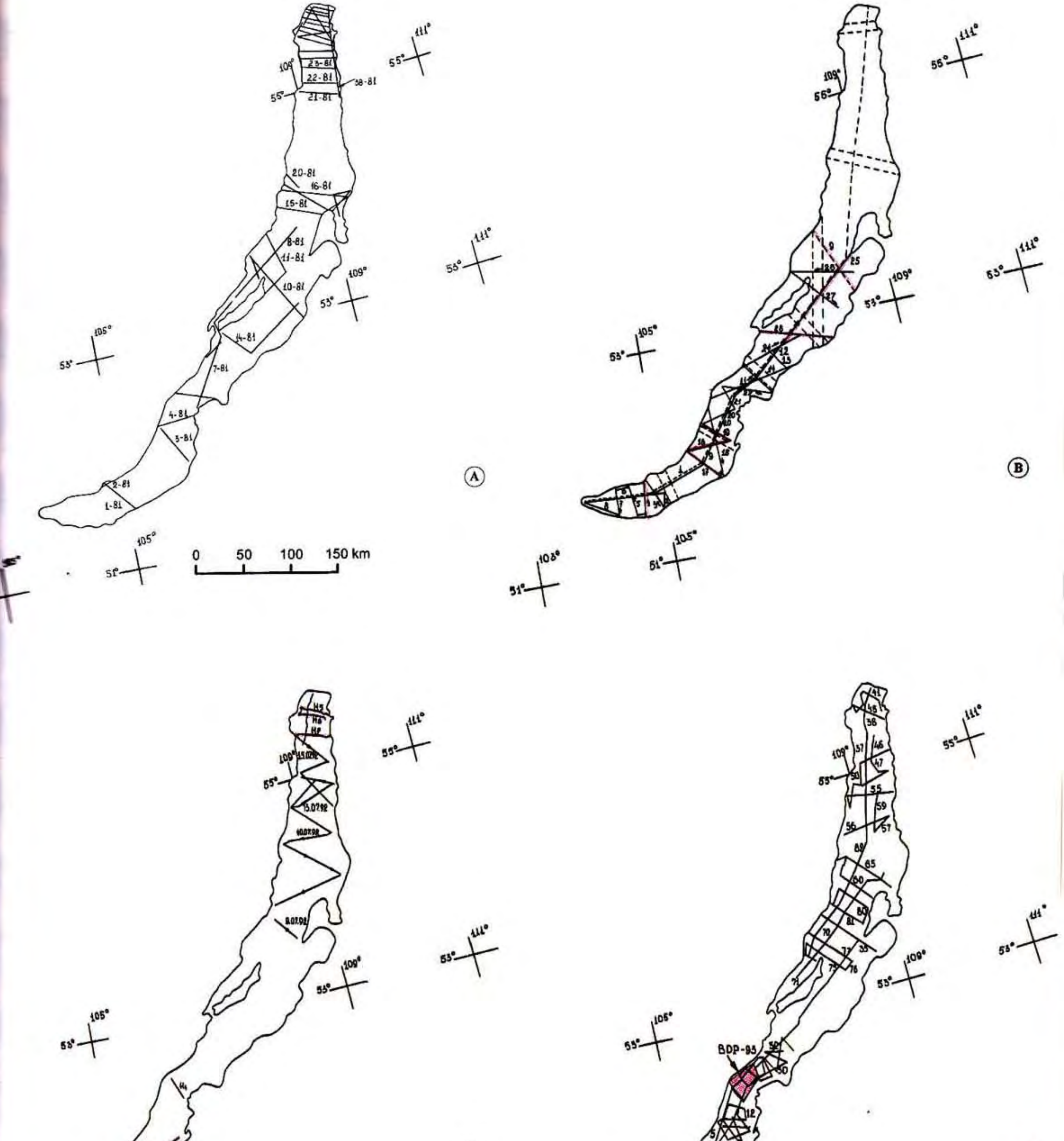
Location maps of the seismic profiles acquired in the Lake Baikal:

A - 1977-1982 by Moscow State University, Institute of the Earth's Crust SB RAS and Institute of Oceanology RAS;

B - 1989 by University of Hamburg, Geological Institute RAS and Limnological Institute SB RAS;

C - 1990-1992 by United Institute of Geology, Geophysics and Mineralogy SB RAS and Institute of the Earth's Crust SB RAS;

D - 1989 and 1992 by Institute of Oceanology RAS, Limnological Institute SB RAS and US Geological Survey (Woods Hole).


A
23-81
22-81
21-81
38-81
20-81
16-81
15-81
8-81
11-81
10-81
14-81
7-81
4-81
3-81
2-81
1-81
0 50 100 150 km
B
C
0 50 100 150 km
D
BDP-93

source, with a signal operating frequency of 80-100 Hz and a gun chamber of 3 litres. This allowed to penetrate 400-1000 metres of sediments.

In the summers of **1989 and 1992**, about 3700 km of high resolution seismic profiles (Fig. 1D) were shot jointly by the Institute of Oceanology RAS, Limnological Institute SB RAS and the US Geological Survey (Woods Hole). These last experiments were carried out in the framework of a major project aiming at the reconstruction of the Quaternary environmental and climatic changes that affected Lake Baikal (COLEMAN *et al.*, 1996). They aimed to define the location of boreholes to be drilled near Buguldeika and in the Academician Ridge by the Baikal Drilling Project (Baikal Drilling Project, 1993).

In 1989, 1500 km of multichannel seismic reflection profiles were acquired by the Institute of Oceanology RAS, jointly with the Institute of Limnology SB RAS and processed by the US Geological Survey (Woods Hole). They used a 24-channel piezoseismograph cable of 1200 metres, low-frequency pneumatic source with a 17-litre chamber and digital recording. These profiles had a limited resolution, aiming at imaging the deep sedimentary section and the crystalline basement (HUTCHINSON *et al.*, 1993).

In 1992, a new multichannel seismic survey was conducted by the US Geological Survey, jointly with the Institute of Oceanology RAS. More than 2200 km of profiles were acquired in the Selenga delta- Posolsky Bank area and in the Academician Ridge accommodation zone. A 96-channel piezoseismograph cable of 2400 metres was used, with a 10-chamber pneumatic source of 27 litres and digital recording. This last piece of equipment allowed a greater depth to be reached with higher resolution (SCHOLZ *et al.*, 1993; KAZMIN *et al.*, 1995).

Most of these existing profiles were provided to the Earth's Crust Institute (SB RAS) through the courtesy of their owners, for the investigation of the tectonic structure of the Baikal sedimentary basin.

2. — BRIEF INTERPRETATION OF SOME SELECTED SEISMIC LINES

The seismic records from different experiments are used here to investigate the structure of the Baikal basin. The most illustrative profiles for tectonic analysis are discussed (location in Figure 1A-D). The main geographical and structural features quoted in this study, as well as Lake Baikal subdivisions, are given on Figures 2,3, 5 and 6.

2.1. SOUTH BAIKAL BASIN

A total of more than 30 seismic profiles were shot in the South Baikal basin, mostly across the strike of its longitudinal axis. Some of them merit a special consideration.

Profile 4 was acquired in 1989 by the Russian-German expedition, in the western part of the south basin (Fig. 1B). This is one of the few records which distinctly shows folding structures in the stratigraphic section (Pl.1). Three depositional sequences are recognised in this area (NIKOLAEV, 1990; HUTCHINSON *et al.*, 1992). The intermediate sequence is deformed by NW-SE trending folds with up to 1 km amplitude and 7-8 km wavelength. It is overlain by a thin undeformed sequence attributed to the Middle Pleistocene-Holocene. Folds with NW-trending axes are also described in the coal-bearing beds of Miocene age (Tankhoy series) along the southern margin of the South Baikal basin (VOROPINOV, 1961) and in the Tunka basin (FLORENSOV, 1964). Their origin was first explained by gravitational sliding of unconsolidated sediments along the basin slopes. However, in that case, the folds should be disharmonic, their axes should follow the orientation of the margins of the basin and their axial surfaces should be tilted towards the centre of the basin. On the basis of profile 4, the folded structures are here related to a short-term tectonic inversion, with horizontal principal compression in a NE-SW direction, parallel to the longitudinal axis of the basin. Such inversion stages in the development of rifting structures are common (e.g. in the western branch of the East African rifting system: SANDER & ROSENDAHL, 1989).

Another possible interpretation is that the formation of these folds might be linked to strike-slip movements in the basement. Sinistral strike-slip movements in the South Baikal basin have already been shown by SHERMAN & LEVI (1978), from field observations. Thus, both explanations for the origin of these folds are possible, but the authors are inclined to think that the second one is the most likely.

Profile 17 of the 1989 Russian-German expedition crosses the eastern part of the South Baikal basin in a NW-SE direction (Fig. 1B). It shows several intense dislocation zones, separating the stratigraphic section into several blocks (Pl. 2). In the southeastern part of the profile, the basement appears directly at the lake floor and is downfaulted in a series of steps towards the centre of the depression. The last narrow basement block is covered by a sequence of a few tens of metres thick. A wide tectonic block, composed of Cenozoic sediments, is displaced to the northwest. The sediments are deformed at the margins of this block, and some intraformational unconformities are present. In addition to subparallel boundary faults dipping to the northeast, listric faults are seen in the internal part of the block. A second large sedimentary block, similar to the first one, is located at the foot of the northwest slope of the basin. The sediments at the block margins are also deformed near the boundary faults. Moreover, a giant landslide is distinctly traced near the foot of the northwestern basin slope. The most deformed sediments are situated along the axial fault in a 10 km wide zone. This suggests the importance of lateral movements in addition to vertical block movements.

Profiles 18 and 19 of the 1989 Russian-German expedition (Fig. 1B) cross the basin from west to east and from the northwest to the southeast respectively. They illustrate the marginal structure of the Selenga River delta (Pl. 3-4). Normal faults, often dipping to the southeast, are clearly seen in the upper depositional sequence. The delta slope is to a great extent dismembered by numerous channels and slumpings, suggesting mass transports of river sediments by mudflows. In the western part of Profile 19, lacustrine-type deposits overlie deltaic-type deposits with a pronounced unconformity. Locally, no reflexions are visible in the deltaic deposits, suggesting that they were reworked by gravity sliding.

Profile H2 was acquired in 1990 by the Institute of Geology, Geophysics and Mineralogy SB RAS, and the Institute of the Earth's Crust SB RAS. It was shot transversally to the strike of the South Baikal basin (Fig. 1C). The younger depositional sequence progressively overlap older sediments, which outcrop at the bottom of the lake just in the northwestern part of the profile (Pl. 5). This indicates that the depositional area of the South Baikal basin was wider in an earlier stage of development. The present depocenter is restricted to the southeastern part of the basin, and is subsiding along a series of normal or oblique-slip faults. These faults are expressed in the lake floor by small scarps, located in the prolongation of the Posolsky bank.

Profile H3 was acquired in 1991 by the same institutions, along the axis of the South Baikal basin (Fig. 1C). The interpretation of seismic records of Profile H3, done by K.G. Levi and S.A. Kashik is presented in Plate 6. In the southwestern part of the profile, an intrabasinal graben is filled with sediments attributed to the Miocene-Early Pliocene Tankhoy series. The latter are overlain by a superficial lacustrine sequence of presumably Late Pliocene-Quaternary age, characterized by highly continuous subparallel reflexions. In the northeastern part of the profile, erosion surfaces can no longer be observed and the sediments are disturbed by normal faults, often of listric type. At the northeastern extremity of the profile, the lacustrine deposits abruptly terminate against the deltaic deposits of the Selenga River delta. In addition, two large lenticular bodies of deformed sediments attributed to the Pliocene-Quaternary sequence are found in the middle of the basin (Pl. 7-8). They most likely correspond to tectonic uplifts, situated along the supposed western prolongation of the Posolsky bank.

2.2. CENTRAL BAIKAL BASIN

The Central Baikal basin was not as intensively studied by single-channel profiling as the South Baikal basin. The sediments did not undergo prominent folding deformation. A good representation of the sedimentary section and basin structure can be obtained from single channel profile 25 and 28 of the 1989 Russian-German survey (Fig. 1B).

Profile 25 was acquired along the axis of the Central Baikal basin. It shows a horizontal sedimentary section deformed by numerous intrabasinal faults (Pl. 9). These faults seem of oblique-slip type, transverse to the axis of the basin. The presence of a strike-slip component is suggested by the bending of reflectors near the fault planes. Most faults do not pierce the surface sediments. In the northeast part of the profile, the base of the observable sedimentary section is strongly deformed and the continuity of the reflections is lost. The fault planes appear vertical in the profile, or tilted to the northeast. This profile also shows variation in sedimentary thickness along the strike of the basin. From SW to NE, at least three depressions separated by small uplifts can be distinguished. These structures are similar in both their dimensions and fault patterns.

Another typical feature of the Central Baikal basin is that it actually consists of two subparallel NNE-trending grabens: the Priolkhon graben on the northwestern side and the Selenga-Chivyrkui graben on the southeastern side. This is illustrated in Profile 28 (Pl. 10), which crosses the central basin at the latitude of the Olkhon Gate (Fig. 1B). The profile also shows a large listric fault, along which the Selenga-Chivyrkui graben is down thrown by more than 150 metres in relation to the Priolkhon graben. From acoustic character alone, the Selenga-Chivyrkui graben seems presently more active. The sedimentary complex is weakly disturbed by faults in the Priolkhon graben whereas tectonic deformations are clearly visible along the margins of the Selenga-Chivyrkui graben.

The southeastern border of the Central Baikal basin has subsided beneath the lake level in two successive steps. The steps composed of crystalline rocks are covered with a thin sedimentary layer. This is an indication for their recent subsidence beneath the lake level. The margin of the basin is dismembered by erosion grooves, some of them having a subaquatic character and some being related to active fault zones. Small landslide masses are sometimes observed at the foot of the scarps.

The structure of the southwestern termination of the Central Baikal basin is illustrated in profiles 92-7 and 92-12, acquired by the US Geological Survey in 1992 in preparation of the BDP-93 hole drilling (Fig. 1D). The seismic lines show the inner structure of the Buguldeika and Selenga deltas (Pl. 11A, B). Sediments of the Buguldeika delta lie almost horizontally on top of the Posolky Bank, with a small NW tilt towards the Primorsky border fault. In its frontal part, the Buguldeika delta is cut by a series of faults and downfaulted by 250 metres. The resulting scarp constitutes the limit between the Posolsky Bank and the Selenga-Chivyrkui graben. In the Selenga delta, the seismic reflexions are inclined towards the central part of the basin and minor normal faults also deform its frontal part. The two deltas are therefore separated by the Selenga-Chivyrkui graben. The upper depositional sequence of this graben is obviously younger than most of the deltaic sediments.

The northeastern termination of the Central Baikal basin is not covered by single-channel seismic profiling. The structure of this area has been interpreted by Hutchinson *et al.*, (1992) and discussed also by Logatchev (1993) on the basis of the 1989 multi-channel seismic line B8 acquired jointly by the Institutes of Oceanology RAS and Limnology SB RAS and Woods Hole.

The following discussion is based on profile B9 of the same 1989 multi-channel survey (Hutchinson *et al.*, 1993). This line was shot from the southwestern termination of the Northern Baikal basin to the northeastern termination of the Central Baikal basin, crossing the Academician ridge (Fig. 1B). In the northwestern part of the profile (Pl. 12), a depositional sequence, a few hundred metres thick with well-defined subparallel reflections, covers the northern basin and the crystalline rocks of the Academician ridge. The southeastern slope of the ridge is bounded by normal faults, along which crystalline rocks are in direct contact with the Cenozoic sediments of the Selenga-Chivyrkui graben. The southeastern margin of this graben is also controlled by normal faults. The Selenga-Chivyrkui graben is the most depressed part of the Central Baikal basin.

2.3. NORTH BAIKAL BASIN

Seismic profiles where acquired in the North Baikal basin during several surveys realised by different teams: in 1977-1982 (Fig. 1A), in 1990-1992 (Fig. 1C) and finally in 1989 and 1992 (Fig.D). As already mentioned, the seismic lines of the first investigations in 1977-1982 are of poor quality. The North Baikal profiles of the 1989 and 1992 survey shot for the Institute of Oceanology RAS, Limnological Institute SB RAS and the US Geological Survey were not available to us. Therefore the North Baikal basin is described according to the interpretation of the 1991 profiles acquired by the UIGGM and the Earth's Crust Institute.

In the North Baikal basin the lines were positioned across and along the strike of the basin. The profiles are all characterized by highly continuous subhorizontal seismic layers. Rare ruptures are observed in the middle part of the basin while the marginal parts are more deformed. The major active faults known onshore can be traced on the seismic profiles. They obliquely cross the basin from one side to the other. It is not possible to present all the seismic profiles acquired in the North Baikal Basin. Three profiles have been selected at the very north of the basin: **profiles H5, H6 and H7** (Fig. 1C). The results of their interpretation are given in Plate 13. Marked subhorizontal seismic horizons are cut by faults of variable inclination, some of them being of reverse type. Lines H5 and H7 are the most typical. The dislocations observed in the axial part of the basin can be associated to the major fault zones which cross the basin obliquely from one side to another. Listric faults are often associated to them. A series of planar faults also affects the upper depositional sequence, but they do not deeply penetrate into the sediments. In general, the tectonic style of the North Baikal basin, radically differs from that of the South and Central Baikal basins. This might reflect different histories of tectonic evolution.

3. — DETAILED STRUCTURAL MAPPING ALONG THE LAKE BAIKAL SHORES

In parallel with the seismic studies of Lake Baikal, the Institute of the Earth's Crust SB RAS performed investigations along its shores, to study active faults on land. Field tectonic investigations were done along the perimeter of the lake itself, and also in key areas like Priolkhonye, Olkhon Island and Svyatoi Nos Peninsula. A brief description of the results is given below.

