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Autor: Finckh, Peter / Frei, Walter

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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[1])

By PETER FINCKH and WALTER FREI[2])

ABSTRACT

Seismic reflection surveying at several locations in the Rhone valley above Lake Geneva (Switzerland) reveals the bedrock form as eroded by glaciers in the Quaternary as well as some internal structures of the Quaternary sediments. Maximum sediment thickness near Lake Geneva is about 1 km, which is in drastic discrepancy to gravimetric investigations in this region which predicted about 420 m. In the region of Turtmann the sediment thickness is in the order of 400 m which agrees much better with the gravimetric model of 300 m. The usefullness of reflection seismology for solving small-scale problems and for high resolution surveys is discussed.

ZUSAMMENFASSUNG

Reflexionsseismische Untersuchungen an verschiedenen Orten im Rhonetal oberhalb des Genfersees zeigen Talformen, welche auf quartäre Gletschererosion hinweisen. Weiter werden auch sedimentinterne Strukturen der Talfüllung sichtbar. Die maximale Mächtigkeit der Quartärsedimente beträgt in der Nähe des Genfersees etwa 1 km, was im Widerspruch zu gravimetrischen Untersuchungen in diesem Gebiet steht, welche etwa 420 m voraussagten. Im Gebiet von Turtmann ist die Talfüllung etwa 400 m mächtig, ein Wert der besser mit den gravimetrischen Modellen (300 m) übereinstimmt. Im Weiteren wird die Anwendbarkeit der Methode der Reflexionsseismik zur Lösung von lokalen und kleinräumigen Fragestellungen und für hochauflösende Untersuchungen besprochen.

Introduction

The method of reflection seismology developed for hydrocarbon exploration was for many years not accessible to universities mainly for financial reasons. This however changed in the decade of 1980 when reliable field instrumentation became available at reasonable prices and when the computing facilities at some universities were adapted to the special requirements for seismic data processing. It became possible for universities to investigate the earth with much higher resolution and some fundamental questions and themes can now be adressed.

In 1983 a 24 channel field recording system was acquired by the Institute of Geophysics at the Federal Institute of Technology (ETH) in Zürich. With this instrumentation first experiments could be made. In 1985 the number of recording channels was expanded to 48 which greatly improved the efficiency of field work. In 1986, the Swiss

[1]) Contribution No. 659 of the Institute of Geophysics, ETH Zürich.

[2]) Institute of Geophysics, ETH Hönggerberg, CH-8093 Zürich, Switzerland.

national research programme Nr. 20 (NFP 20) was set up with the purpose of investigating the deep geological structure underneath Switzerland. At the same time processing facilities were installed at the Institute of Geophysics at ETH Zürich as well as at the University of Lausanne at the site of the Federal Institute of Technology in Lausanne. During the extended field work for NFP 20 the 48-channel recording system was intensively used for complementary lines. Some of these lines were recorded to provide the essential static corrections for the program's main Vibroseis lines across areas of thick Quaternary sediments. Others were shot to test the lateral continuity of structures revealed beneath the main lines.

The experiment carried out in October 1983 as well as two lines shot as part of NFP 20 in 1987 along the western traverse are all situated in the Rhone valley above the Lake of Geneva. The earlier line lies in the northwestern part of the Rhone valley just south of Lake of Geneva, between the villages of Roche and Vouvry (Fig. 1). The two other lines are closely spaced in the middle part of the valley near Turtmann and Agarn, respectively. All three lines traverse the valley and thus permit to determine the geometry of the reflective hard bedrock underlying the softer and looser Quaternary sediments. It is the purpose of this paper to show the structures of the sediment fill of the Rhone valley at the two different locations as revealed by seismic reflection profiling.

