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Artikel: Acquisition of land based high resolution seismic profiles in glacial basins, two case studies in the Alpine foreland of Switzerland

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Acquisition of land based high resolution seismic profiles in glacial basins, two case studies in the Alpine foreland of Switzerland [1])

By André Pugin and Sandro Rossetti [2])

ABSTRACT

High resolution land-based seismic reflection profiles from Ecoteaux and the Areuse delta within Pleistocene glacial basins of Switzerland are presented in this paper. This method is shown to be particularly useful in recognizing the geometry of subsurface sediments and neotectonic features in glacial basins. Seismofacies are described here to aid interpretation of geological facies through analysis of drill core.

RESUME

Quatre profils de sismique réflection terrestre à haute résolution provenant d'Ecoteaux et du delta de l'Aureuse en Suisse vous sont présentés ici. Cette méthode donne de bons résultats pour reconnaître la géométrie des sédiments et les failles néotectoniques dans les bassins glaciaires. Les sismofaciès sont discutés pour l'interprétation des faciès géologiques avec l'analyse d'une carotte.

Introduction

The development of high resolution land based seismic reflection is now absolutely fundamental to understand the geometry of unconsolidated glacial sediments. Glacial depositional environments are very variable (Eyles et al. 1987), which greatly complicates the delineation of aquifers and aquitards in hydrogeological and environmental investigations. Research on glacial sediments in Switzerland has shown that even where it is relatively easy to recognize the interface between bedrock and Pleistocene sediments (Wildi 1984, Pugin 1988), the architecture of sediments within glasial basins is much more difficult to determine from core or outcrop studies (Pugin 1989, Pugin 1991). The other objective of this paper is to describe the relationship between seismofacies and sedimentological characteristics (e.g. Jongerius & Helbig 1988).

Over the last 20 years, many high resolution seismic profiles have been acquired from Swiss lakes (Finckh et al. 1984, Matter et al. 1971, Schoop & Wegener 1983, Vernet et al. 1974). In contrast, high resolution land based seismic reflection acquisition has not been used extensively in Switzerland. Recently, high resolution land based seismic profiles have been acquired in the Swiss Rhône valley (Finckh & Frei 1991). In the last 10 years, very good results have been obtained in Holland with acquisition in tidal flat settings (Doornenbal & Helbig 1983, Herber et al. 1981, Jongerius & Helbig 1988) but this is

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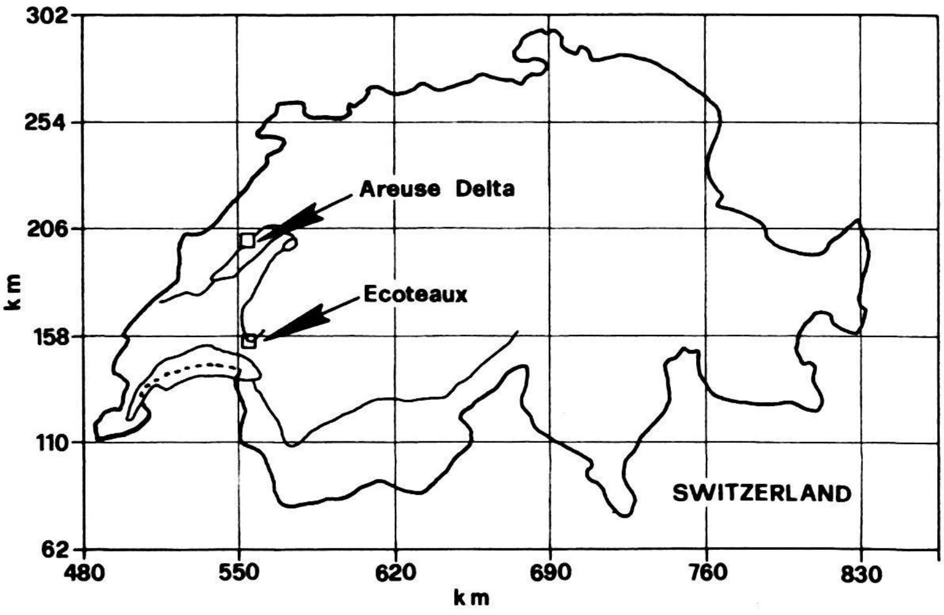


Fig. 1. Situation map of the two case studies in Switzerland, Ecoteaux and Areuse Delta.

because the water table is directly below the surface of the land. At the same time, research teams have been working on this method in North America on glacial sediments for gold exploration or for the delineation of shallow oil reservoirs (Knapp & Steeples 1986, Hunter et al. 1984, Seeber & Steeples 1986).