3.1. PRIOLKHONYE AND OLKHON ISLAND

Priolkhonye and Olkhon Island are large elongated tectonic blocks forming the western shoulder of the Central Baikal basin. They are tilted to the northwest and are lowered with respect to the adjacent Primorsky rift shoulder by 500 to 700 metres. They appear as a large tectonic step between the Primorsky ridge and Lake Baikal, forming both the footwall of the Olkhon fault and the hangingwall of the Primorsky fault. The Primorsky fault is a leading Cenozoic structural element in Central Baikal. The width of the dislocation zone in the crystalline basement is about 4 km. The fault zone itself is expressed by a narrow valley-graben in the relief of Priolkhonye (Fig. 2). The Primorsky fault is dominantly a normal fault, with a minor strike-slip component, either dextral (SHERMAN, 1977) or sinistral (LEVI, 1980). New microstructural data and kinematic analysis along the Sarma valley, confirmed the presence of a limited sinistral component. The tilting of the Priolkhon and Olkhon blocks suggests that the Primorsky fault is a crustal-scale listric fault (PLESHANOV & ROMAZINA, 1981). It should be mentioned that listric faults are typical in the recent tectonic structure of Priolkhonye, Olkhon Island and Small Sea. They are arch-shaped in plan view, with a preponderant normal move-

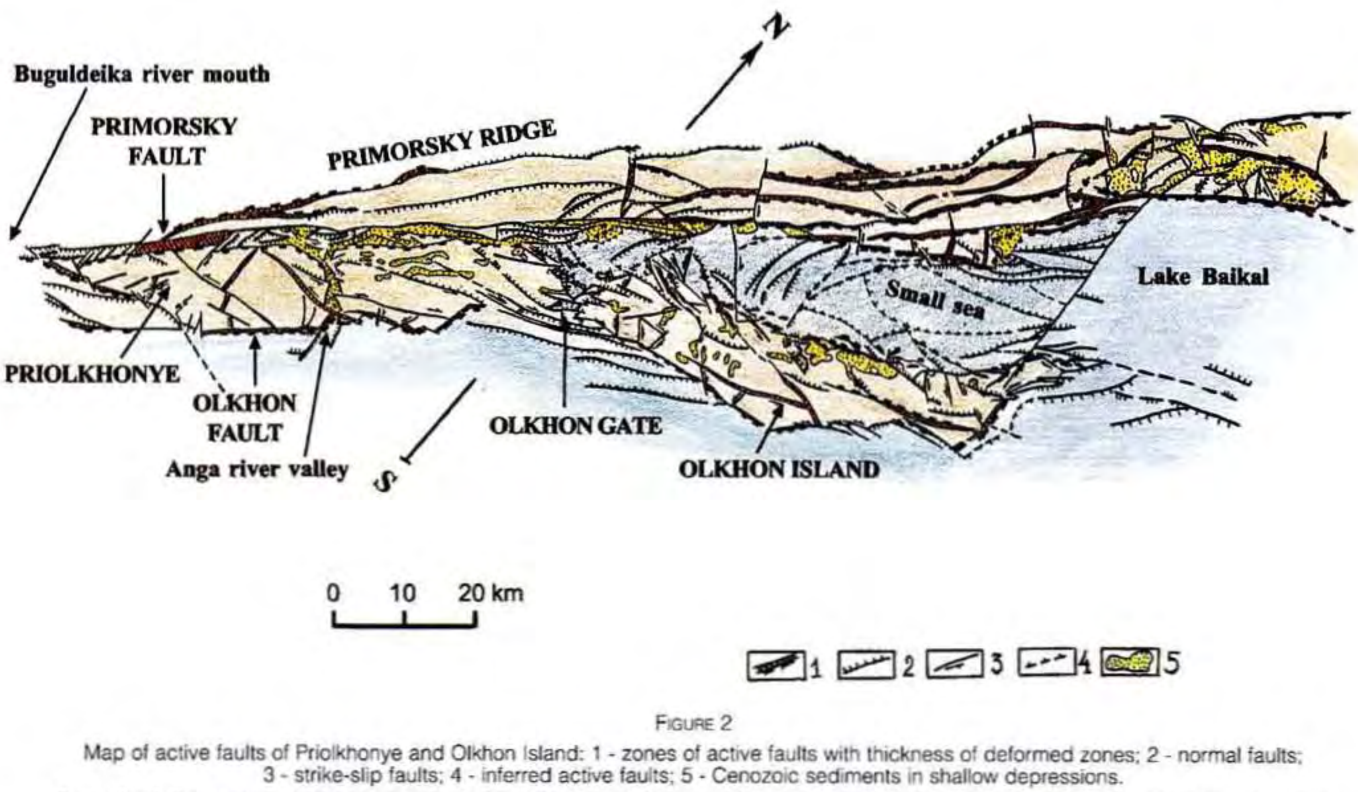


FIGURE 2

Map of active faults of Priolkhonye and Olkhon Island: 1 - zones of active faults with thickness of deformed zones; 2 - normal faults; 3 - strike-slip faults; 4 - inferred active faults; 5 - Cenozoic sediments in shallow depressions.

Carte des failles actives de Priolkhonye et de l'île d'Olkhon : 1 - failles actives avec épaisseur des terrains déformés ; 2 - failles normales ; 3 - décrochements ; 4 - failles actives supposées ; 5 - sédiments cénozoïques dans des dépressions peu profondes.

ment in the central part of the fault and a marked strike-slip component at the fault extremities (Fig. 2).

The Priolkhonye and Olkhon blocks are separated from the Central Baikal basin by the Olkhon fault. The latter branches from the Primorsky fault at the Buguldeika River mouth, southwest of Figure 2. The analysis of offshore seismic lines in combination with field structural data suggests that the underwater Academician ridge forms, together with the Priolkhonye and Olkhon blocks, a major diagonal interbasinal link, separating the Central and North Baikal basins (Olkhon-Academician Accommodation Zone). This interbasinal link is dissected by a series of transverse faults. Two of them are onshore and the others are observed on seismic profiles. Transverse faults are well expressed in the land morphology by the valley of the Anga River and Olkhon Gate (Fig. 2).

The complex pattern of active faults in Priolkhonye, Olkhon Island and Primorsky ridge caused the dislocation of the basement in lenticular blocks of different size and has a pronounced effect on the seismic activity of this region.

3.2. SVYATOI NOS PENINSULA AND CHIVYRKUI BAY

The Svyatoi Nos (Holy Nose) peninsula is connected to the land by an isthmus composed of Quaternary sands (Fig. 3). It is a large basement horst, situated near the northeastern termination of the Central Baikal basin and is part of the Olkhon-Academician Accommodation Zone. It is framed to the northwest by the termination of the Central Baikal basin, and to the southeast, by the graben lying under the Barguzin and Chivyrkui bays. The peninsula is tectonically limited from all sides, mostly by normal or strike-slip faults. The internal structure of the Chivyrkui graben is similar to that of the Small Sea. Listric faults are widespread in both sides of the Chivyrkui bay. The small islands of the Chivyrkui bay are of tectonic origin. The Svyatoi Nos peninsula itself is divided by faults into four segments, the eastern one being down faulted along a system of orthogonal faults. Several hydrothermal springs are located along the major active faults.

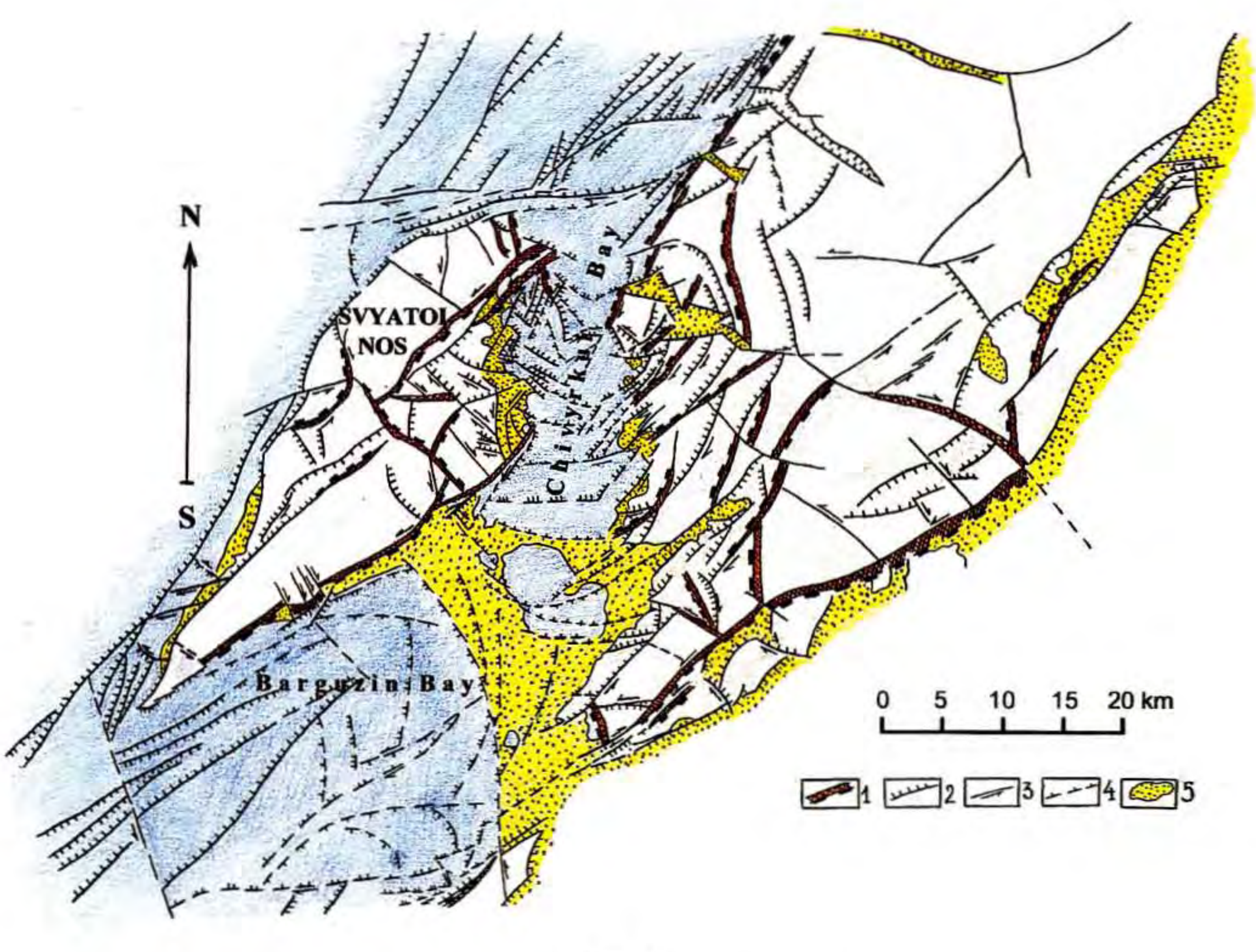


FIGURE 3

Map of active faults of Svyatoi Nos peninsula (see notations in Figure 2).

Carte des failles actives de la péninsule de Svyatoi Nos (voir légende de la Figure 2).

4. — MAP OF ACTIVE FAULTS OF THE BAIKAL DEPRESSION AND ADJACENT TERRITORIES

In the Baikal depression and adjacent territories (Pribaikalye) , active faults refer to those faults with evidence of Pliocene-Pleistocene activity. The active faults were mapped along the lake shores by structural field investigations with the help of 1:1 000 000 Russian satellite images. In the lake, they were interpreted from offshore seismic investigations. The complete structural interpretation of Pribaikalye area is shown in Figure 4 and a synthesis is presented in Figure 5. The density of active faults per unit area is maximum in the Baikal basin itself. However, it should be remembered that within the Baikal basin, the faults are observed in the sedimentary section, and not all of them originate from tectonic deformations. Some of them might be synsedimentary, thus not related to active tectonics.

The synthetic map (Fig. 5) allows to define the main structural elements of the Baikal rift basin and adjacent territories. The major fault zones active during the Pliocene-Pleistocene, like the Main Sayan, Tunka, Obrutchev, Primorsky, Barguzin... fault zones, control the structural development of the Baikal rift zone during the Late Cenozoic. At first sight, the Baikal basin is divided into two large basins: the North Baikal basin and a complex southern depression (A & B in Figure 6), separated by the interbasinal link formed by the Olkhon Island, underwater Academician ridge and Sviatoy Nos peninsula. After a more detailed examination of the tectonic structure in the seismic profiles, the southern part of the Baikal depression is more accurately subdivided into two basins of smaller size: the Central - and South Baikal basins, separated by the Posolsky Bank (Fig. 6). They are internally inhomogeneous and consist of more smaller depressions, with different styles of tectonic development and sedimentation.

4.1. SOUTH BAIKAL BASIN

The South Baikal basin is subdivided into two depressions: the Kultuk and Mishikhin grabens (Fig. 6).

The Kultuk depression is limited by the Obrutchev fault on the north, by the Main Sayan fault on the west, by the Angara fault on the east, and on the south by the system of active faults known as Chersky fault. This tectonic block, diamond-shaped in plan, is remarkable for the intensive development of folded deformations in the Cenozoic sediments, as it is shown in Plate 1, and for the great number of tectonic dislocations (Fig. 5). The latter was studied within the Obrutchev oblique-slip fault zone, and in the Miocene and Pliocene-Quaternary deposits along the Chersky fault zone. The main interest is that the sedimentary section in the inner part of the depression is generally not faulted, and the folds in the sediments probably originated from sinistral strike-slip movements in the basement.

The Mishikhin depression is limited by the Angara fault on the western side, by the underwater prolongation of the Obrutchev oblique-slip fault on the northern side, and by the Chersky fault on the south. This depression is characterized by a small-block structure, already described in profile 17 (Pl. 2). Here, folds are almost absent and the sediments lie subhorizontally. It is difficult to determine the age of the ruptures, because the deep geometry of the basin is poorly known. It is only known that the crystalline basement lies at a depth of more than 8 km beneath the lake (SELEZNYEV, 1994). The faults in the Mishikhin depression are subparallel to its sides, but they converge eastwards in a narrow tectonic zone. The latter turns in a northeastern direction at the transition to the Central Baikal basin.

The Angara fault had an important role in the structural development of this depression. The latter is supposed to be an ancient PreCenozoic dislocation, activated during rifting. During the Cenozoic, it was reactivated by oblique reverse-dextral movements. There were no considerable tectonic movements along the fault, despite its great length. It can be traced along the Angara River valley from a Irkutsk area to the opposite side of the lake (Trans-Baikal area), as far as the Gusinoiozosk depression (see Fig. 5). In Lake Baikal, it probably acted as a tectonic boundary between the Kultuk and Mishikhin depressions, and is responsible for their difference in tectonic style. Its importance in the kinematics of the Baikal basin opening has already been shown by BALLA *et al.* (1991).

4.2. CENTRAL BAIKAL BASIN

At least five structural elements are clearly distinguished in the Central Baikal basin (Fig. 6): the Selenga-Chivyrkui graben, the horst of Posolskaya bank, the Priolkhon graben with the Buguldeika Corridor, and the Svyatoi Nos uplift (the southwestern part of the Priolkhon graben is generally known as the Buguldeika Corridor). The Priolkhon and Selenga-Chivyrkui grabens form the major structure of the Central Baikal basin (Fig. 5-6). They are parallel to each other, and already described in detail along Profiles 28 (Pl. 10) and B9 (Pl. 12). They differ in the extent of activity at the present stage of their evolution.

The Priolkhon graben is a narrow elongated structural element situated along the NW side of the Central Baikal basin. The morphological expression of this graben in the lake floor varies along strike. In Profiles H4 and 28 (Pl. 10), it is a full graben, while in Profiles 18 and 19 (Pl. 3-4), it is a simple tectonic step. In many parts, the graben is crossed by transverse fault zones trending NW and E-W. These faults are mostly

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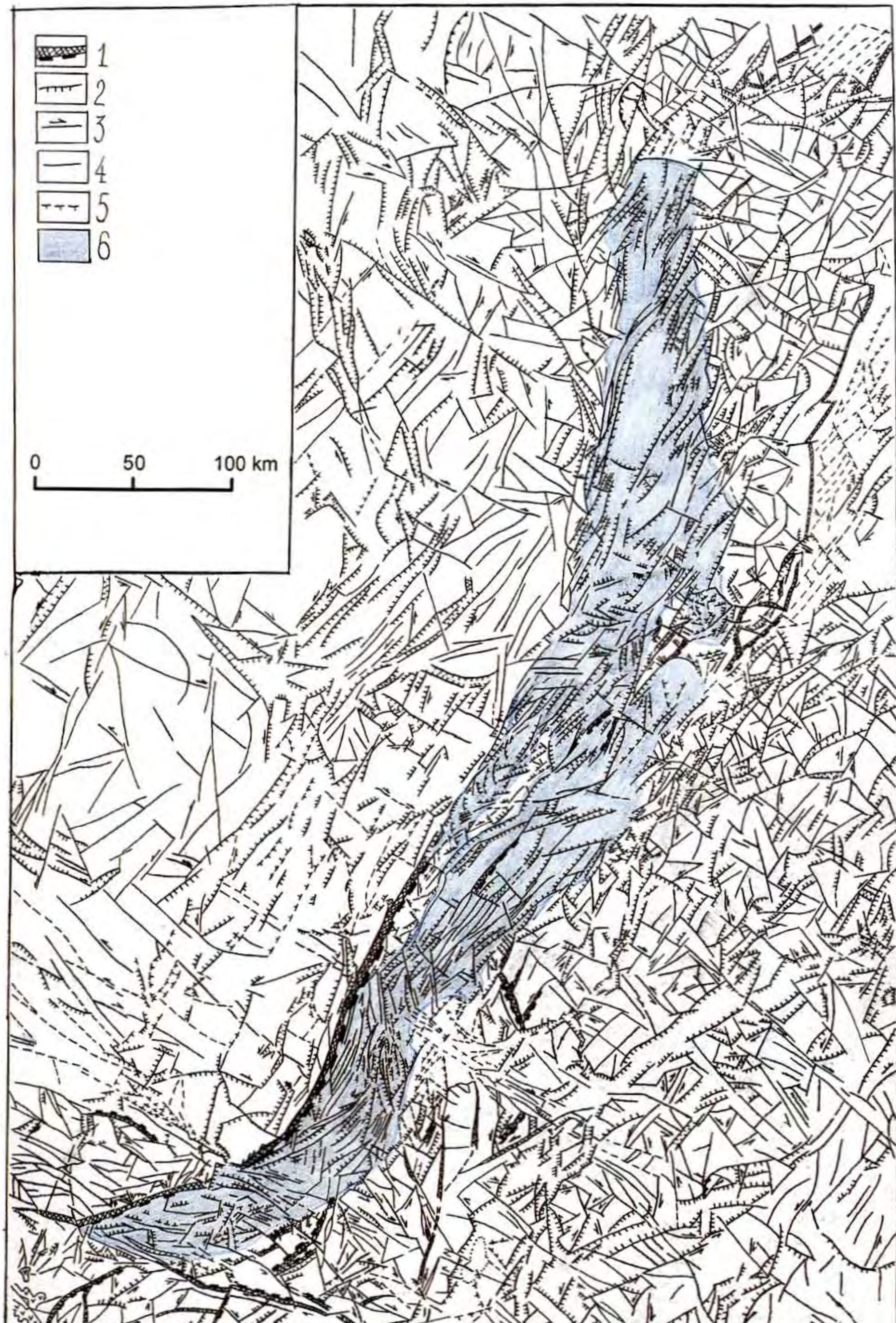
FIGURE 4

Map of active faults of the Baikal basin and adjacent territories, prepared using seismic profiles, field structural observations, airphotos and satellite images: 1 - active faults with the assessed thicknesses of zones of tectonic dislocation; 2 - normal faults; 3 - strike-slip faults; 4 - faults with an unknown type of movements; 5 - inferred active faults; 6 - Lake Baikal.