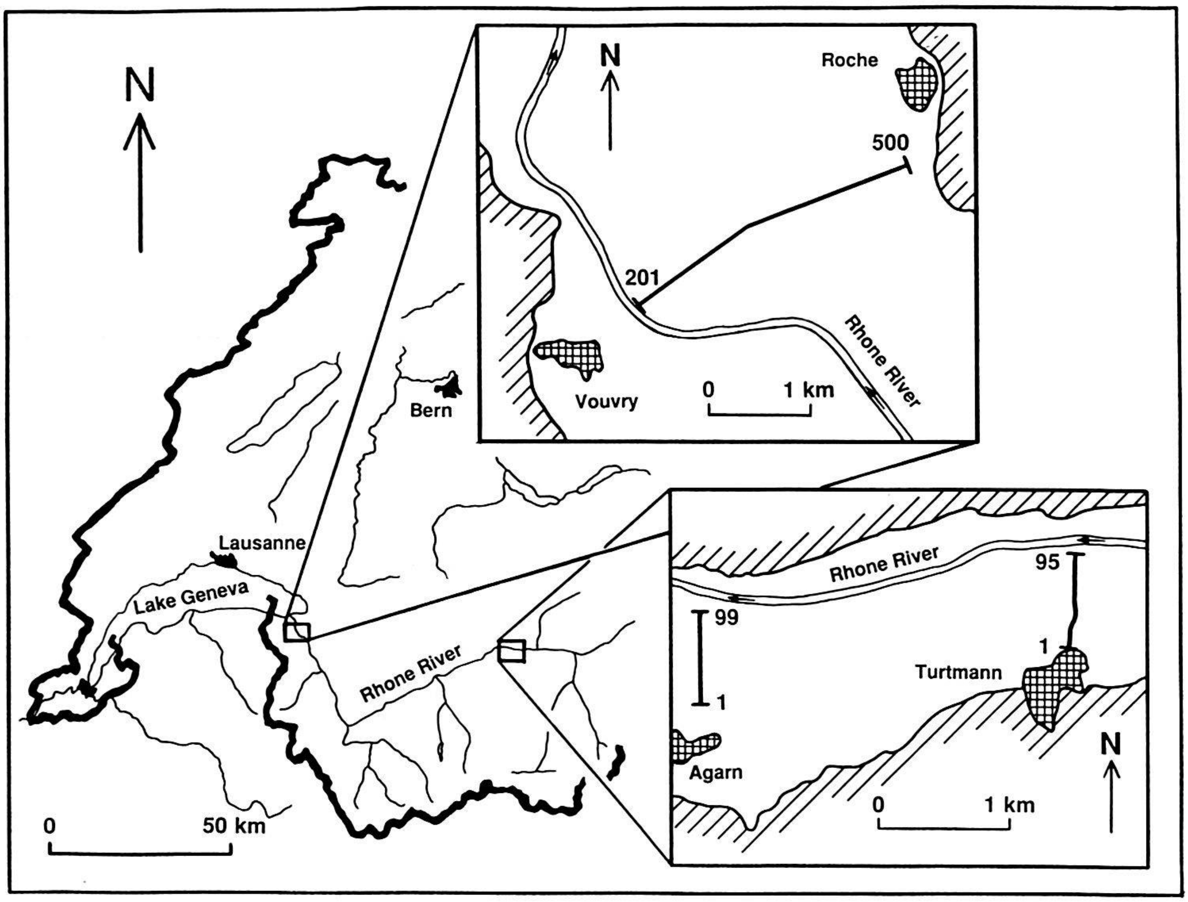

Fig. 1. Map of western Switzerland indicating the Rhone river and its major tributaries. The insets shows the areas of the surveys and the emplacement of the seismic lines with their respective CDP numbering, the hatched border lines show the boundary of outcropping bedrock. The cross-hatched areas represent towns or villages.

Geological and geophysical setting

Both areas under investigation are situated in a major alpine valley (Fig. 1), which to a great extent was formed by glacial erosion during the Quaternary. In the case of the Roche-Vouvry line this erosion took place perpendicular to the large complex structures of the nappes of the "préalpes médianes". These are underlain by Tertiary Flysch and Molasse units which themselves overlie the autochthonous Mesozoic limestones (GONET 1965). The exact depths of these boundaries are not known. However, more recent investigations by FINGER & WEIDMANN (1987) and by PUGIN (1988) indicate considerable glacial oversteepening in this region. It is not clear whether the glacial erosional process and its location was guided by some tectonically weakened zone.

The glacial erosion in the Turtmann region, however, clearly follows the outline of the Pennine Front. Since the retreat of the last glaciation some 13,000 to 15,000 years ago, Quaternary sediments have been brought to the valley by the Rhone and its tributaries. These sediments consist of detrital clays, silts, sands and gravel. Particularly the mouth of the Rhone river has moved rather rapidly to the northwest to its present position due to the rapid infill. The thickness of the Quaternary sediments in these regions are known only approximately (FINGER & WEIDMANN 1987; PUGIN 1988), nor is known whether they contain internal structures. Boreholes in these regions are usually drilled to the depth of the commercial target, e.g. the water table, and thus give no further information.

Gravimetric measurements and interpretative modelling was carried out by GONET (1965) for the entire lower Rhone valley between St. Maurice and Lake Geneva. He predicted a depth of the glacial trough of about 420 m in the region of the Roche-Vouvry line, thus reaching a bedrock depth slightly below sea level. Greater depths have been predicted by FINGER & WEIDMANN (1987) based on unpublished seismic investigations. In the Turtmann/Agarn region similar work by BERNAUER & GEIGER (1986) resulted in a thickness of the Quaternary sediments of about 300 m, without any indications of internal structures.

Seismic field acquisition parameters therefore have to be selected appropriately for a given seismic recording system to obtain the desired horizontal and vertical resolution. The utilized technique of reflection seismology consists of an integrated concept of field acquisition and subsequent data processing. A concise description of this technique in the German language is given by SPRECHER (1987); a complete set of textbooks was published by SHERIFF & GELDART (1982). This paper will thus not repeat the description of the concepts used and will only point out special aspects, deviating from standard exploration procedures.

Field acquisition

a) The Roche-Vouvry line

The emplacement of the line across the Rhone valley was chosen, where along an easy driveable path about 80% of the valley could be encompassed (Fig. 1). This choice had also the advantage of being entirely on the territory of the Canton of Vaud, simplifying the procedure of permitting. Likewise a crossing of the Rhone river could be avoided and the line was 3.0 km long. In 1983 only explosive charges were available as a low-cost energy source, thus intensive permitting had to be done prior to field measurements. Permission of the Canton of Vaud and from each community passed through as well as of all land owners had to be obtained.