The purpose of this article is to report results of two case studies in Swiss glacial basins (Fig. 1). In the first study, seismic profiles have been acquired from well compacted old Pleistocene sediments. Other profiles acquired on the late glacial Areuse Delta are shown in the second study of this paper.

Acquisition and processing

Field acquisition

Seismic reflection profiles were recorded using two seismographs (EG & G 1225). 24 traces per shot were registered into memory of 8 bits per word; therefore it was difficult not to saturate records. No analog input filter has been used for acquisition; ground roll energy was decreased by using 50 Hz geophones as low cut filter (Hunter et al. 1984).

The seismic source energy was produced by a 7 kg hammer dropped on an aluminium plate. High frequencies of 200–300 Hz were produced by hitting the plate on a well compacted road. Dynamite and shot gut sources were not used here because they produce lower frequencies. The difficulty with hammer source is to produce enough energy to see deep reflectors. However with our experiences, we have shown that impact or shot gun sources are the most suitable (see also Miller et al. 1986, Herber et al. 1981).

The seismic acquisition geometry of the geophones and shots were decided as a function of the local geology. To see reflectors between 40 m and 200 m depth, offsets were chosen between 10 m and 40 m from the first geophone, with a 5 m geophone group interval. Many shots with different offsets were performed before the geophones were moved from their initital site. For example, for a geophone interval of 5 m, shots were performed at 30, 20 and 10 m offset before the geophones were moved. With this method, a six fold CDP profile with CDP 2,5 m trace interval along a 1300 m profile was acquired in 4 days (see plate 1).

As the offsets were relatively large for high resolution seismic reflection, variations in the amplitude and phase of a reflection signal were not too strong at the interface between Pleistocene sediments and bedrock (Pullan & Hunter 1985). According to these authors, the acquisition window was out of the critical area.

Data processing

Seismic data were processed on a IBM compatible computer. The Software used was "Eavesdropper" from the Kansas Geological Survey to perform normal move out, filters, common depth point distribution with or without stack. Graphical interface using mouseware has been developed at the Geology Department of University of Geneva to perform mute, statics or velocity reflections modelling. 288 traces with different colours as a function of frequency can be shown at one time.

The processing sequence used is the following:

1) edition of geometry
2) static corrections on a datum surface (first arrivals on a constant velocity).
3) bulk and surgical mute
4) common depth point gather without stack
5) velocity analysis
6) normal moveout
7) filter band pass 200–400 Hz
8) AGC scaling, window length 1/5 of the recorded time
9) stacking, maximum 6 fold.
10) filter band pass 200–400 Hz
11) static corrections on a datum plane, (wheathered zone: 800 m/s)
12) print of the section.

Static corrections on a datum surface are not possible in every case because first arrival waves are not always visible. The mute operation is very important since it allows to reject noise as air sound, ground roll and first arrival waves. To see reflectors under the bedrock-Pleistocene interface, it is important to perform normal moveout corrections with velocity functions following exactly the bedrock reflector or any other surface.

Analysis of seismic profiles

1) Ecoteaux

The Ecoteaux area is situated at the front of the Alps. This region is characterized by an old glacial Pleistocene basin, older than 700.000 years B. P. (Pugin, in prep.). This glacial basin is eroded in the Subalpine Molasse thrust against the Plateau Molasse. This

Molasse (Lower Freshwater Molasse, mainly Chattien) is formed by conglomerates, sandstones, silts, limestones and coal beds. The glacial succession is characterized by deltaic gravel, sand and silt sediments all highly compacted. A 75 m deep hole was put down into the succession.

Eight seismic profiles were acquired in this area in order to study the sedimentary geometry and to determine the optimum location of the drill hole. Two profiles are presented here (Fig. 2, 3 and Plate 1). Profile P1 (Fig. 2) has 72 m length with 1 m of geophone spacing, after the CDP stack number of 12, the intertrace is of 0.5 m. The profile P2 (Plate 1) has a length of 1307.5 m and is acquired with 5 m of geophone group interval and a CDP stack number of 6.

Observation

Four distinct units of seismofacies are present in the Ecotheaux area. The three first units are discussed on the profile P1 (Fig. 2). The profile P2 (Fig. 3) shows a more complex interface between bedrock and Pleistocene.

Unit a: in the profile P1, the first reflectors are semicontinuous with a continuous basis with various amplitudes at about 40 ms from the surface topography. In the profile P2, this seismofacies is also observable in some parts: at the distance 15 m to 150 m this facies is well represented and becomes very clear from 195 m to 500 m, from 500 m to 540 m diffractions are present and the base of this facies is about 50 ms below the topography. Afterwards, the observation of this unit becomes less clear because the first layer is a low velocity gravel sediment. We again observe a reflector representing probably the base of this unit between cordinates 1150 m to 1260 m.