Carte des failles actives du bassin du Baïkal et des environs établie à partir de profils sismiques, d'observations de terrain, de photos aériennes et d'images satellites : 1 - failles actives avec l'épaisseur estimée des terrains disloqués ; 2 - failles normales ; 3 - décrochements ; 4 - failles à déplacement indéterminé ; 5 - failles actives supposées ; 6 - Lac Baïkal.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6
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50
100 km

strike-slip or oblique-slip faults. Northwards, the Priolkhon graben is separated from the Selenga-Chivyrkui graben by a system of longitudinal horsts which join each other in tectonic steps. This is well expressed offshore in the seismic profiles H2, H3, and 28, in lake bottom morphology by the Posolsky Bank and on-land by the Svyatoi Nos peninsula.

The Posolsky bank horst plays an important role in the evolution of the junction between the South- and Central-Baikal basins, adjacent to the Selenga River delta. It was directly studied with the help of the Pisces inhabited submarine (ZONENSHAIN *et al.,* 1995). Diving operations, supplemented by palynological analysis, showed the presence of Miocene sediments at 800 metres depth, in the lower part of the underwater scarp. These sediments appear in a fault zone, that can be traced to the top of the bank. This indicates that the horst's uplift probably started during the Pliocene. The horst of the Posolsky Bank is substantially younger than the formations of the Selenga River delta (LOGATCHEV, 1993). Since there is a limited penetration of subaerial delta deposits from the Selenga River into the Buguldeika Corridor, it is inferred that the Posolsky Bank had a pronounced effect on the development of the Buguldeika Corridor during the Pliocene-Quaternary. Morphologically, the uplift related to the Posolsky Bank is expressed towards the northeast up to the latitude of the Anga River mouth. Further in the same direction, it corresponds to the tectonic step which forms the boundary between the Priolkhon and Selenga-Chivyrkui grabens.

The Selenga-Chivyrkui graben is the main structural element of the Baikal basin at its present stage of evolution. It originates from the Selenga River delta to the southwest and terminates to the northeast in the Chivyrkui bay. As for the Priolkhon graben, it is affected by a series of transverse faults, often oblique-slip (e.g. profile 25, Pl. 9). The Selenga-Chivyrkui graben is characterized by a high seismic activity. During the last century, at least 5-6 strong shocks occurred in this area. In winter 1892, a strong earthquake caused a part of the Selenga delta along with several villages to subside under the water, forming the Proval trough.

In 1992-1993 the trace of the boundary fault of this structure was examined. Minor joint systems were measured in loose sand and clays, for the reconstruction of the tectonic stress associated to that earthquake. The earthquakes of the Selenga-Chivyrkui graben are often characterized by surperficial seismotectonic manifestations, like mud volcanoes (1959 Central Baikal earthquake: RUBTSOV *et al.,* 1960) and others. In addition, oil spills can be observed on the lake surface in the Selenga River delta (LAMAKIN, 1968). The Selenga-Chivyrkui graben seems therefore to be the most interesting object for the study of active tectonics in Central Baikal.

The Olkhon-Academician interbasinal high, formed by the Olkhon Island and underwater Academician ridge, is the largest structural element of the entire Baikal basin. Together with the Sviatoy Nos peninsula, it forms a natural barrier between the Central - and North Baikal basins (Fig. 5). The Olkhon-Academician interbasinal high is covered by a thin layer of Cenozoic sediments both in its onshore and underwater parts (Profile B9, Pl. 12). In the Olkhon Island, Cenozoic sediments fill small depressions on the northwestern slope. But the outcropping sections are discontinuous and it is not clear whether all the stratigraphic units which characterize the Baikal rift basin are present. Judging from the results of seismostratigraphic investigations of the underwater Academician ridge, the thickness of the Cenozoic does not exceed 300 metres. Miocene, Pliocene and Pleistocene sediments are expected to be the main constituents. This indicates that the ridge has recently subsided beneath the level of the lake. The small sedimentary thickness may also testify to its repeated subsidence and uplift in the Miocene-Pleistocene.

From the NW and SE, all this intrabasinal high is limited by active fault systems. The total amplitude of movement along the Academichesky and Olkhon faults, along the SE side of the underwater Academician ridge and Olkhon Island is of several kilometres. On the NW side of the ridge, the amplitude of tectonic movements are much less and distributed on a series of small ruptures. In addition, the faults which delimit the intrabasinal high are branching to the Primorsky fault in the Buguldeika River mouth. The intrabasinal high is itself dissected by transverse faults of sublatitudinal and northwestern strike, most of them being oblique-slip. The Barguzin ridge is an onshore extension of the intrabasinal high of the Olkhon Island and of the Academician ridge on the eastern side of the North Baikal basin.

4.3. NORTH BAIKAL BASIN

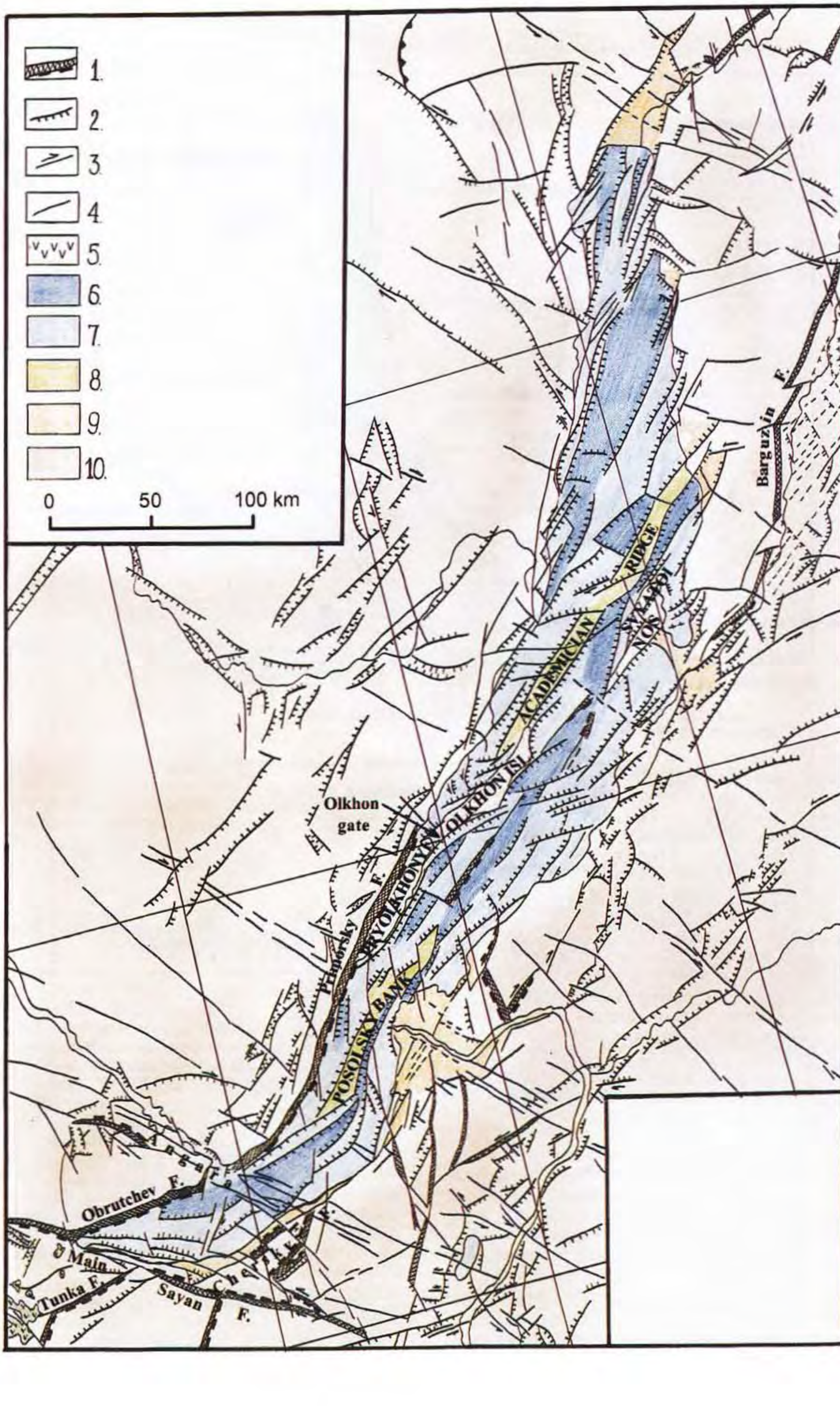
The North Baikal basin consists actually of at least three separate depressions: Maloe More-Ezovsky, Kedrovoi-Tompudinsk and Rel-Kitchera (Fig. 6). As it has already been mentioned, the internal part of the depressions is structurally quiet, and intense deformations occur only in the marginal parts of the basins.

The Maloe More-Ezovsky depression extends obliquely from the Small sea (Maloe More in Russian), to the eastern shore of Lake Baikal, and is flanking the Olkhon-Academician intrabasinal to the west (Fig. 6). It is bordered on both northwest and southeast sides by major faults which branch to the Primorsky fault zone in the western extremity of the Small Sea (Mukhor bay). The southwestern side of this depression is better known in the Small sea, where it appears intensely dissected by faults (Fig. 2). Listric faults are frequent in the

FIGURE 5

Map of main active tectonic elements of the Baikal basin and adjacent territories: 1 - active faults with the assessed thickness of zones of tectonic dislocation; 2 - normal faults; 3 - strike-slip faults; 4 - faults with an unstated type of movements; 5 - Cenozoic volcanics; 6 - blocks, subsided at their maximum beneath the lake level; 7 - blocks of an intermediate step; 8 - underwater uplifts of interbasinal high; 9 - accumulative fields of dry-valley rift basins; 10 - Pre-Cenozoic basement.

Carte des principaux éléments tectoniques actifs du bassin du Baïkal et des terrains environnants : 1 - failles actives avec l'épaisseur estimée des terrains disloqués ; 2 - failles normales ; 3 - décrochements ; 4 - failles à type de déplacement indéterminé ; 5 - volcanites cénozoïques ; 6 - blocs effondrés au maximum sous le niveau du lac ; 7 - blocs à un niveau intermédiaire ; 8 - soulèvements subaquatiques de haut-fond interbasinal ; 9 - aires d'accumulation des fossés de vallée sèche ; 10 - socle ante-cénozoïque.



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50
100 km
Barguzin F.
RIDGE
ACADEMICIAN
OLKHON ISL.
Olkhon gate
Primorsky F.
POSOLSKY BANK
Angara
Obrutchev F.
Main
Tunka F.
Sayan F.

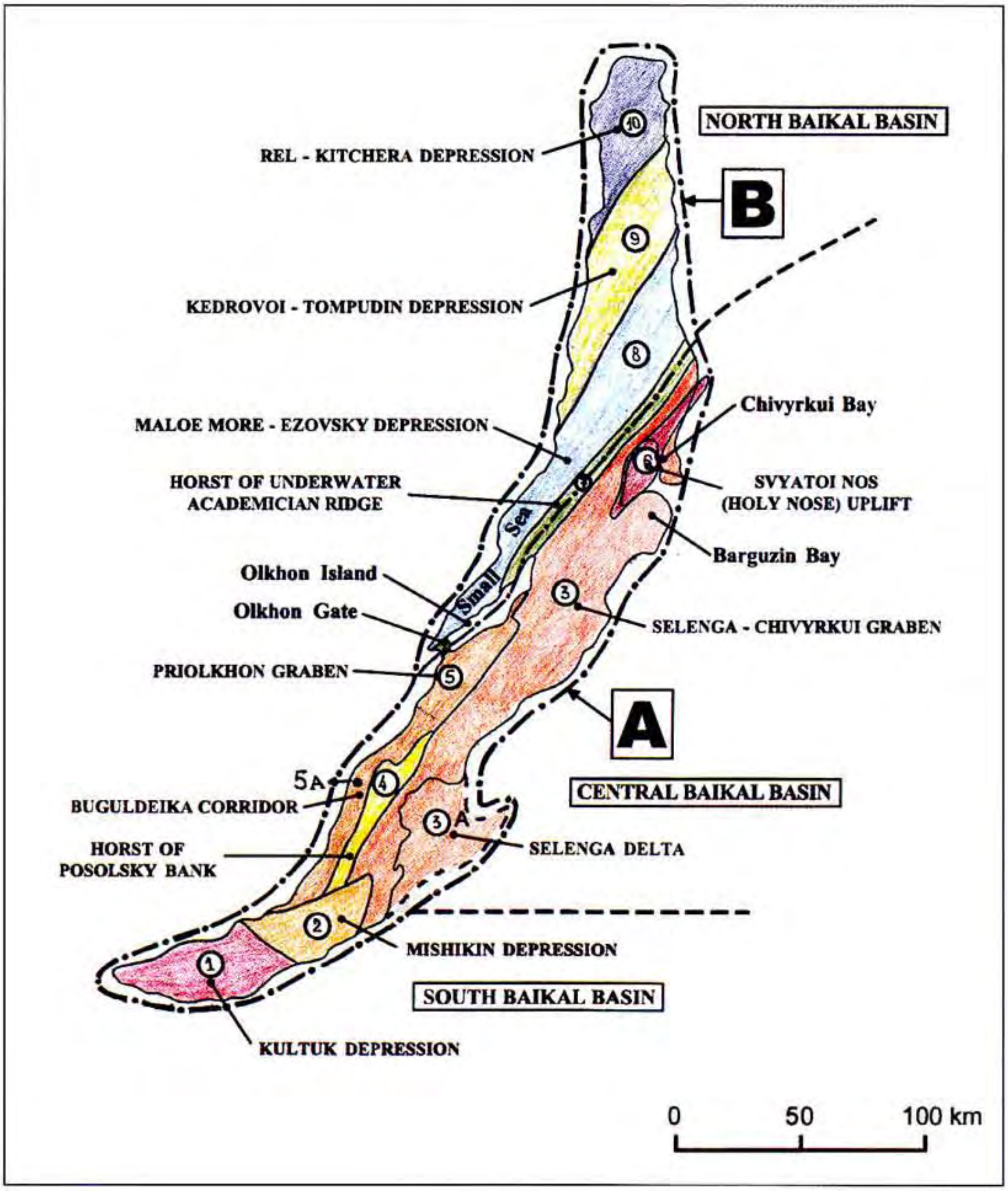

FIGURE 6

General structure of the Baikal basin : A - South Baikal basin; B - North Baikal basin; 1 - Kultuk depression; 2 - Mishikhin depression; 3 - Selenga-Chivyrkui graben; 3A - Selenga River delta ; 4 - Horst of Posolsky bank; 5 - Priolkhon graben; 5A - Buguldeika Corridor graben; 6 - Svyatoi Nos (Holy Nose) uplift; 7 - Horst of underwater Academician ridge; 8 - Maloe More-Ezovsky depression; 9 - Kedrovoi-Tompudin depression; 10 - Rel-Kitchera depression.

margins of the Small Sea. The most depressed part of the Maloe More-Ezovsky depression is adjacent to the NW slope of the underwater Academician ridge. The Maloe More-Ezovsky depression is seismically inactive, as is the whole North Baikal basin, except along the northwestern slope of the Academician ridge and along the eastern margin of lake Baikal, where weak earthquakes have occurred.

The Kedrovoi-Tompudinsk depression is situated northward of that of the Maloe More-Ezovsky (Fig. 6), and is separated from it by another major fault zone. The sedimentary section is only faulted at the margins of the depression and on its southwestern and northeastern terminations (Fig. 5). The top of the basement under the Kedrovoi-Tompudinsk depression is in a lower position than the adjacent blocks. The whole sedimentary section is deformed above the tectonic boundaries of this block. The depression itself is not seismically active, except along the eastern margin of Lake Baikal.

The Rel-Kitchera depression is the northernmost sub-basin of the Baikal depression (Fig. 6). It is fault bounded along practically all its sides (Fig. 5). Its central part is even dissected into

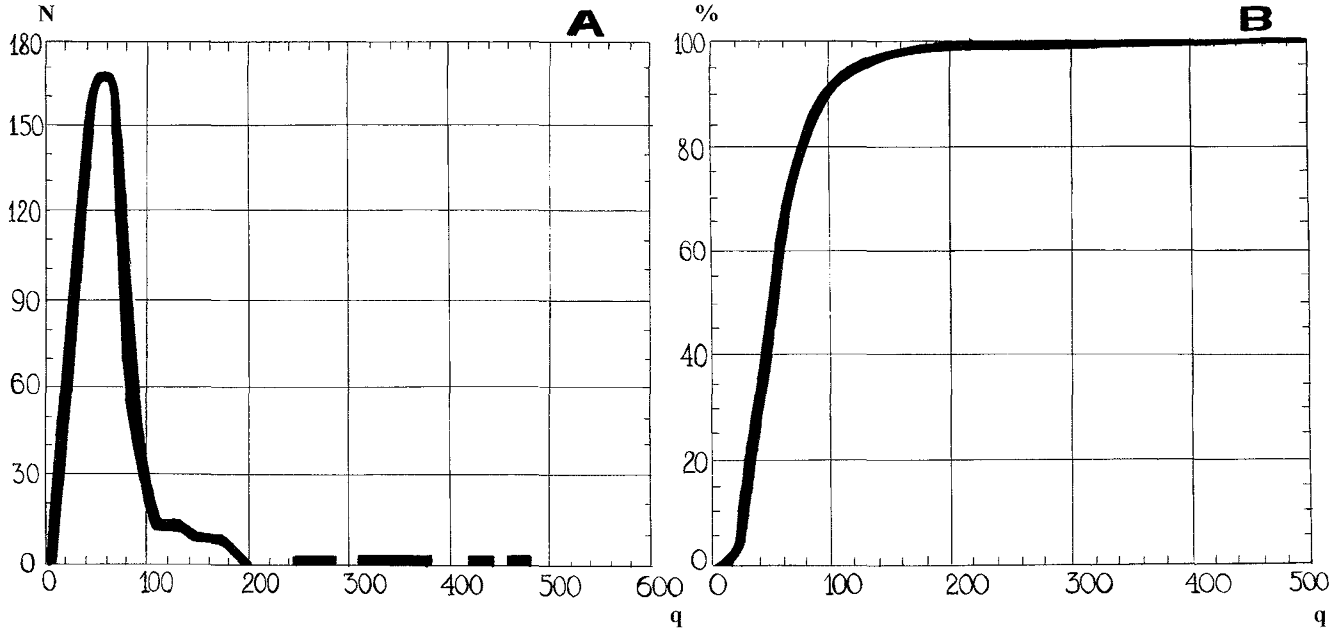

FIGURE 7
Statistical distribution of heat flow measurements (A) and cumulative-frequency curve of heat flow measurements (B) within the Baikal region, using the complete data set.
Distribution (A) et courbe de fréquence cumulée (B) des mesures de flux de chaleur dans la région du Baïkal, à partir de l'ensemble des mesures.
q = Heat flow (mW/m^2), N = Number of measurements, % = Cumulative percentage of measurements.

two small subparallel grabens (Profiles H5, H6, H7; Pl. 13). Oblique-slip faults trending NW and NE have a dominant role in the structure of the depression. From all the three depressions of the North Baikal basin, the Rel-Kitchera is the only one which is seismically active.

5. — ACTIVE FAULTS AND HEAT FLOW ANOMALIES IN THE BAIKAL BASIN

The role of deep mantle heat flow is of great importance in the initiation and evolution of rift zones. Therefore, geothermal fields are of major interest. This is also the case for the Baikal rift (GOLUBEV, 1982; LYSAK, 1988, 1995). Deep heat flow may reach the surface through the lithosphere by both conductive and convective processes. Conduction is not affected by lithospheric discontinuities, whereas convection is strongly influenced by the presence of active faults. In consequence, the role of the active faults in the Baikal depression are examined here in spatial relation to the geothermal anomalies.

The total of geothermal measurements in Lake Baikal largely exceeds 400. They were made according to a more or less regular network. Heat flow values (q) in the Baikal basin vary from 20 to 480 mW/m^2 with an average of 76±52 mW/m^2 and a non-normal distribution (Fig. 7A). By comparison, the average density of heat flow (q) in the adjacent territories is 66.7±45.4 mW/m^2, with a mean value (qm) of 57 mW/m^2. Such statistical distribution and the large mean square deviations do not allow the use of the average values (q) for the cartography of the spatial distribution of geothermal anomalies. We cannot exclude that the available data set combines the measurements related to two or more populations. If we assume that part of the q values is related only to conductive heat flow, and the rest, to both conductive and convective heat flow, then the q values can logically be divided into its components.

For the statistical division we plotted a cumulative-frequency curve (Fig. 7B), which shows that q belongs to two general sets, evidenced by a sharp bend of the curve within q = 100-150 mW/m^2. On this basis, all the data set was divided into two sets: one with q values less than 100 mW/m^2 and the other, with q values exceeding 100 mW/m^2. After separation into two sets, a curve of the distribution of heat flow values ≤ 100mW/m^2 (Fig. 8A) and a cumulative-frequency curve (Fig. 8B) were again plotted. It appears that the majority of q values display a normal distribution, with insignificant difference between the averages q (56±18 mW/m$^{2)}$ and qm (which is 55 mW/m$^{2)}$, and a cumulative-frequency curve without any sharp bendings. This testifies an internal homogeneity of the two populations.

Two maps were prepared for the structural analysis of the geothermal field in relation to the active tectonics (Fig. 9, 10). As the observation network is highly heterogeneous, the data are homogenized by Kriging. Isolines of heat flow values are computed by matrix averaging. The first map (Fig. 9) is obtained using a neighbourhood of 75 km radius and includes heat flow measurements of both the Baikal basin and the adjacent territories, in which q do not exceed 100 mW/m^2. This map slightly differs from the one published by LYSAK (1995), mainly

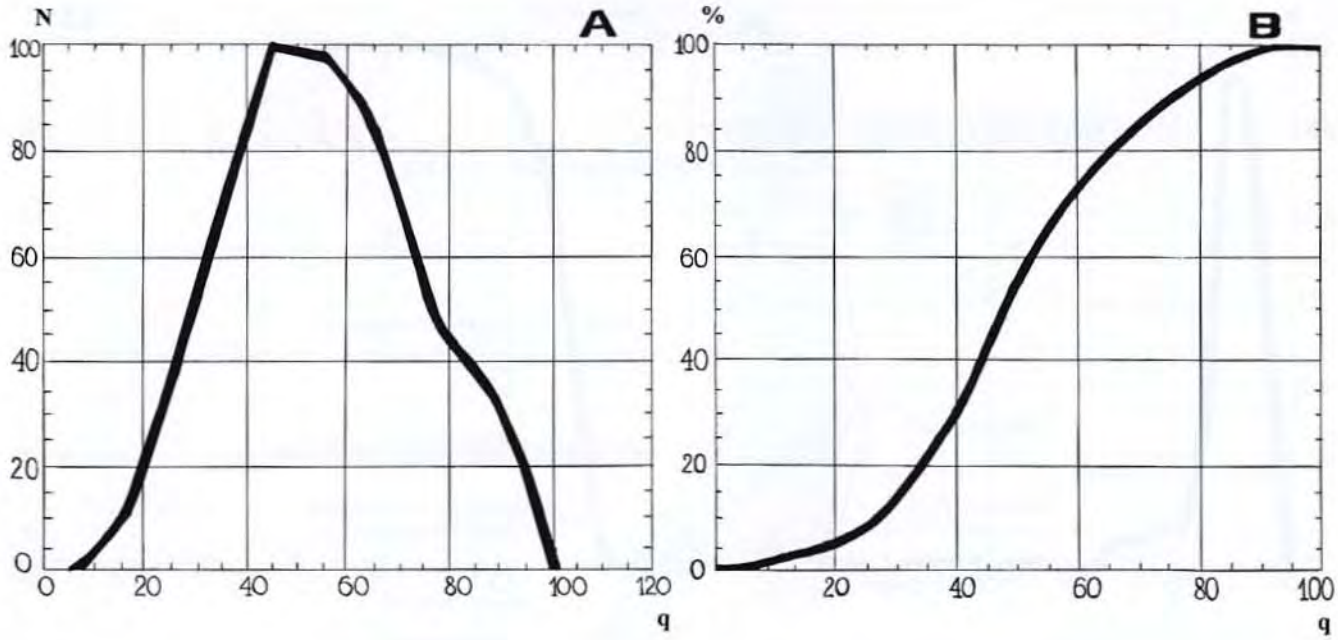

FIGURE 8

Statistical distribution of heat flow measurements (A) and cumulative-frequency curve of heat flow measurements (B) within the Baikal region. Heat flow values exceeding 100 mW/m^2 are excluded.

Distribution (A) et courbe de fréquence cumulée (B) des mesures du flux de chaleur, excluant les valeurs supérieures à 100mW/m^2.

q = Heat flow (mW/m^2), N = Number of measurements, % = Cumulative percentage of measurements.

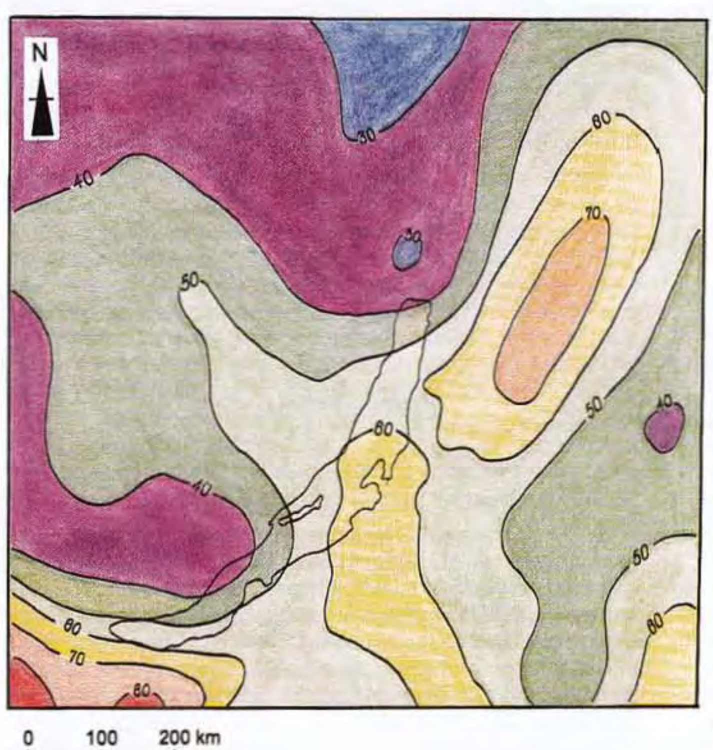

FIGURE 9

Sketch map reflecting the structure of the Baikal region geothermal field, based on data from the Baikal basin and the adjacent territories averaged using a neighbourhood of 75 km radius (excluding values of q>100mW/m^2). The range of q values is similar to that of Figure 10.

Carte du champ géothermique de la région du Baïkal, fondée sur des données du bassin du Baïkal et des terrains environnants lissées en utilisant un voisinage de 75 km de rayon. Les valeurs de q >100mW/m^2 sont exclues. L'échelle des valeurs de q est identique à celle de la Figure 10.

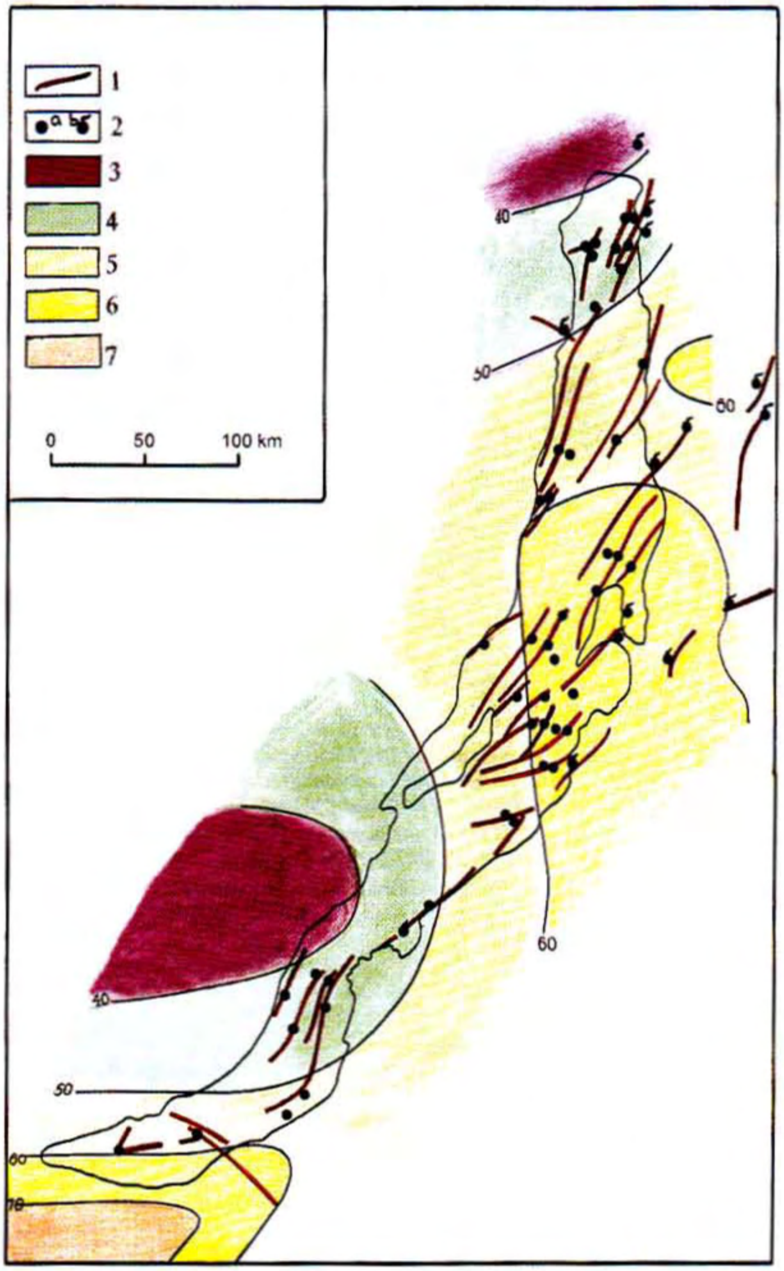

FIGURE 10

Map of thermoactive faults in the Baikal region: 1 - thermoactive faults; 2 - a - points with rather high values of heat flow (q > 100 mW/m²), b - hydrothermal springs ; 3-7- heat flow values in mW/m², averaged using a neighbourhood of 75 km radius: 3 - < 40 mW/m², 4 - 40-50 mW/m², 5 - 50-60 mW/m², 6 - 60-70 mW/m², 7 - more than 70 mW/m².

Carte des failles thermoactives de la région du Baïkal : 1 - failles thermoactives ; 2 - a - points présentant une intensité de flux de chaleur plutôt élevée (q > 100 mW/m²), b - sources hydrothermales ; 3 -7 intensités de flux de chaleur en mW/m² lissées en utilisant un voisinage de 75 km de rayon.

as a consequence of the poor data coverage in the Siberian Platform, west of the North Baikal basin. The second map (Fig. 10) shows the relation between abnormally high heat flow values (exceeding 100 mW/m²), active faults and hydrothermal springs.

The map of background heat flow (Fig. 9) does not show any prominent relationship between heat flow anomalies and active tectonic structures. Only a general relationship between heat flow highs and the regions of high topographic relief can be evidenced in East Sayan and Northeast Baikal. This suggests that the structure of the geothermal field, as evidenced by the averaged "normal" heat flow values (less than 100-150 mW/m²), results from conductive heat flow in the lithosphere beneath the Baikal Rift Zone.

The heat flow anomalies are calculated by subtraction of "normal" heat flow values (obtained by the averaging of q<100 mW/m² according to the neighbourhood of 75 km radius) from the complete data set of geothermal measurements. When analyzing the abnormally high and low values, it appears that all of them are somehow related to active fault zones mapped in Figure 4. These anomalies have a typically local character and probably result from heat convectivity. It is significant that most fault zones, characterized by the presence of the heat flow anomalies are also controlling the location of hydrothermal springs (Fig. 10). Examples are found in such hydrothermal springs as Frolikha bay, Kotelnikovsky cape, Khakusi cape and others, situated at the lake bottom or in the immediate vicinity of its coast.

If the nature of hot fault zones can be explained by deep heat flow directed towards the surface, then what is the explanation for the few anomalies along the active faults but with low heat flow values? The analysis of the structural situation in the vicinity of these anomalies shows that they are most generally conditioned by external factors, such as present-day high rates of sedimentation (EDGINGTON *et al*, 1991), underwater landslides etc. Such anomalies occur both in the South and North Baikal basins (Fig. 10).

In summary, active faults not only control the structural mosaic of individual basins of the Baikal depression, but also they contribute to the heat flow distribution. This, in turn, is an important indicator of high asthenospheric and lithospheric activities beneath the rift zone as a whole.

6. — CONCLUSION

Complex off-shore seismic profiling and field structural investigations enabled us to detail the sedimentary structure of the Baikal basin, to trace the main rift faults from one coast to another, to specify the nature of their movement, to determine the block structure of the depression and to identify a number of secondary depressions and uplifts. In parallel, the vast amount of morphostructural and microstructural data collected along rift-related faults allow SAN'KOV *et al.* (1997) to reconstruct the tectonic stress field related to the development of the Baikal depression. The data collected for the compilation of the map of active faults will also allow us refine the kinematics of the opening of this large intracontinental basin, an earlier model of which was proposed by BALLA *et al.* (1991) on the basis of coastal data only.