Unit b: in both profiles, this facies appears as a low amplitude, discontinous to blind facies. In the profile P1, this facies is represented by short horizontal reflectors (to about 75 ms) and in P2, some more continuous reflectors are observable from distance 350 m to 380 m and from 620 m to 730 m. An oblique zone of reflectors going through every seismofacies is observable from (1050 m, 150 ms) to (1250 m, 50 ms). With this geometry of acquisition, strong dipping events can be observed.

Unit c: in the profile P1, this unit is formed by a short layer of about 5 ms with discontinuous, oblique and curved reflections with low amplitudes. The dip is generally directed to the south. In profile P2, this facies is suspected at 280 m, 740 m and 835 m but in this profile, the geophone group interval is too large to evidence such fine structures. The basis of this facies is characterized by very well defined amplitudes and continuous reflectors corresponding to a high reflection index.

Unit d: high amplitude, discontinuous and oblique reflectors. The angle of reflectors varies from 5 degrees in the South to 30 degrees in the North in the profile P2. Diffractions occur at 350 m and 500 m. Most of the observable oblique reflections are present from (540 m, 250 ms) to (830 m, 90 ms) and from (1050 m, 150 ms) to (1250 m, 50 ms).

Interpretation

To make correspondence with geology, a core has been drilled in Ecoteaux formations. Geophones have been let down into the borehole to determine velocities from shots performed at the surface. From the top, this core shows:

1) 11 m of till deposited during the last Würm glacial age. This till comprises 6 m of matrix supported diamict (velocity 800 m/s) and of 4 m of clast supported sandy diamict (velocity 1900 m/s).

2) 25 m of Pleistocene interglacial lacustrine sediment (velocity 1900 m/s). This sandy and silty sediment has been affected by slumps, almost at the bottom of this sequence which begins with a matrix supported diamict.