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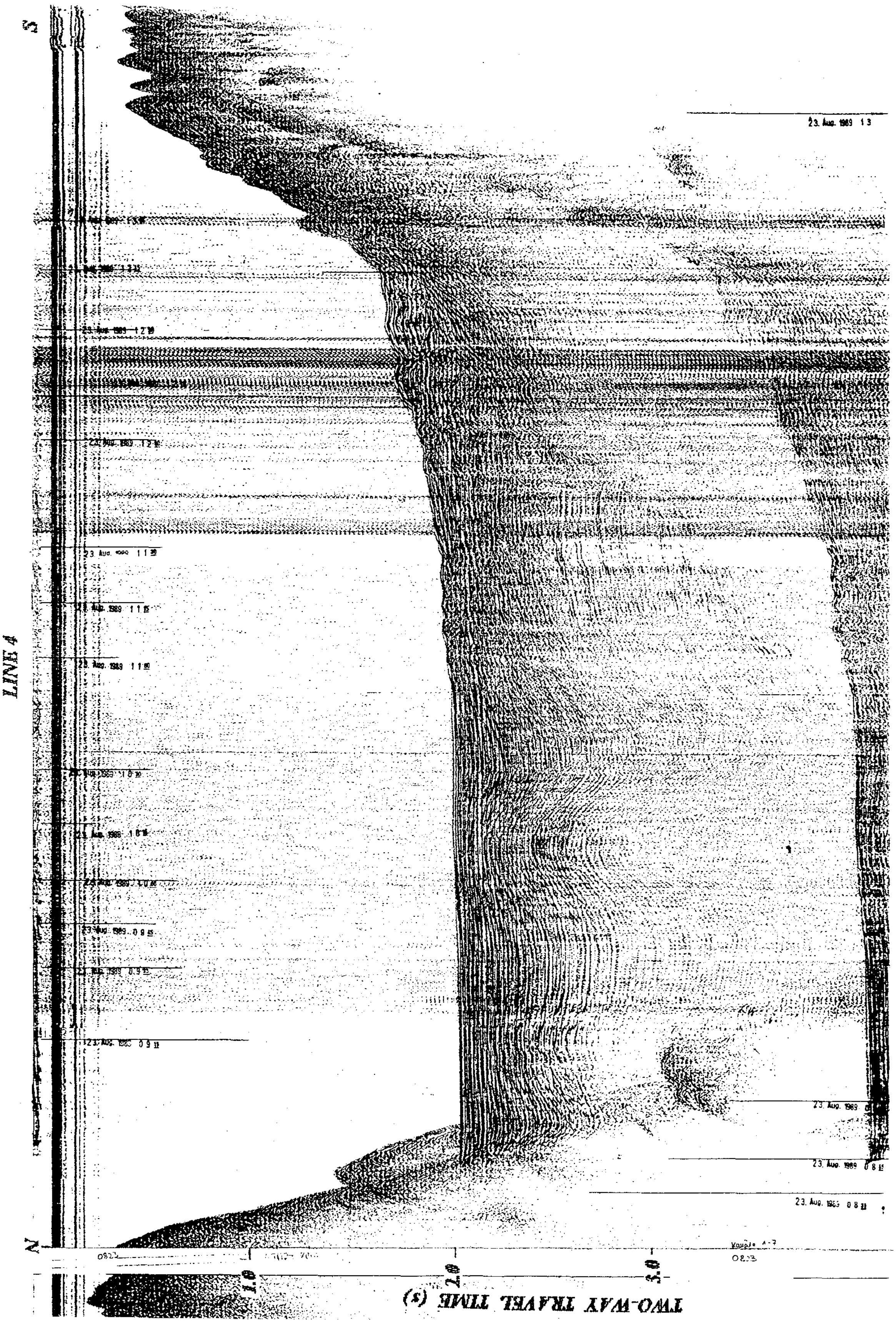


PLATE 1

Seismic Profile 4 in the western part of the South Baikal basin (see Fig. 1B).

Profil sismique 4 dans la partie occidentale du Bassin Sud du Baikal.

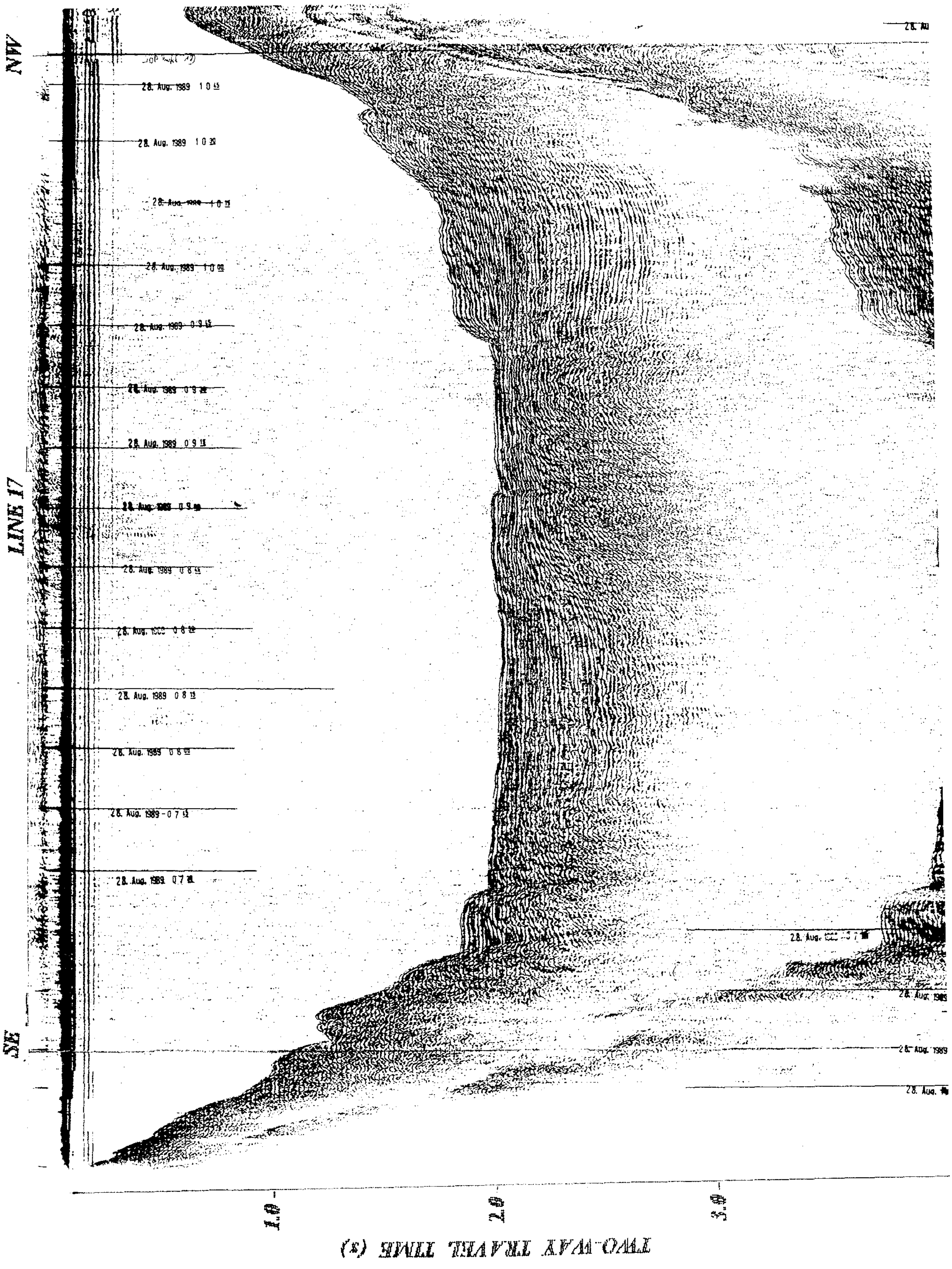


PLATE 2

Seismic Profile 17 in the eastern part of the South Baikal basin (see Fig. 1B).

Profil sismique 17 dans la partie orientale du Bassin Sud du Baïkal.

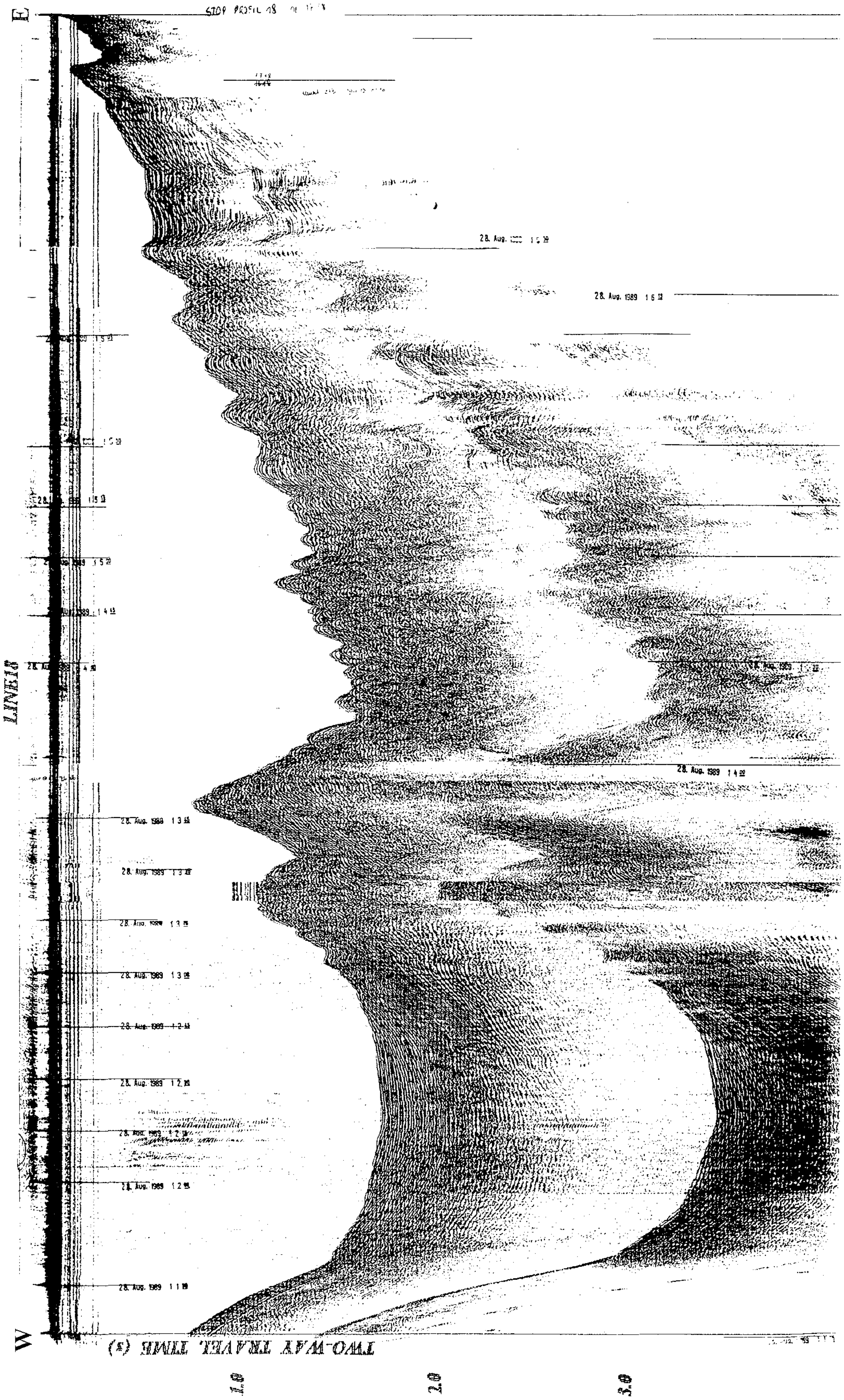


PLATE 3

Seismic Profile 18 in the southwestern slope of the Selenga River delta (see Fig. 1B).

Profil sismique 18 dans le versant sud-ouest du delta de la Selenga.

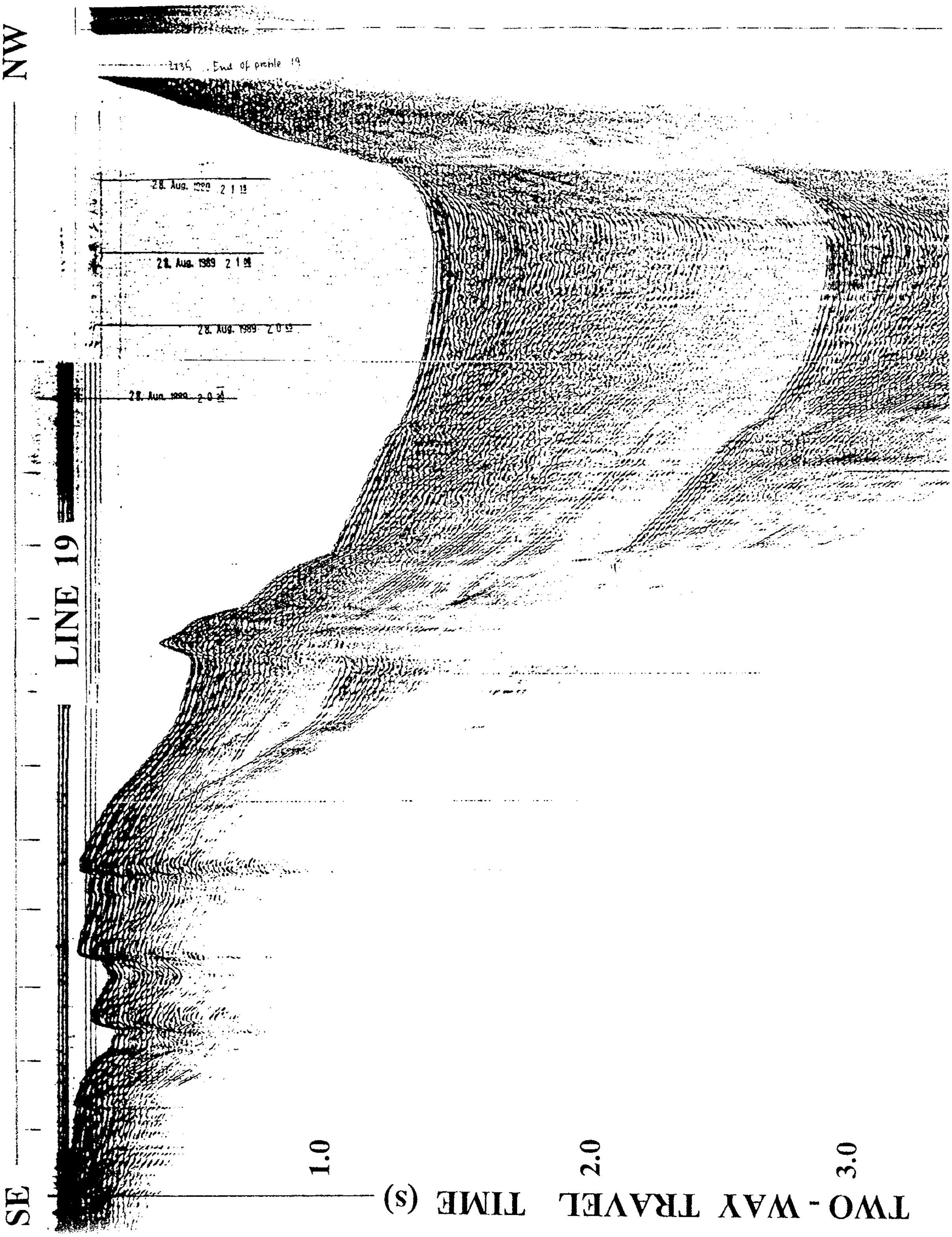


PLATE 4
Seismic Profile 19 in the southwestern slope of the Selenga River delta (see Fig. 1B).
Profil sismique 19 dans le versant sud-ouest du delta de la Selenga.

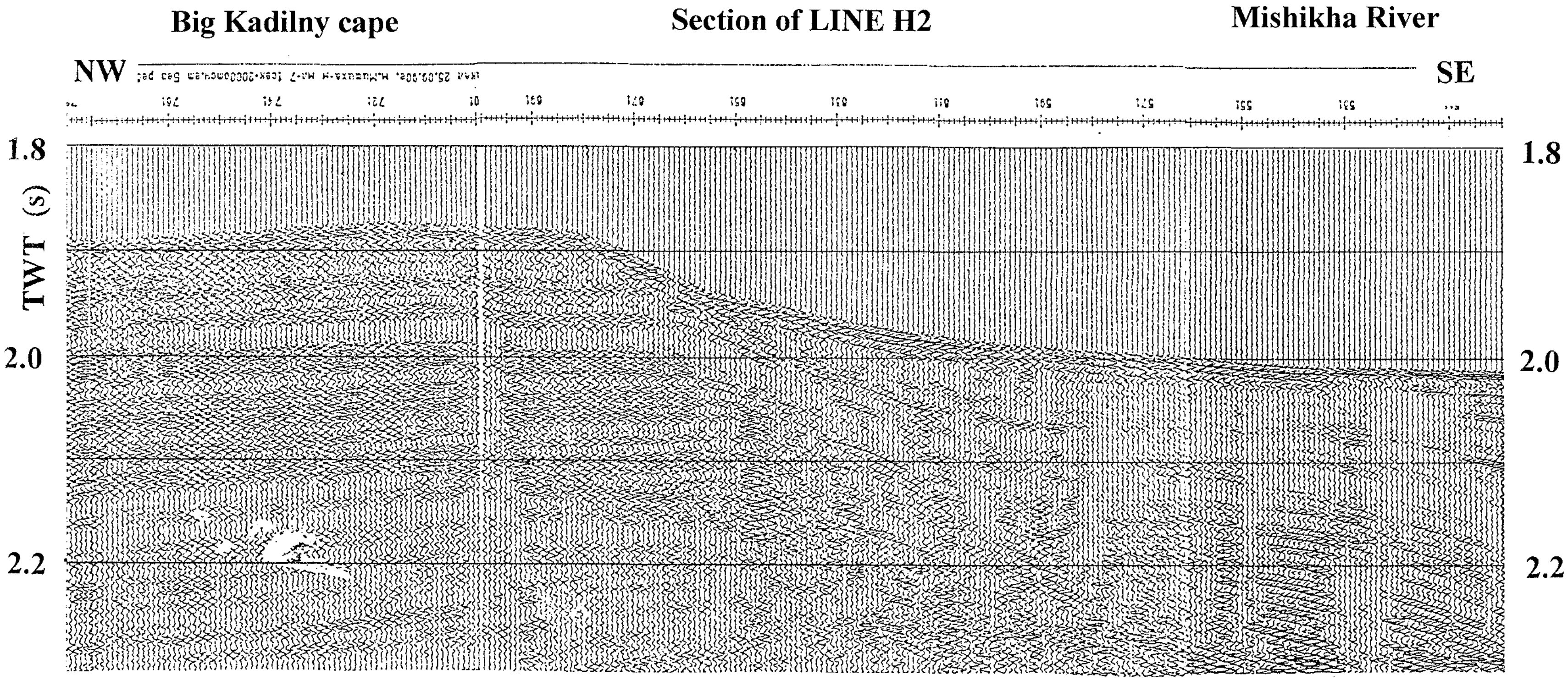


PLATE 5
Seismic Profile H2 in the central part of the South Baikal basin (see Fig. 1C).
Profil sismique H2 dans la partie centrale du Bassin Sud du Baïkal.