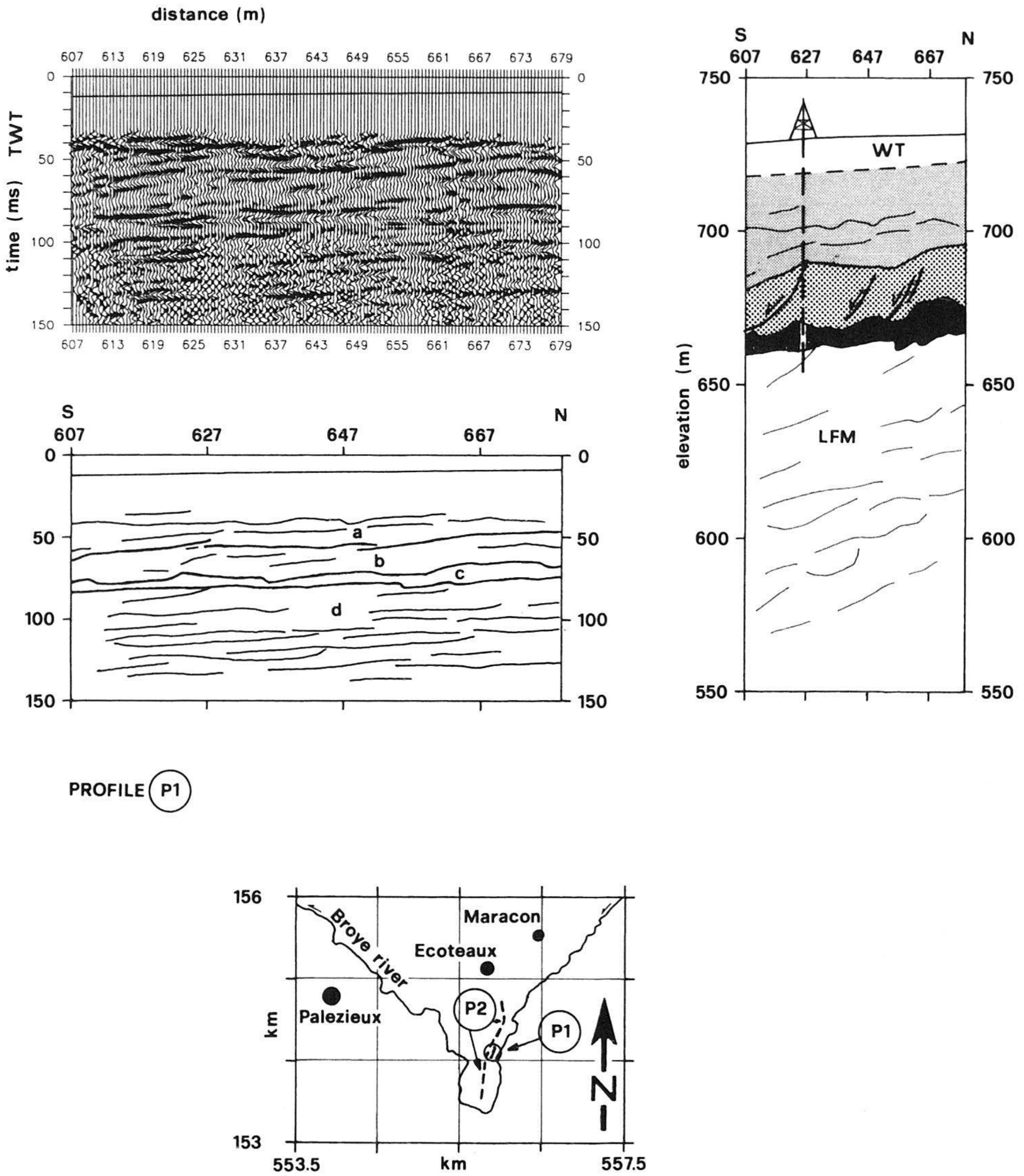
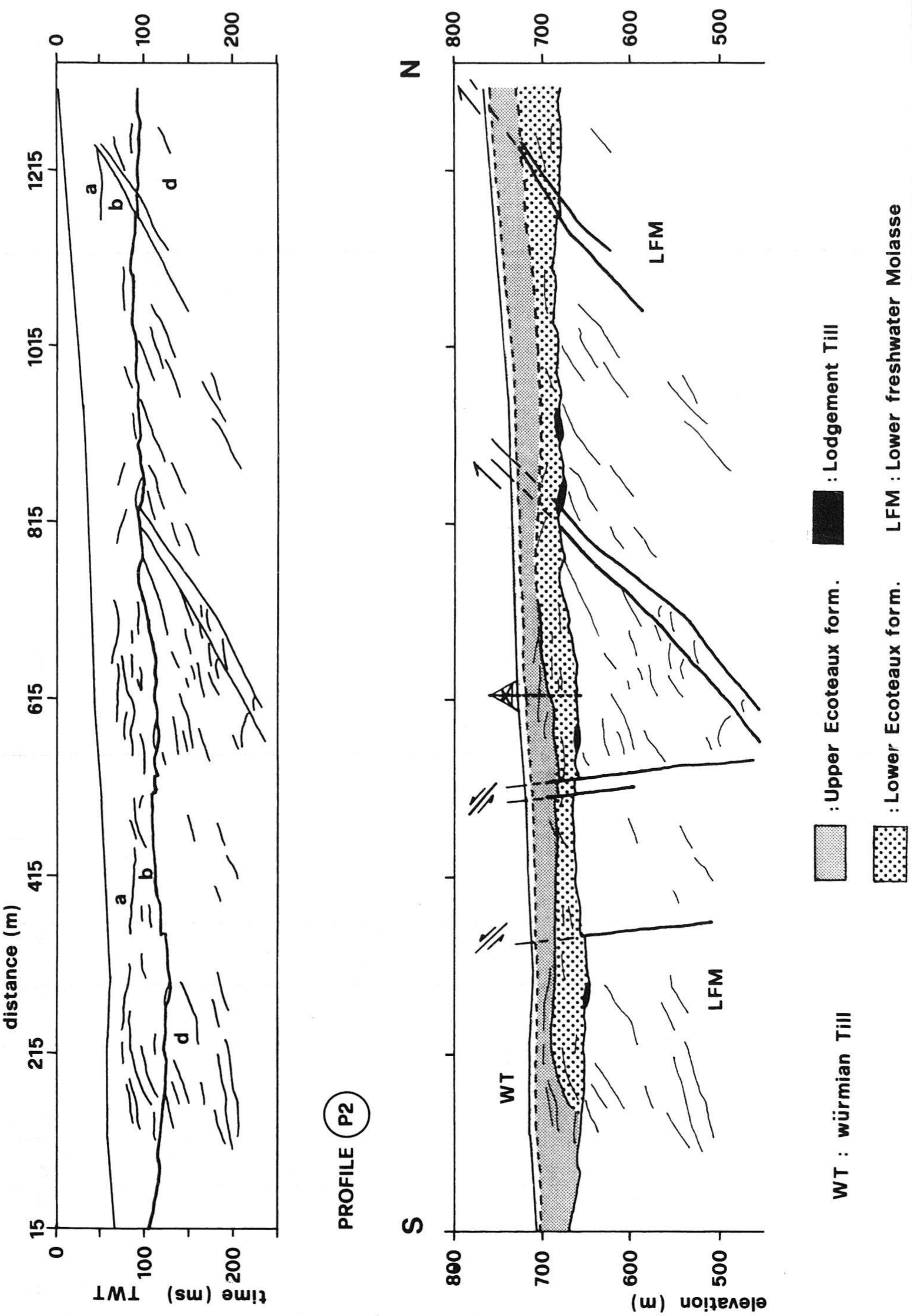