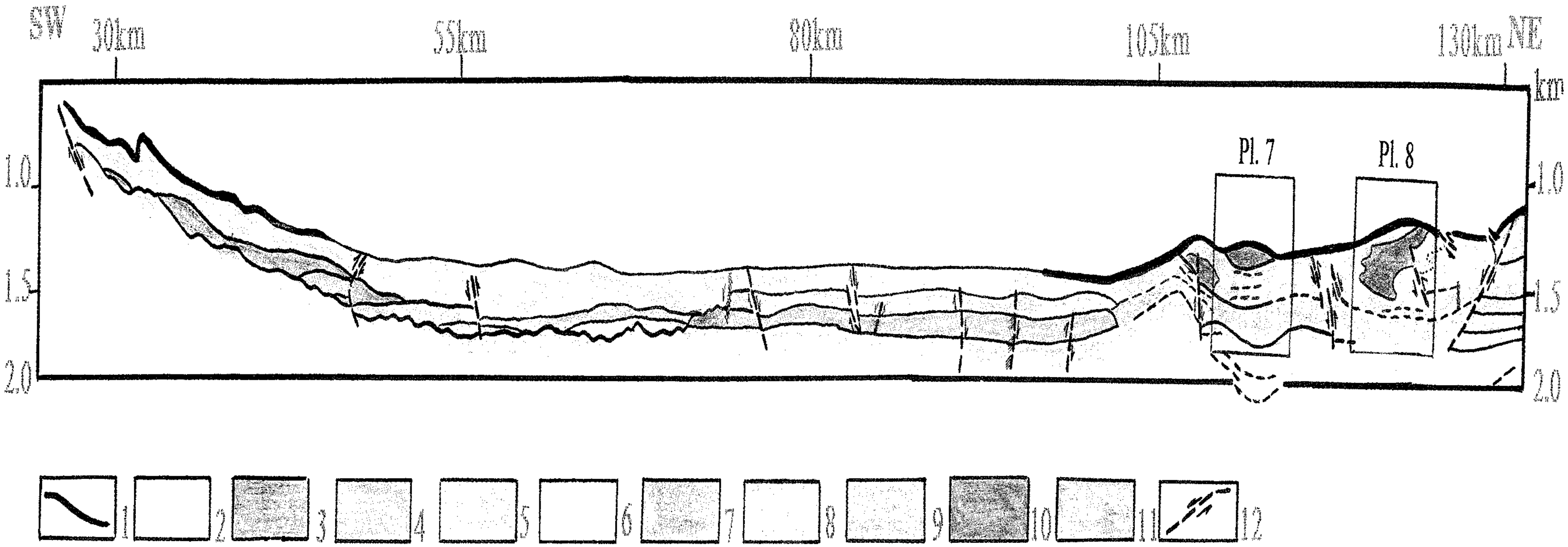


PLATE 6

Geological interpretation of seismic Profile H3 (see Fig.1C) in the South Baikal basin: 1 - recent lake sediments; 2 - upper depositional sequence (probably Pleistocene); 3-7 - middle depositional sequence (probably Late Pliocene); 8 - lower depositional sequence (probably Miocene - Early Pliocene), separated of the middle depositional sequence by a scoured surface; 9 - undeformed middle depositional sequence; 10 - reworked upper depositional sequence; 11 - delta deposits of the Selenga River; 12 - active faults with sense of movement.

Interprétation géologique du profil sismique H3 (voir Fig.1C) dans le Bassin Sud du Baïkal : 1 - sédiments lacustres récents ; 2 - séquence de dépôt supérieure (probablement Pléistocène) ; 3-7 séquence de dépôt moyenne (probablement Pliocène supérieur) ; 8 - séquence de dépôt inférieure (probablement Miocène à Pliocène inférieur), séparée de la séquence de dépôt moyenne par une surface érodée ; 9 - séquence de dépôt moyenne non déformée ; 10 - séquence de dépôt moyenne remaniée ; 11 - dépôts deltaïques de la Selenga ; 12 - failles actives avec sens du mouvement.

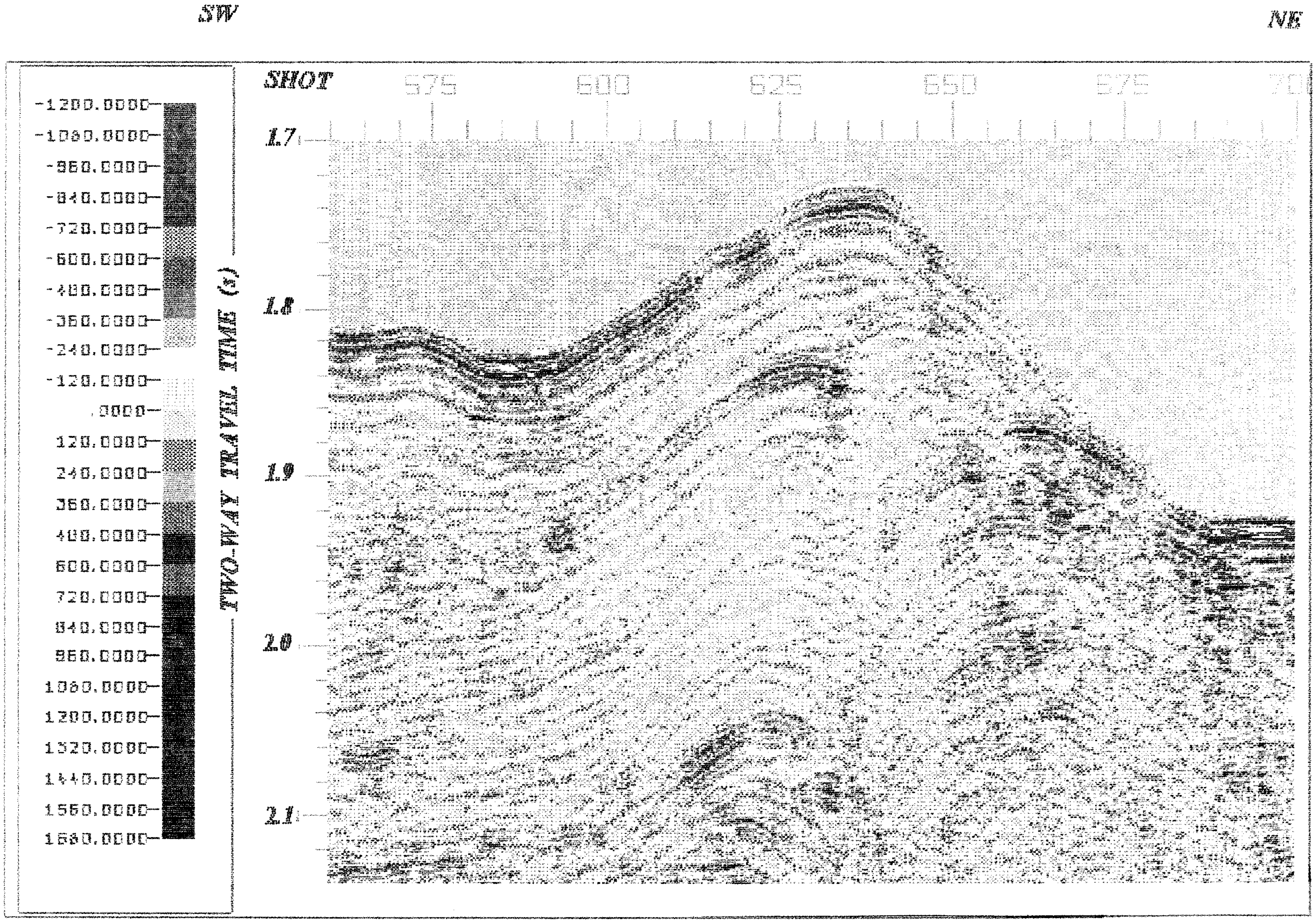


PLATE 7
Section of seismic Profile H3 (see Pl.6 and & 2.1.).
Partie du profil sismique H3 (voir Pl.6 et & 2.1.)

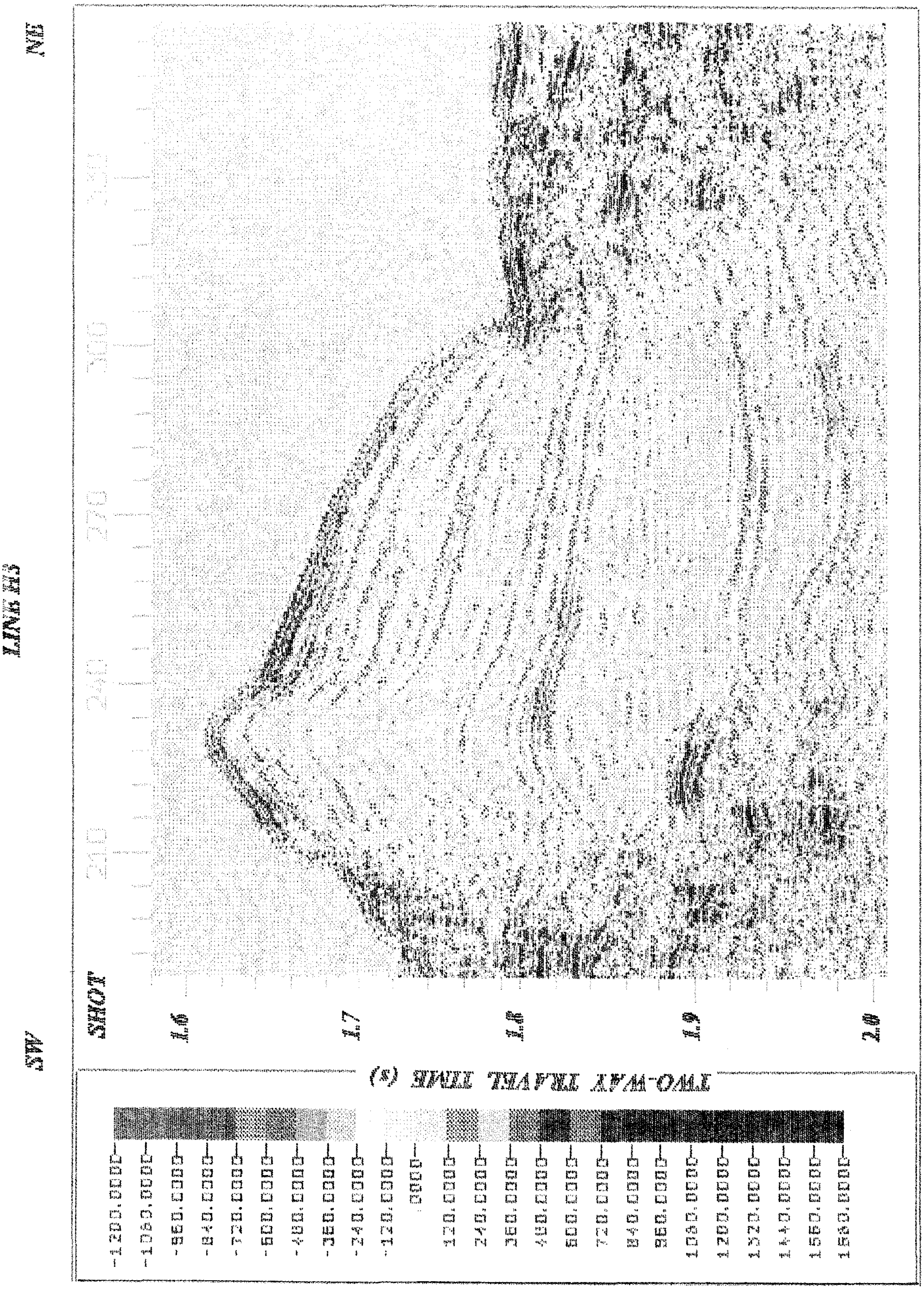


PLATE 8
Section of seismic Profile H3 (see Pl.6 and & 2.1.).
Partie du profil sismique H3 (voir Pl.6 et & 2.1.)

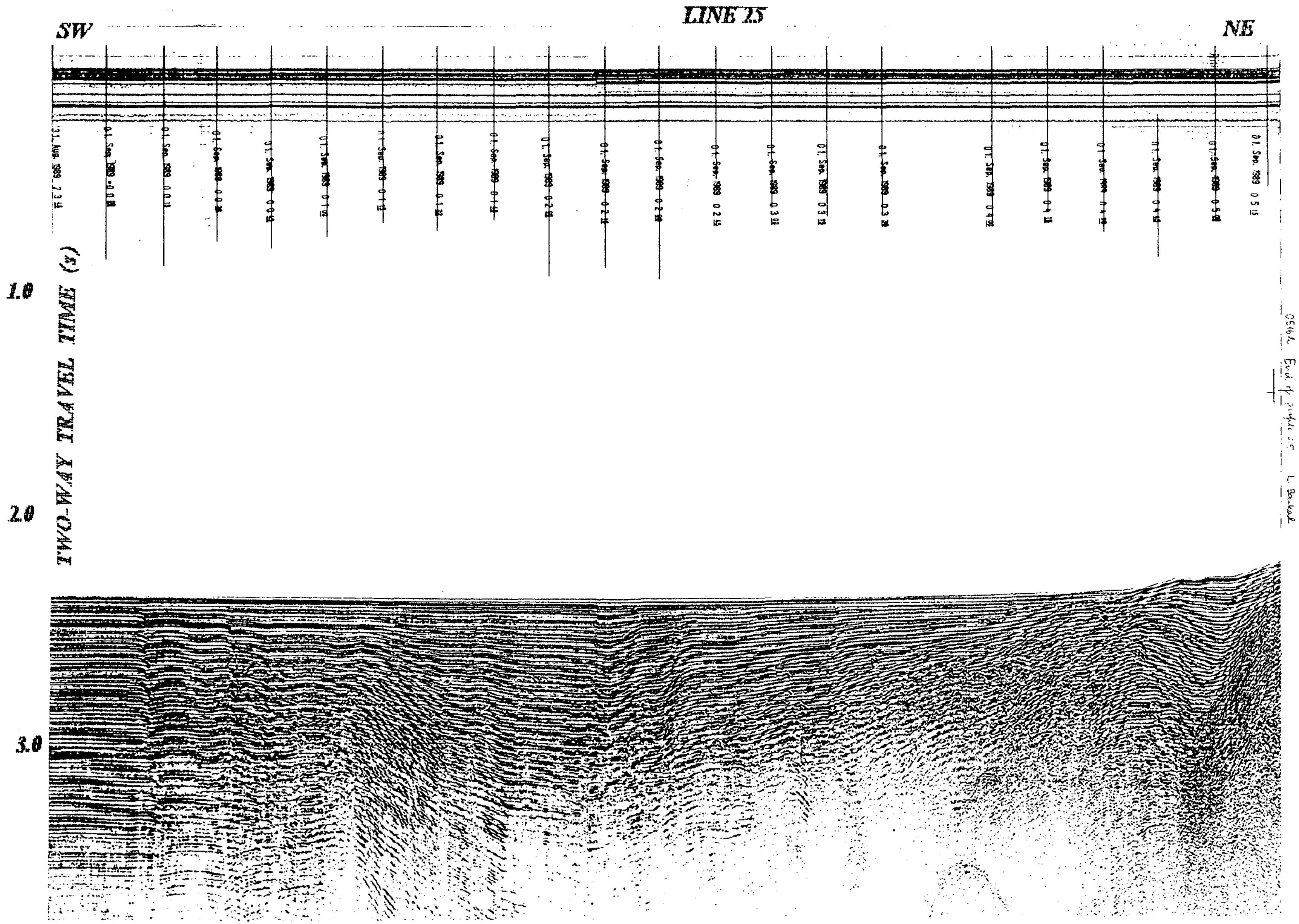


PLATE 9
Seismic Profile 25 in the Central Baikal basin (see Fig 1B).
Profil sismique 25 dans le Bassin Central du Baïkal.

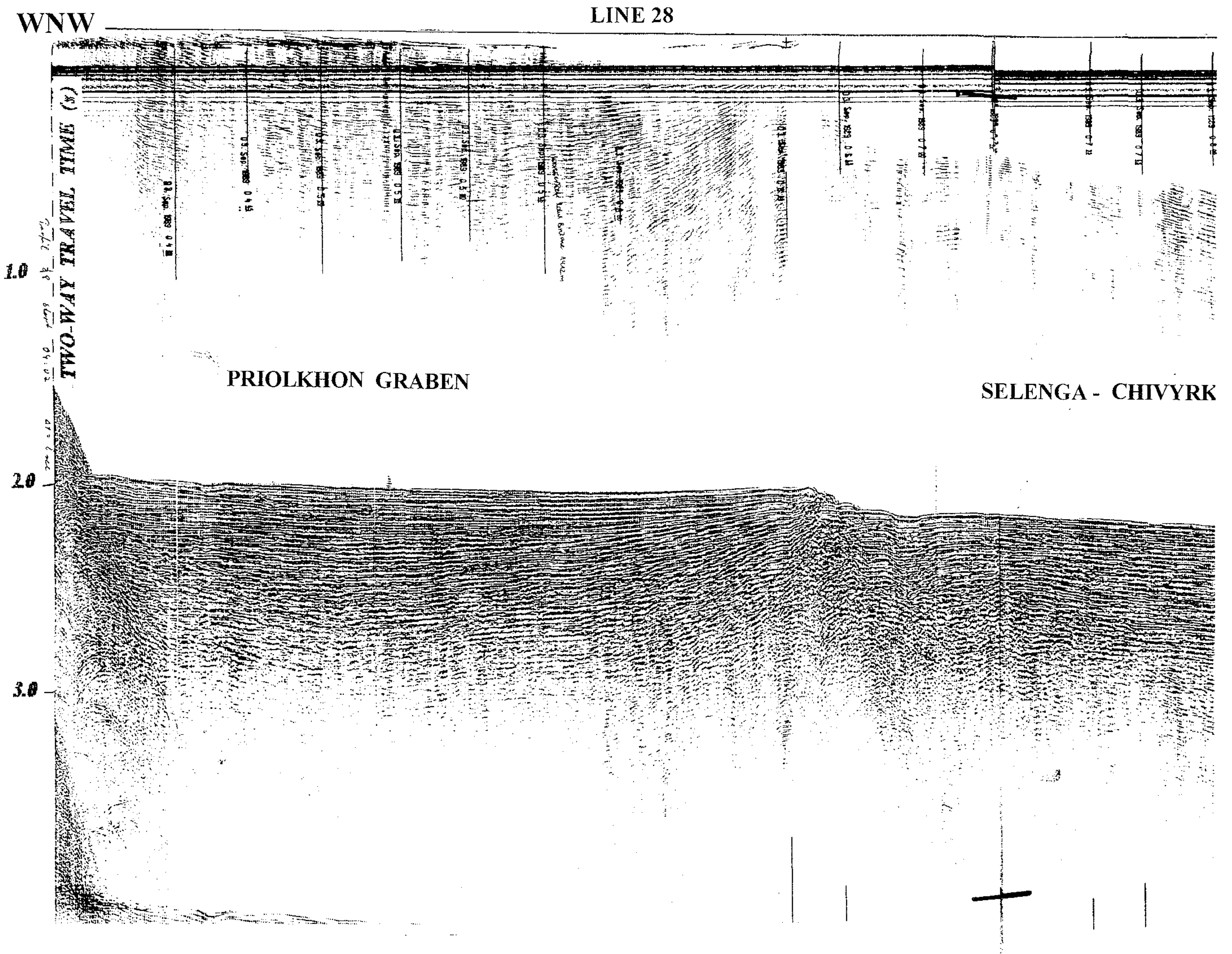
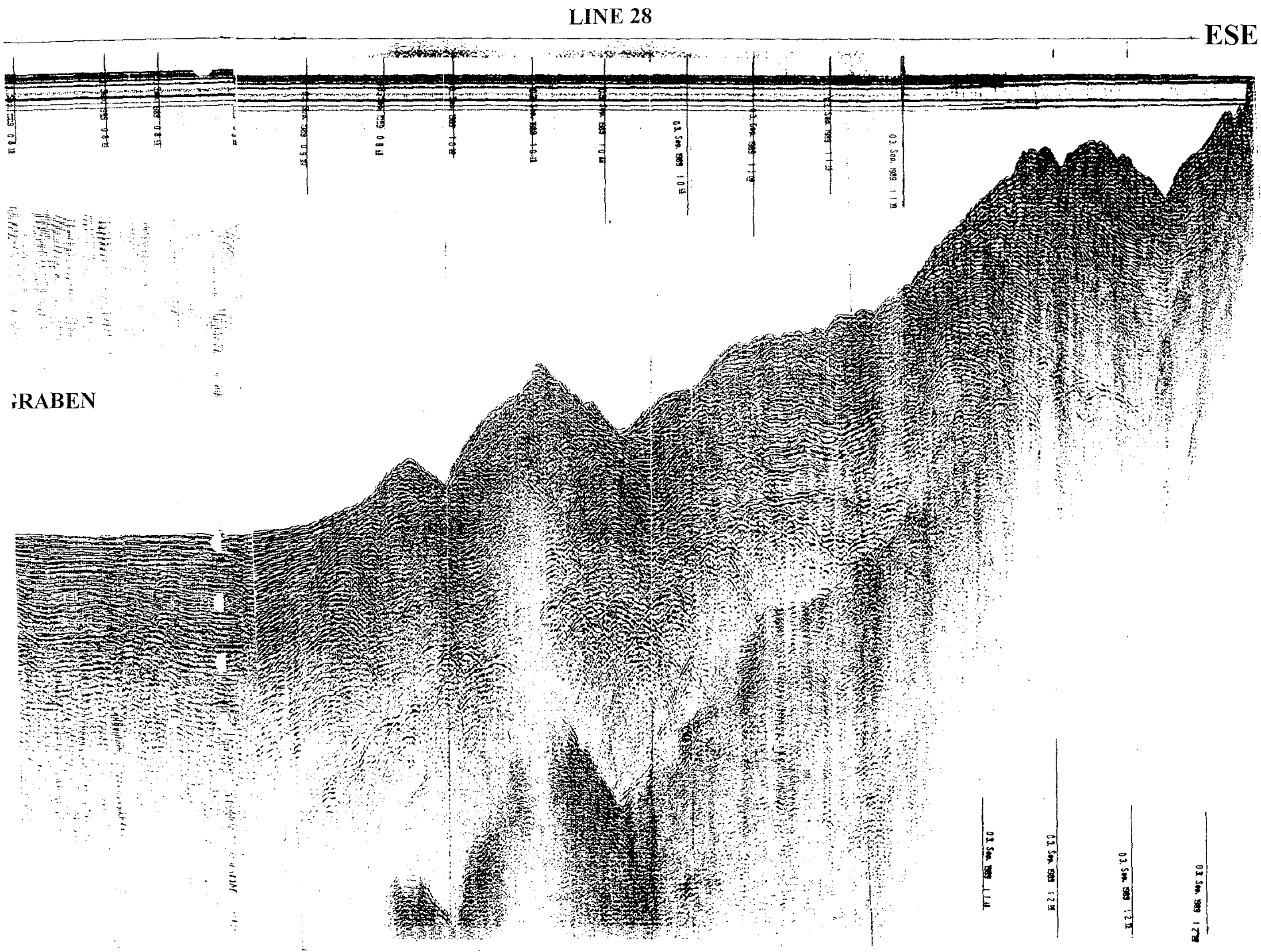
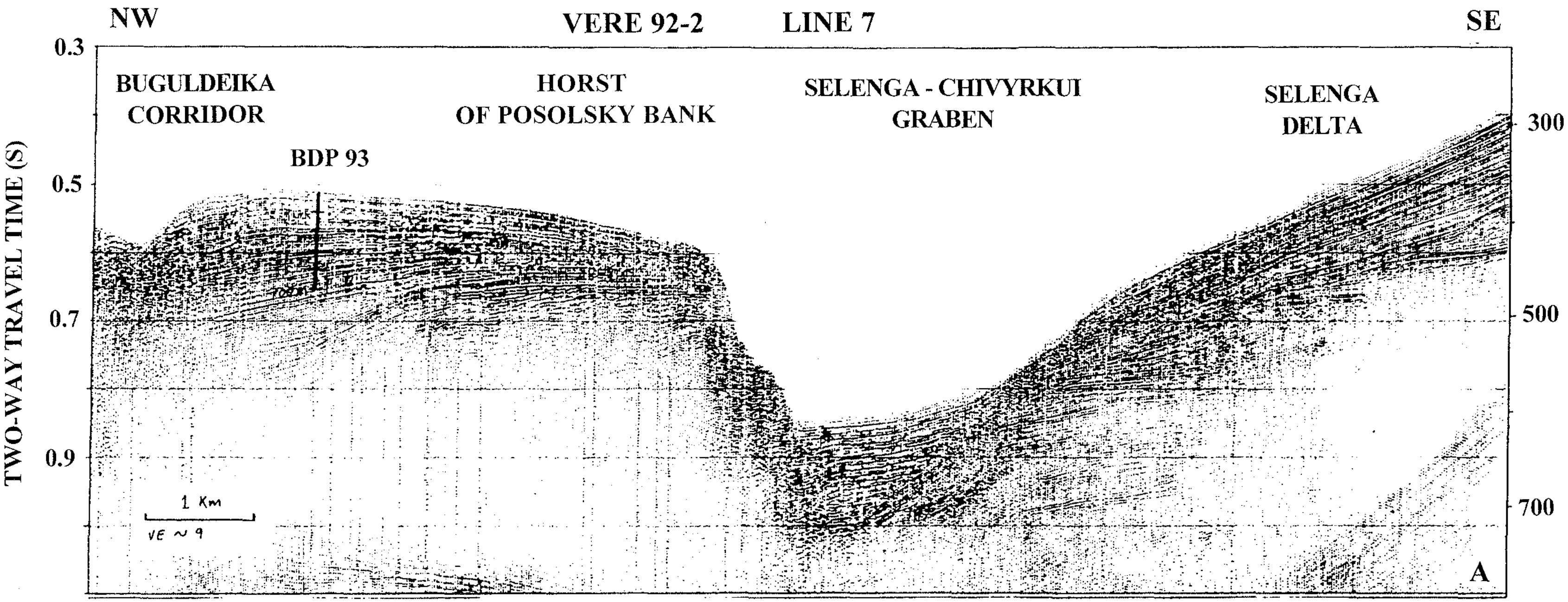


PLATE 10
Seismic Profile 28 in the Central Baikal basin (see Fig 1B).
Profil sismique 28 dans le Bassin Central du Baïkal.


LINE 28
ESE
;RABEN


NW
VERE 92-2
LINE 7
SE
BUGULDEIKA
CORRIDOR
HORST
OF POSOLSKY BANK
SELENGA - CHIVYRKUI
GRABEN
SELENGA
DELTA
BDP 93
TWO-WAY TRAVEL TIME (S)
0.3
0.5
0.7
0.9
APPROXIMATE DEPTH (M)
300
500
700
1 Km
VE ~ 9
A

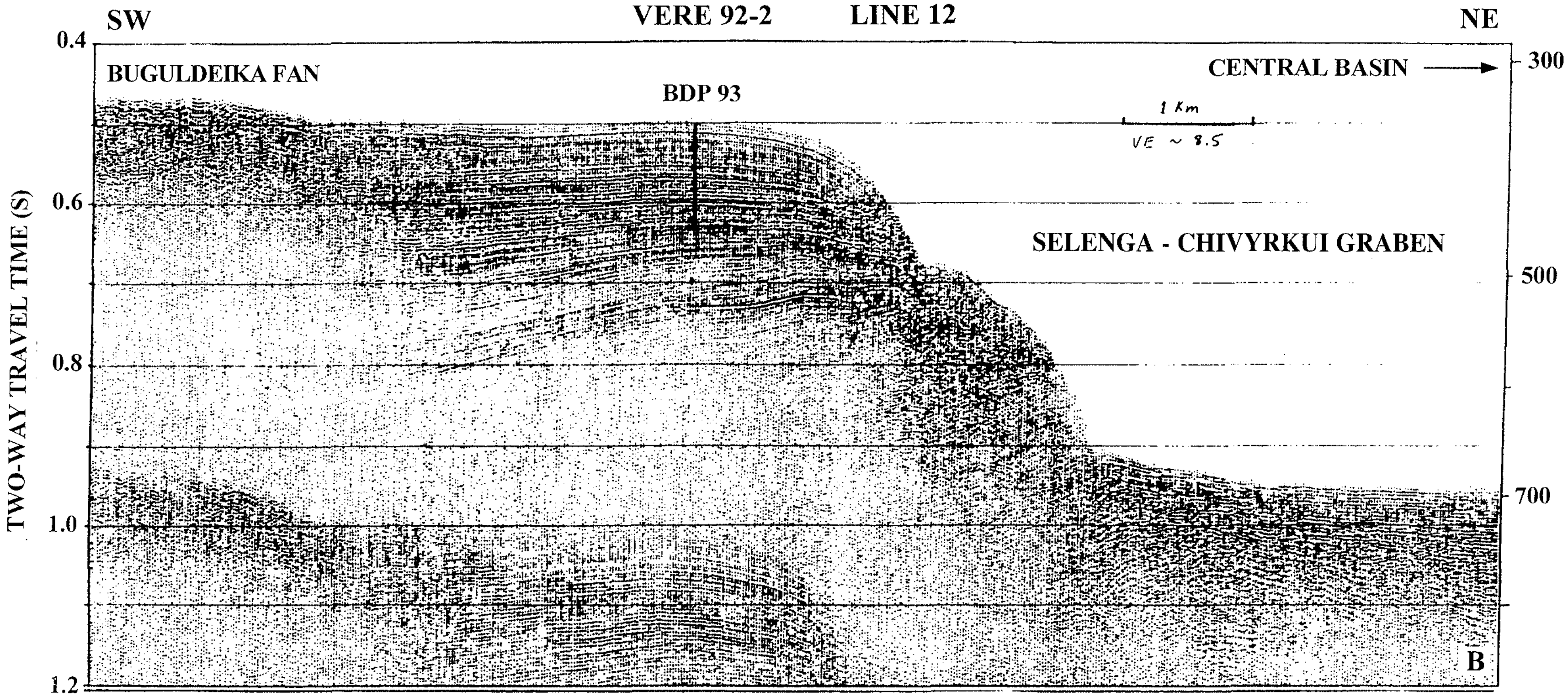


PLATE 11

Seismic Profiles 7 and 12 (Pl. 11A and 11B respectively) opposite to the Buguldeika River delta - area of BDP-93 borehole (see Fig 1D).

Profils sismiques 7 et 12 (Pl.11A et 11B respectivement) en face du delta de la Buguldeika - secteur du puits BDP 93.

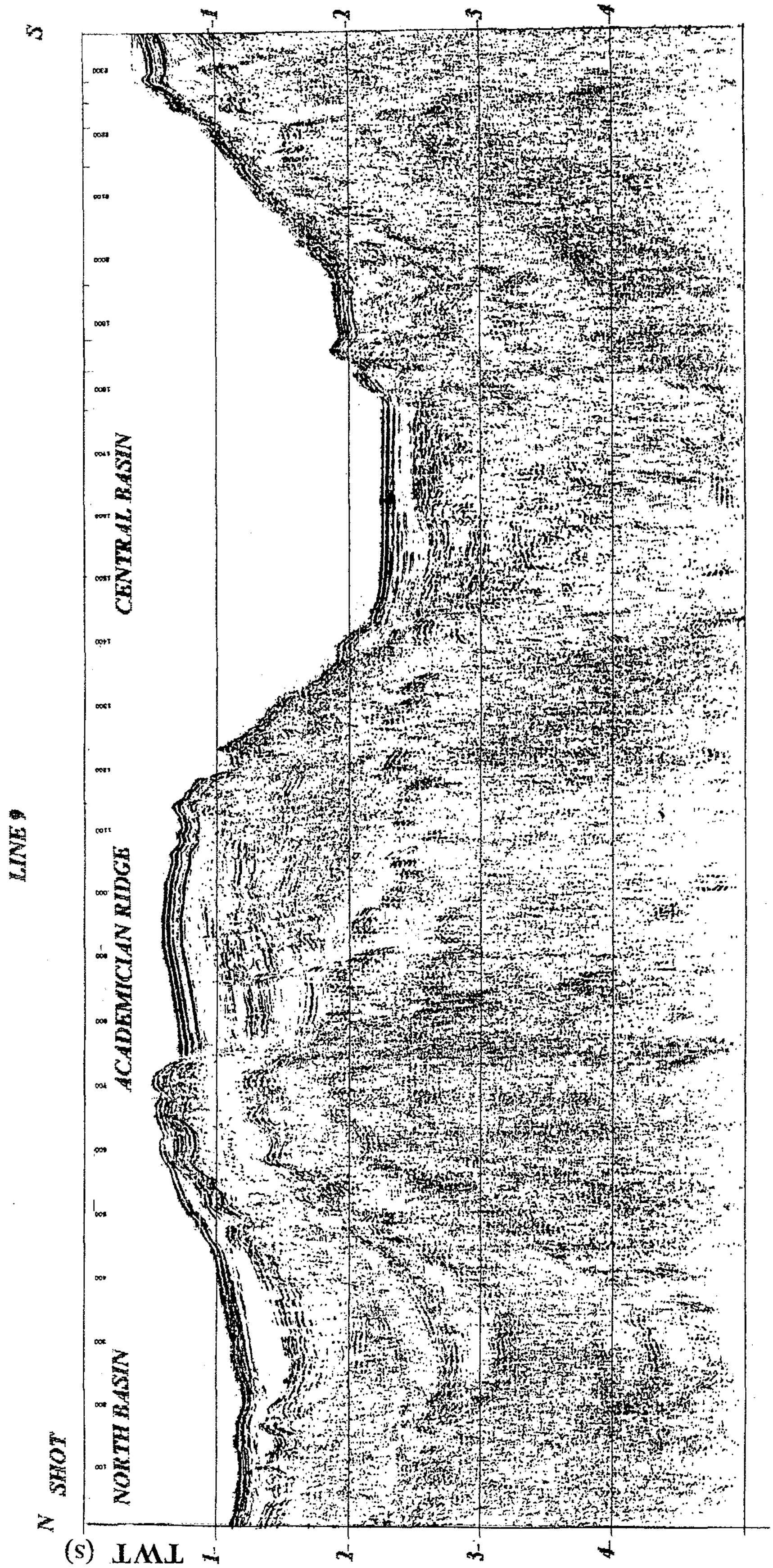


PLATE 12

Seismic Profile 9 (HUTCHINSON *et al.*, 1993) in the northeastern part of the Central Baikal basin (see Fig 1B).

Profil sismique 9 (HUTCHINSON et al., 1993) dans la partie nord-orientale du Bassin Central du Baïkal.