Fig. 2. Ecoteaux, seismic profile P1 and situation map of profiles P1 and P2. The well location is at the South of the P2 profile. The polarity is SEG-reversed, gain is 2,5; datum plane for static corrections is 740 m. Letters written in the interpretation are representation of seismofacies discussed in the text. Signification of layers in the geological profile are shown in fig. 3.

3) 26 m of annual varved glaciolacustrine sediments (velocity 1900 m/s). The top is completely sheared below the diamict of unit 2.

4) 9 m of diamict with sand (velocity 2350 m/s); the bottom of this lithology is characterized by a highly compacted diamict (lodgement till) lying on a striated bedrock.


distance (m)
15
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415
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815
1015
1215
time (ms) TWT
0
100
200
a
b
d
PROFILE P2
S
N
elevation (m)
800
700
600
500
WT
LFM
: Upper Ecoteaux form.
: Lower Ecoteaux form.
: Lodgement Till
LFM : Lower freshwater Molasse
WT : würmian Till

5) 4 m of sandstone alternating with clay and coal levels forming the bedrock have been drilled (velocity 3200–3500 m/s; determination on core samples, S. Selami, departement of Geophysic, Geneva).

The würmian till is evidently not observed by the seismic reflection method. Seismofacies unit (a) corresponds to the slumped lacustrine sequence 2; the slumps are probably responsible for discontinuous, oblique and curved reflections.

Seismofacies unit (b) with small reflections corresponds to the geological facies association 3: the annual varves do not present good conditions for reflections, only few turbidite horizons present in this sequence induce reflections.

Unit (c) corresponds to highly compacted tills having contrasting velocities with varved sediments. Seismic reflections along the interface are not well developed because the interface is not sharp; due to shearing at the base of the glacier. This interface can better be seen in profile P1 because the geophone group interval here is only of 1 m.

The top of the bedrock is generally easy to follow with high contrasts of velocities and densities. Breaking points indicate neotectonic features (Fig. 3). Unit (d) is characterized by layers of sandstone, clay and cloal levels which have good internal contrasts to generate reflections. The depositional environment of this formation is fluvial: discontinuous reflectors may be the result of channeled geometry.

Oblique reflecting surfaces in the Molasse and in the old Pleistocene sediments are probably thrust faults which are common in the Subalpine Molasse (Weidmann et al. 1982). Diffraction zones correspond to stike slip faults which are aligned along the Rhône valley and which affect overlying Pleistocene sediments. From these observations, the last tectonic event of the Ecoteaux region is probably due to transpressive strike slip faults.

2) Areuse Delta

The Areuse delta is located at the northern part of Lake Neuchâtel. It is fed by the Jurassian Areuse river (Fig. 4). This delta is a classical Gilbert type delta with topset, foreset and bottomset beds. Topsets and foresets may attain 25 m to 50 m or more. Sand and silts form the bottomsets. In this area, two seismic profiles P3 and P4 have been acquired near the lake where the water table is close to the surface (Fig. 4). There is no intersection between the two lines because due to human activities, sites for good acquisition are rare. In the central part of the delta, the energy of the source was almost insufficient to penetrate the 4 m of dry gravel above the water table.

The first profile (profile P3, Fig. 4) is parallel to the axis of the delta. The acquisition parameters are the same as in Ecoteaux, profile P1.

The second profile (profile P4, Fig. 4) is perpendicular to the delta, close to the shore of the lake. Very high frequencies have been obtained, from 200 Hz to 300 Hz. This results from the fact that gravel under the water table has a relatively high velocity, here about 2050 m/s. The offset is always 10 m here and shot spacing 5 m, thus it is possible to observe reflectors already at 15 ms.

Fig. 3. Ecoteaux, line drawing and interpretation of the profile P2 shown in plate 1. Letters written in the interpretation are representation of seismofacies discussed in the text.

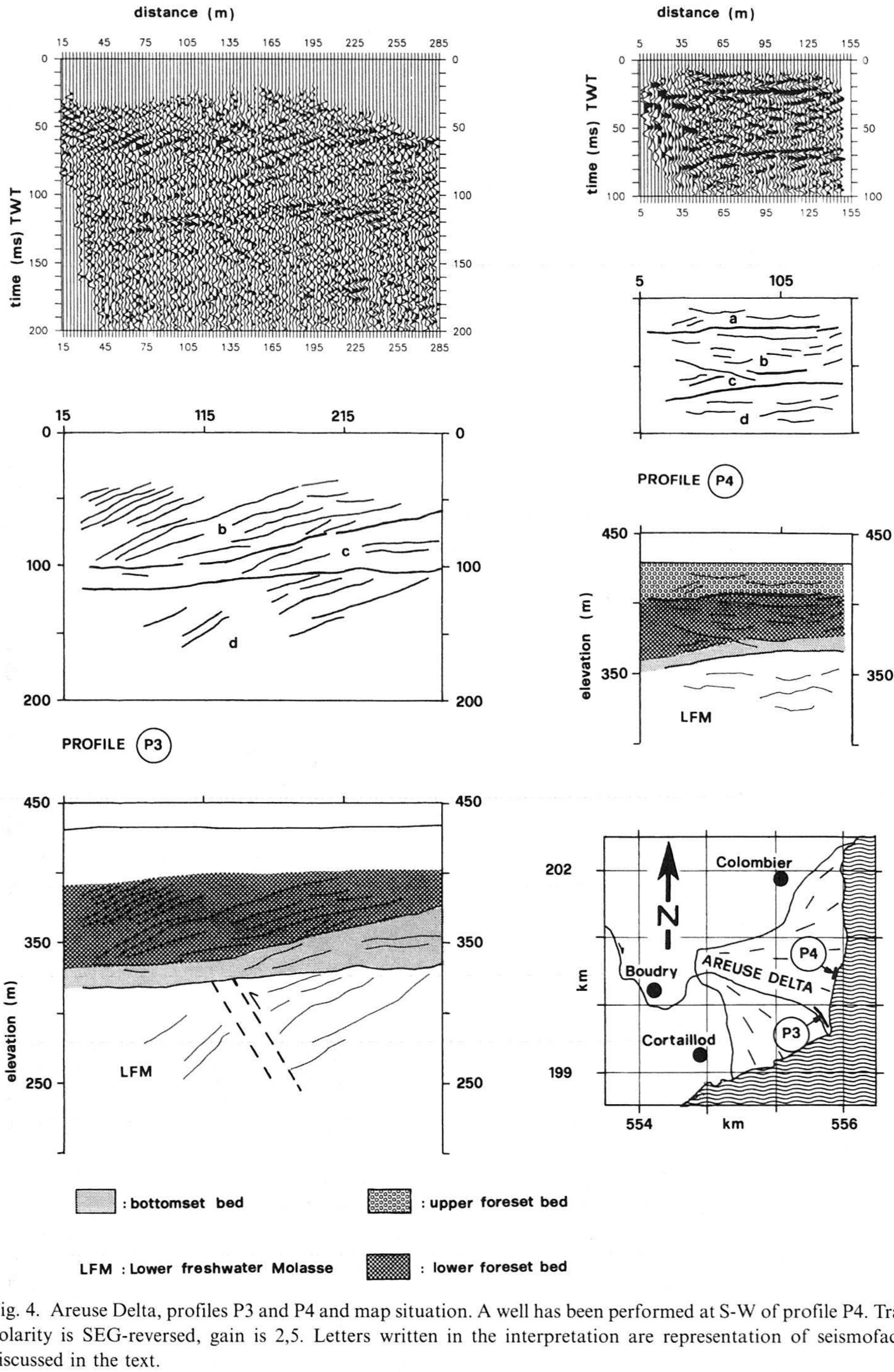

Fig. 4. Areuse Delta, profiles P3 and P4 and map situation. A well has been performed at S-W of profile P4. Trace polarity is SEG-reversed, gain is 2,5. Letters written in the interpretation are representation of seismofacies discussed in the text.

Observation

Four distinct seismofacies are present in these two sections (Fig. 4).

Unit a: semi-continuous or curved reflections with high amplitudes. Due to the chosen geometry of acquisition, this unit is not recognizable in profile P3. The base of this facies is formed by a reflection with a very high amplitude.

Unit b: 28 ms to 60–70 ms, low amplitude and high frequencies oblique parallel reflectors in the profile P3 and through structures in the profile P4.

Unit c: 60–70 ms to 90 ms, relatively blind zone.

Unit d: 60–70 ms to 100 ms, discontinuous oblique reflection with moderate amplitudes. Relation between unit c and unit d is sharp with high amplitudes.