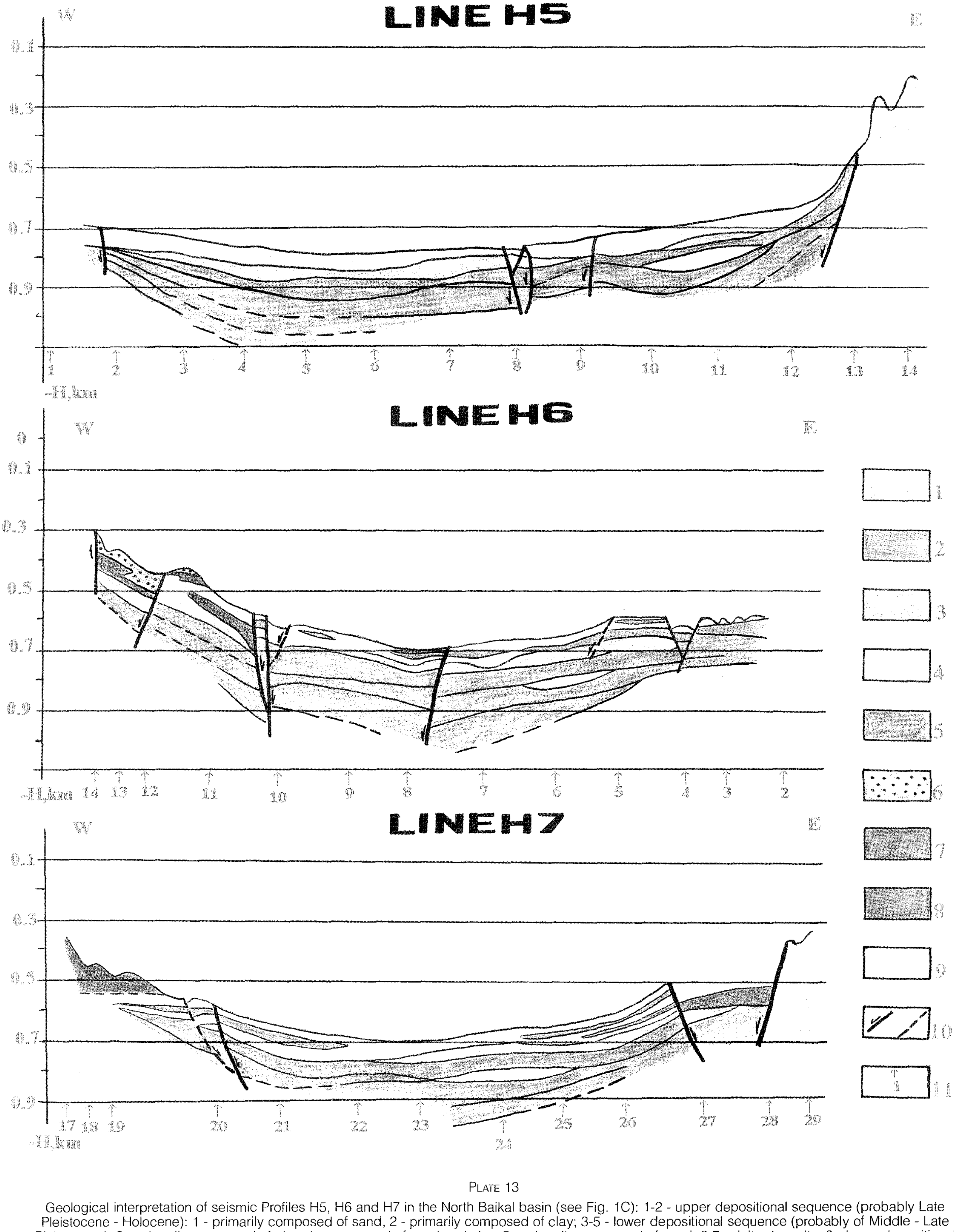


PLATE 13

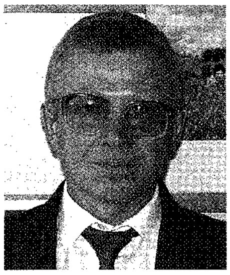
Geological interpretation of seismic Profiles H5, H6 and H7 in the North Baikal basin (see Fig. 1C): 1-2 - upper depositional sequence (probably Late Pleistocene - Holocene): 1 - primarily composed of sand, 2 - primarily composed of clay; 3-5 - lower depositional sequence (probably of Middle - Late Pleistocene): 3 - primarily composed of clay, 4 - composed of sand and clay, 5 - primarily composed of sand; 6-7 - delta deposits: 6 - lower depositional sequence, 7 - upper depositional sequence; 8 - detail of the cross-section where reflectors are not correlated; 9 - crystalline rocks of the basement of the basin; 10 - active faults: a - stated for sure, b - inferred faults; 11 - points of GPS-positioning on the profiles and their numbers.

Interprétation géologique des profils sismiques H5,H6 et H7 du Bassin Nord du Baïkal (voir Fig.1C) : 1-2 - séquence de dépôt supérieure (probablement

Pléistocène supérieur à Holocène) : 1 - essentiellement composée de sable, 2 - essentiellement composée d'argile ; 3-5 - séquence de dépôt inférieure (probablement Pléistocène moyen à supérieur) : 3 - essentiellement composée d'argile, 4 - composée de sable et d'argile, 5 - essentiellement composée de sable ; 6-7 - dépôts deltaïques, 6 - séquence de dépôt inférieure, 7 - séquence de dépôt supérieure ; 8 - intervalles où les réflecteurs ne sont pas corrélés ; 9 - roches cristallines du socle ; 10 - failles actives : a - certaines, b - supposées ; 11- points de positionnement GPS sur les profils.

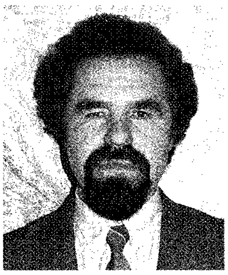
Kirill Georgievich LEVI obtained a Geomorphology degree from the Irkutsk State University in 1974 and a doctorate in geology and mineralogy from the Institute of Geology, Geophysics and Mineralogy, Novosibirsk in 1981. In 1991, he became the Deputy Director of the Institute of the Earth's Crust for the Siberian Branch of the Russian Academy of Sciences. Since 1998, he has been head of Laboratory of Recent Geodynamics. His research activities include neotectonics, recent geodynamics, crustal movements, seismic hazard and risk. He is an associate researcher with the Laboratoire de Géodynamique sous-marine de l'Université Paris VI at Villefranche-sur-Mer, the Institut de Géodynamique de l'Université de Nice – Sofia Antipolis, France and the Musée Royal de l'Afrique Centrale , Tervuren, Belgium.

***Kirill Georgievich LEVI** a acquis sa licence de Géomorphologie à l'Université d'État d'Irkoutsk en 1974 et son doctorat en géologie et minéralogie à l'Institut de Géologie, Géophysique et Minéralogie de Novossibirsk en 1981. En 1991, il est devenu sous-directeur de l'Institut de la Croûte Terrestre de la Section Sibérie de l'Académie des Sciences de Russie. Depuis 1998, il est chef du Laboratoire de Géodynamique actuelle. Il fait des recherches sur la néotectonique, les mouvements de la croûte terrestre et les risques sismiques. Il est chercheur associé du Laboratoire de Géodynamique sous-marine de l'Université Paris VI à Villefranche-sur-mer, de l'Institut de Géodynamique de l'Université de Nice - Sofia Antipolis, France et du Musée Royal de l'Afrique Centrale, Tervuren, Belgique.*



Andrei Ivanovich MIROSHNICHENKO graduated with a degree in Geology from the State University of Irkutsk (1976) and a doctorate in Geology and Mineralogy from the Institute of Geology, Geophysics and Mineralogy in Novosibirsk (1989). In 1997, he became a Senior Researcher at the Laboratory of Recent Geodynamics at the Institute of the Earth's Crust for the Siberian Branch of the Russian Academy of Sciences. He studies deformation and block movements, faulting and stress field. He is an associate researcher with the Laboratoire de Géodynamique sous-marine de l'Université Paris VI at Villefranche-sur-Mer, the Institut de Géodynamique de l'Université de Nice – Sofia Antipolis, France and the Musée Royal de l'Afrique Centrale, Tervuren, Belgium.

***Andrei Ivanovich MIROSHNICHENKO** a obtenu sa licence de Géologie à l'Université d'État d'Irkoutsk en 1976, et son doctorat en Géologie et Minéralogie à l'Institut de Géologie, Géophysique et Minéralogie de Novossibirsk en 1989. En 1997, il est devenu maître de recherches au Laboratoire de Géodynamique actuelle à l'Institut de la Croûte Terrestre de la Section Sibérie de l'Académie des Sciences de Russie. Il étudie la déformation et les mouvements des blocs, la formation des failles et les champs de contrainte. Il est chercheur associé du Laboratoire de Géodynamique sous-marine de l'Université Paris VI à Villefranche-sur-mer, de l'Institut de Géodynamique de l'Université de Nice - Sofia Antipolis, France et du Musée Royal de l'Afrique Centrale, Tervuren, Belgique.*

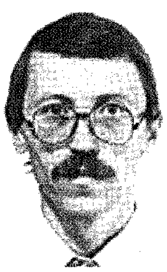


Vladimir Anatolievich SAN'KOV holds a degree in Geology from the Irkutsk State University (1978) and a doctorate in Geology and Mineralogy from the Institute of Geology, Geophysics and Mineralogy in Novosibirsk (1985). In 1988, he became the Scientific Secretary of the Institute of the Earth's Crust for the Siberian Branch of the Russian Academy of Sciences. Since 1997, he has been a Senior Researcher at the Laboratory of Recent Geodynamics. His main scientific interests focus on the study of recent geodynamics stress field, GPS geodesy, and the relationship between fault and seismicity. He is an associate researcher with the Laboratoire de Géodynamique sous-marine de l'Université Paris VI at Villefranche-sur-Mer, the Institut de Géodynamique de l'Université de Nice – Sofia Antipolis, France and the Musée Royal de l'Afrique Centrale, Tervuren, Belgium.

***Vladimir Anatolievich SAN'KOV** a acquis sa licence de Géologie à l'Université d'État d'Irkoutsk en 1978, et son doctorat en Géologie et Minéralogie à l'Institut de Géologie, Géophysique et Minéralogie de Novossibirsk en 1985. En 1988, il est devenu secrétaire scientifique de l'Institut de la Croûte Terrestre de la Section Sibérie de l'Académie des Sciences de Russie. Depuis 1997, il est maître de recherches au Laboratoire de Géodynamique actuelle. Ses principales recherches portent sur le champ de contrainte en géodynamique, la géodésie par GPS et le rapport entre failles et sismicité. Il est chercheur associé du Laboratoire de Géodynamique sous-marine de l'Université Paris VI à Villefranche-sur-mer, de l'Institut de Géodynamique de l'Université de Nice - Sofia Antipolis, France et du Musée Royal de l'Afrique Centrale, Tervuren, Belgique.*

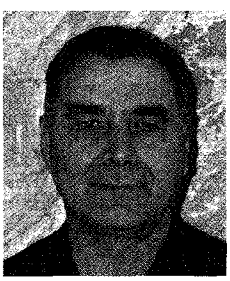
Sergey Mihaylovich BABUSHKIN graduated from the Department of Geophysics at the State University of Novosibirisk in 1975. Since 1982, he has been the head of the Geophysical Monitoring Division in the Geophysical Survey of the Siberian Branch of the Russian Academy of Sciences. He has written over 15 scientific papers. His major works include marine seismic exploration and the application of electromagnetic methods for civil engineering and ecological problems.

Sergey Mihaylovich BABUSHKIN est diplômé du Département de Géophysique de l'Université d'État de Novossibirsk (1975). Depuis 1982, il est chef du contrôle géophysique au Département Géophysique de la Section Sibérie de l'Académie Russe des Sciences. Il est auteur de plus de 15 communications scientifiques. Ses principaux travaux portent sur la sismique marine et l'application de méthodes électromagnétiques au génie civil et aux problèmes écologiques.



Gennady Vasilevich LARKIN graduated from the State University of Novosibirsk in 1974, specialising in digital processing of seismic data. Up until 1978, he was head of seismic velocities interpretation group for Siboilgeophysics. From 1978 to 1988, he worked at the Institute of applied mathematics and mathematical geophysics for the Siberian Branch of the Russian Academy of Sciences. Since 1988, he has been the technical head of a geophysical monitoring group for environment at SB RAS. He is the author of 30 scientific publications and an expert in the field of digital processing of geophysical data. His scientific interests include applied seismic researches (marine and civil engineering seismic), development of algorithms for processing seismic data and the interpretation of geophysical data.

Gennady Vasilevich LARKIN a passé sa licence à l'Université d'État de Novossibirsk en 1974, se spécialisant dans le traitement numérique des données sismiques. Jusqu'en 1978, il a travaillé comme chef d'un groupe d'exploitation des vitesses sismiques à Siboilgeophysics. De 1978 à 1988, il a travaillé à l'Institut de mathématiques appliquées et de géophysique mathématique à la Section Sibérie de l'Académie Russe des Sciences. Depuis 1988, il est ingénieur en chef d'un groupe de surveillance géophysique de l'environnement à la SS ARS. Il est auteur de 30 publications scientifiques, et spécialiste en matière de traitement numérique des données géophysiques. Ses principaux travaux portent sur la sismique appliquée (sismique marine et du génie civil), le développement d'algorithmes de traitement des données sismiques et l'interprétation des données géophysiques.



Alik Anvarovich BADARDINOV holds a degree in Geochronology from the State University of Irkutsk (1974). In 1993, he became a Researcher in the Department of Limnology at the Institute of the Earth's Crust for the Siberian Branch of the Russian Academy of Sciences. He is an expert in seismic stratigraphy and seismic acquisition. He is an associate researcher at the USGS, University of South Carolina (USA), University of Gent (Belgium) and the Geological Museum at the Geological and Paleontological Institute of Hamburg (Germany).

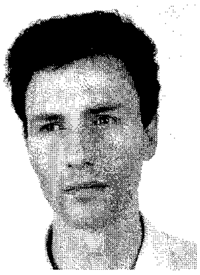
Alik Anvarovich BADARDINOV a acquis sa licence de Géochronologie à l'Université d'État d'Irkoutsk en 1974. En 1993, il est devenu chercheur au Département de Limnologie de l'Institut de la Croûte Terrestre, Section Sibérie de l'Académie Russe des Sciences. Il est spécialisé en stratigraphie sismique et en acquisition sismique. Il est chercheur associé de l'USGS, Université de Caroline du Sud (USA), de l'Université de Gand (Belgique) et du Musée géologique de l'Institut de Géologie et Paléontologie, Université de Hambourg (Allemagne).

How Kin WONG obtained his B.Sc. in Physics and Mathematics (1963) and his Ph.D. in Marine acoustics (1968) from the University of Hong Kong. In 1967, he became Assistant Scientist at the Woods Hole Oceanographic Institution (USA), in 1971, Associate Professor in Geology at the Northern Illinois University (USA) and in 1975, Professor at the Geological and Palaeontological Institute of Hamburg University (Germany). In 1989, he became founding Director of the Institute of Biogeochemistry and Marine Chemistry of the Centre for Marine and Climate Research, Hamburg University, where he is currently Deputy Director. His research interests include sedimentation processes, sea level changes and neotectonics.

How Kin WONG a obtenu sa licence de Physique et Mathématiques en 1963, et son doctorat d'Acoustique marine en 1968 à l'Université de Hongkong. En 1967, il est devenu assistant à la Woods Hole Oceanographic Institution *(USA) et en 1971, maître de conférences en Géologie à l'Université d'Illinois du Nord (USA). En 1975, il est nommé professeur à l'Institut de Géologie et Paléontologie de l'Université de Hambourg (Allemagne). En 1989, il est devenu directeur fondateur de l'Institut de Biogéochimie et Chimie marine du Centre de Recherches marines et climatiques de l'Université de Hambourg où il est actuellement sous-directeur. Ses principaux travaux portent sur les processus de sédimentation, le changement de niveau de la mer et la néotectonique.*

Steven M. COLMAN received a B.Sc. from the University of Notre Dame in 1971, a M.Sc. from PennState University in 1974 and a Ph.D. from the University of Colorado in 1977, all in Geology. From 1977 until 1983, he worked for the U.S. Geological Survey in Denver Colorado, on projects related to Quaternary geology and neotectonics. In 1983, he transferred to the USGS Marine Geology Centre in Woods Hole, Massachusetts, from where he pursued studies of estuarine evolution and the paleoenvironmental records of large lakes. He has served as a visiting scientist at the Past Global Changes Project of the International Geosphere-Biosphere Programme and as President of the Quaternary Geology and Geomorphology Division of the Geological Society of America.

Steven M. COLMAN a acquis sa licence à l'Université de Notre Dame en 1971, sa maîtrise à l'Université de Pennsylvanie en 1974 et son doctorat à l'Université du Colorado en 1977, ces trois diplômes dans l'option Géologie. De 1977 à 1983, il a travaillé à l'U.S. Geological Survey, sur des projets concernant la géologie du Quaternaire et la néotectonique. En 1983, il est entré au Centre de géologie marine de l'USGS à Woods Hole, Massachusetts, où il a poursuivi des études sur l'évolution des estuaires et sur les conditions paléoenvironnementales enregistrées dans les grands lacs. Il a travaillé comme associé scientifique au Past Global Changes Project, *du programme international Géosphère-Biosphère et comme président de la Section géologie et géomorphologie du Quaternaire de la Société géologique des États Unis.*



Damien DELVAUX obtained a B.Sc. in Geology and Mineralogy from the University of Louvain-La-Neuve (Belgium), in 1980. After one year of geological mapping in Belgium and four years in the Geochemistry Laboratory of the Petrofina oil and gas company, he received his doctorate in Geology and Mineralogy from the University of Louvain-la-Neuve in 1988. Since 1989, he has been Assistant-researcher at the Department of Geology and Mineralogy of the Royal Museum for Central Africa. He is involved in the investigation of rifting processes in the Tanganyika and Malawi rift systems, and their comparison with the Baikal Rift System. He focuses mainly on the tectonic control of sedimentary basin formation, neotectonics and active tectonic processes.

Damien DELVAUX a obtenu sa licence en Géologie et Minéralogie à l'Université de Louvain-la-Neuve (Belgique), en 1980. Après une année de cartographie géologique en Belgique et quatre années au Laboratoire de Géochimie de la compagnie pétrolière Petrofina, il a acquis son doctorat en Géologie et Minéralogie à l'Université de Louvain-la-Neuve, en 1988. Depuis 1989, il est chercheur-assistant au Département de Géologie et Minéralogie du Musée Royal de l'Afrique Centrale. Il est impliqué dans des recherches sur les processus de riftogenèse dans les rifts du Tanganyika et du Malawi, et leur comparaison avec le système de rift du Baïkal. Ses principaux sujets de recherche sont le contrôle tectonique des bassins sédimentaires, la néotectonique et la tectonique active.