Interpretation

From a drill core near profile P4, it is known that unit (a) corresponds to gravel beds without silt. This is the upper part of the foreset of the Areuse delta. Foresets continue to the unit (b): after conversion of time to depth using a velocity of 1900 m/s, reflectors dipping at 20 degrees are identified as gravely foreset beds. In the drill core unit (b) is a silty gravel. In the perpendiular profile P4 the reflectors appears to be like a trough. The unit (c) has never been drilled but should correspond to a muddy bottemset bed or/and a till bed. Those three first units are late to post Würmian.

Unit (d) begins with a high amplitude interface indicating a high reflection index. A velocity of 3200 m/s indicates the Tertiary Molasse which is constituted here by clay, sandstone, limestone beds. The supposed inverse fault in the profile P3 may be due to the folding of the Jura Mountains.

Discussion and conclusions

Success in Seismic reflection acquisition is highly dependant on the nature of the surface weathered zone. This zone should be not too thick in order to allow seismic waves to penetrate the substrate and not to filtrate high frequencies. In practice hammer seismic programs are the best carried out on roads or near the water table. Over a low velocity weathered zone, dynamite or seismic guns should be used.

Sections from Ecoteaux show high frequencies because the sediments are well compacted under the würmian till. Profiles from the Areuse Delta have high frequencies because the water table is near or at the surface of the land.

High resolution seismic reflection is clearly a good method to evaluate the subsurface infill geometry of glacial basins and to identify depositional environments and neotectonic features. Further modeling of geological facies is needed to understand the relationship between seismic facies and geology.

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REFERENCES

DOORNENBAL, J. C. & HELBIG, K. 1983: High resolution seismics on a tidal flat in the dutch Delta – acquisition, processing, and interpretation. First Break 1, 9–20.

EYLES, N., CLARCK, B. M. CLAGUE, J. J. (1987): Coarse grained sediment gravity flow facies in a large supraglacial lake. Sedimentology 34, 193–216.

FINCKH, P., KELTS, K. R. & LAMBERT, A. 1984: Seismic stratigraphy and bedrock forms in perialpine lakes. Bull. geol. Soc. Amer. 95, 1118–1128.

FINCKH, P. & FREI W. (1991): Seismic reflection profiling in the Swiss Rhone valley, Part 1: Seismic reflection field work, seismic processing and seismic results of the Roche-Vouvry and Turtmann and Agarn lines. Eclogae geol. Hel. 84, 345–358.

HERBER, M. A., RUNIA, D. J. & HELBIG, K. 1981: The shallow structure or the Roggenplaat (the Netherlands) as deduced from high-resolution multi-channel seismic profiling. Geol. en Mijnb. 60, 225–236.

HUNTER, J. A., PULLAN, S. E., GAGNE, R. E. & GOOD, R. L. 1984: Shallow seismic reflection mapping the overburden-bedrock interface with the engineering seismograph, some simple techniques. Geophysics 49, 1381–1385.

JONGERIUS, P. & HELBIG, K. 1988: Onshore high-resolution seismic profiling applied to sedimentology. Geophysics 53/10, 1276–1283.

KNAPP, R. W. & STEEPLES, D. W. 1986: High-resolution commond-depth-point seismic reflection profiling: instrumentation. Geophysics 51, 276–282.

MATTER, A., SÜSSTRUNK, A. E., HINZ, K. & STURM, M. 1971: Ergebnisse reflexionseismischer Untersuchungen im Thunersee. Eclogae geol. Helv. 64, 505–520.

MILLER, R. D. PULLAN, S. E. WALDNER, J. S. & HAENI, F. P. 1986: Field comparison of shallow seismic sources. Geophysics 51, 2067–2092.

PUGIN, A. 1988: Carte des isohypses de la base des sédiments du Quaternaire en Suisse occidentale, avec quelques commentaires. Rapp. géol. Serv. Hydrol. Géol. natl. 3.

– 1989: Déglaciation dans la vallée préalpine de la Sarine en Gruyère: une analyse sédimentologique. Eclogae geol. Helv. 82, 285–324.

– 1991: Séquences sédimentaires glaciaires dans le Seeland et le Mittelland bernois et soleurois. Eclogae geol. Helv. 84, 177–205.

PULLAN, S. E. & HUNTER, J. A. 1985: Seismic model studies of the overburden-bedrock reflection. Geophysics 50, 1684–1688.

SCHOOP, R. W. & WEGENER, H. 1983: Einige Ergebnisse der seismischen Untersuchungen auf dem Bodensee. Bull. Ver. schweiz. Petroleum-Geol. u. -Ing. 50/118, 41–47.

SEEBER, D. S. & STEEPLES, D. W. 1986: Seismic data obtained using. 50-caliber machine gun as high-resolution seismic source. Amer. Assoc. Petroleum Geol. Bull. 70, 970–976.

VERNET, J. P., HORN, R., BADOUX, H. & SCOLARI, G. 1974: Etude structurale du Léman par sismique réflexion continue. Eclogae geol. Helv. 67, 515–530.

WEIDMANN, M., HOMEWOOD, P. & FASEL, J. M. 1982: Sur les terrains subalpins et le wildflysch entre Bulle et Montreux. Bull. Soc. vaud. Sci. nat. 76, 151–183.

WILDI, W. 1984: Isohypsenkarte der quartären Felstäler in der Nord- und Ostschweiz, mit kurzen Erläuterungen. Eclogae geol. Helv. 77, 541–551.

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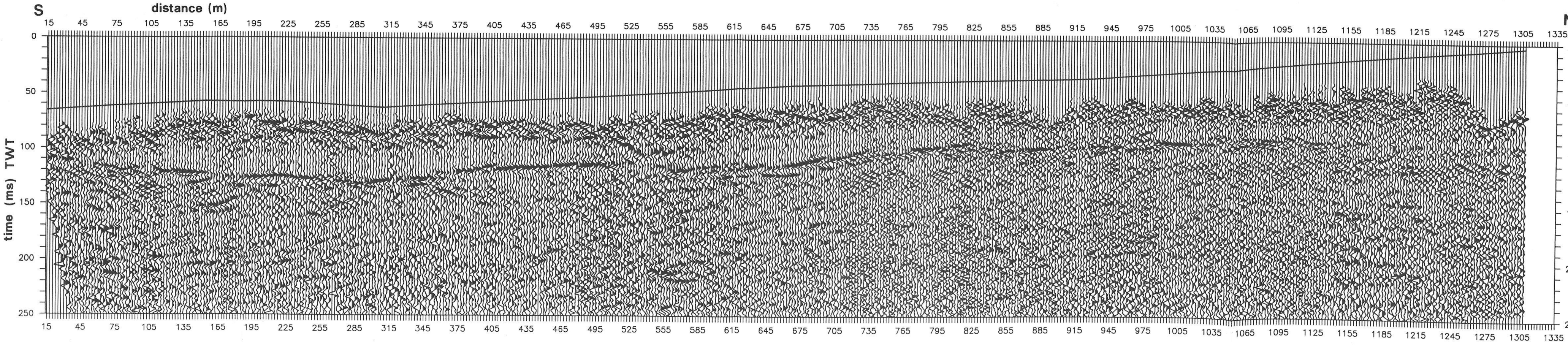
Plate 1. Ecoteaux, profile P2 and line drawing. Trace polarity is SEG-reversed, gain is 2,5. Datum plane for static corrections is 770 m.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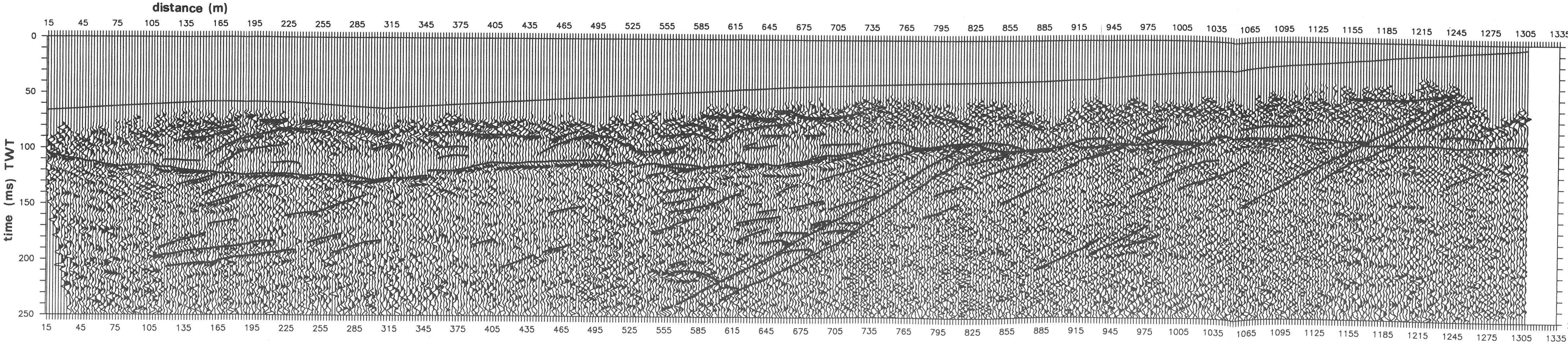
distance (m)
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0 50 100 150 200 250