In order to obtain the best horizontal resolution a spacing of the geophone groups of 20 m was chosen. Each group consisted of 12 geophones with an equidistant spacing of 2 m for ground roll supression. At the time of recording the instrument was equipped with only 24 channels. Therefore to improve coverage (i.e. to obtain more reflecting energy) the shot point interval was set equal to the geophone group spacing. At each point 3 shots were fired with a charge of 150 g of safety explosives in one hole of about 1.5 m depth filled in with gravel. These 3 shots had an inline offset of −5, 0, and + 5 m respective to the geophone station peg and were stacked vertically during processing, i.e. summed to form a single record. This disposition should allow for improved ground roll suppression and increased energy input into the ground at low costs. The shots were fired electrically and triggered by the recording system.

The line was recorded in October 1983 from west to east, moving with the shots from the western end station along the line until 12 channels of the recording system were on either side of the shots (split spread configuration). This configuration was then moved from shotpoint to shotpoint (roll-along method) until the line reached the final eastern station and where the shots were moved again out to the end of the line. With this procedure a nominal coverage of 12 fold could be obtained along the major part of the line, except at both ends where it dropped linearly from 12 to single fold. The records of 2 seconds length were digitally sampled at the rate of 1 ms and stored on magnetic tape for subsequent processing.

b) The lines at Turtmann and Agarn

The Rhone valley in the region of Turtmann is considerably narrower, thus the expanded 48 channels recording system covered almost the entire width of the valley with a single spread and a trace spacing of 15 m. Extensive line displacement therefore could be avoided and the source moved through the stationary spread. In consequence the coverage at both ends is single fold and increases linearly up to 24 fold from both ends to the middle. Only 6 geophones were used per station, planted in line with a spacing of 2 m. The non-explosive impulsive energy source was a prototype model "P-shooter" of the French Compagnie Générale de Géophysique. It consisted of an accelerated weight-dropper of 100 kg mounted on an all-terrain vehicle. The acceleration force on the dropping weight is generated by two vacuum cylinders. The release of the drop is triggered by the recording system. Unfortunately the drop time varied slightly between 720 and 840 ms necessitating later zero-time adjustments. The source was operated four times at each geophone station for later vertical stacking after time adjustments. The data were sampled at 2 ms with a trace length of 4 seconds.

The recording of the Roche-Vouvry line took 5 days, mainly because of the safety procedures involved in the large number of explosive shots (450). The two lines at Turtmann and Agarn were recorded in two days only, showing the efficiency of non-explosive impact sources and multichannel systems.

Processing

a) The Roche-Vouvry line

The seismic data processing on the Roche-Vouvry data was made with the software package DISCO running on a VAX 11/780 at the University of Wyoming. This package contains all programs necessary for standard seismic data processing. The left hand side of Table 1 shows the processing steps which were adopted for the line Roche-Vouvry. The final Roche-Vouvry seismic section is shown in Figure 2. It is not migrated for geometric distortion.

- Demultiplex and gain recovery	- Demultiplex and gain recovery
- Data editing	- Bandpass filtering for ground roll suppression
- Vertical stacking of 3 shots per station	- Deconvolution for power line pick-up (50 and 16.6 Hz)
- Bandpass filtering for groundroll suppression	- Correction for drop time variations
- Notch filtering for power line pick up (50 and 16.6 Hz)	- Vertical stacking (4 records per station summed)
- Line geometry	- Line geometry
- Muting of first breaks	- Time variable bandpass filter and scaling
- CDP sorting	- Mute of first breaks
- Velocity analysis	- CDP sorting
- Normal move out correction	- Velocity analysis
- Bandpass filtering and scaling	- NMO correction
- CDP stacking	- CDP stacking
- Display of the final stacked section	- Migration for restoring real structures
	- Display of the final stacked section

Table 1: List of the adopted processing steps, in the left column for the line Roche-Vouvry, to the right for the lines at Turtmann and Agarn.

b) The Turtmann and Agarn lines

Financed by NFP 20 the Institute of Geophysics at ETH Zürich operates its own processing facilities since 1986 with the software package PHOENIX from Seismograph Services Ltd, UK, on a VAX 11/780, which is managed by the ETH computer center. Again a standard sequence of processing steps, given on the right side of Table 1, was applied to the data.

The stacked sections of the lines of Turtmann and Agarn are shown in Figures 4 and 5, respectively, in both the unmigrated and the migrated version for comparison.

Discussion

a) The Roche-Vouvry line

Figure 2 shows the unmigrated stacked section with 300 common depth points (CDPs) spaced at 10 m from west to east. The vertical axis is two-way travel time (TWT) in seconds, which with knowledge of seismic velocities can be converted to depth. Ideally a seismic section resembles a geological cross section, however, the basics of reflection seismology must be understood to be correctly interpreted. Seismic

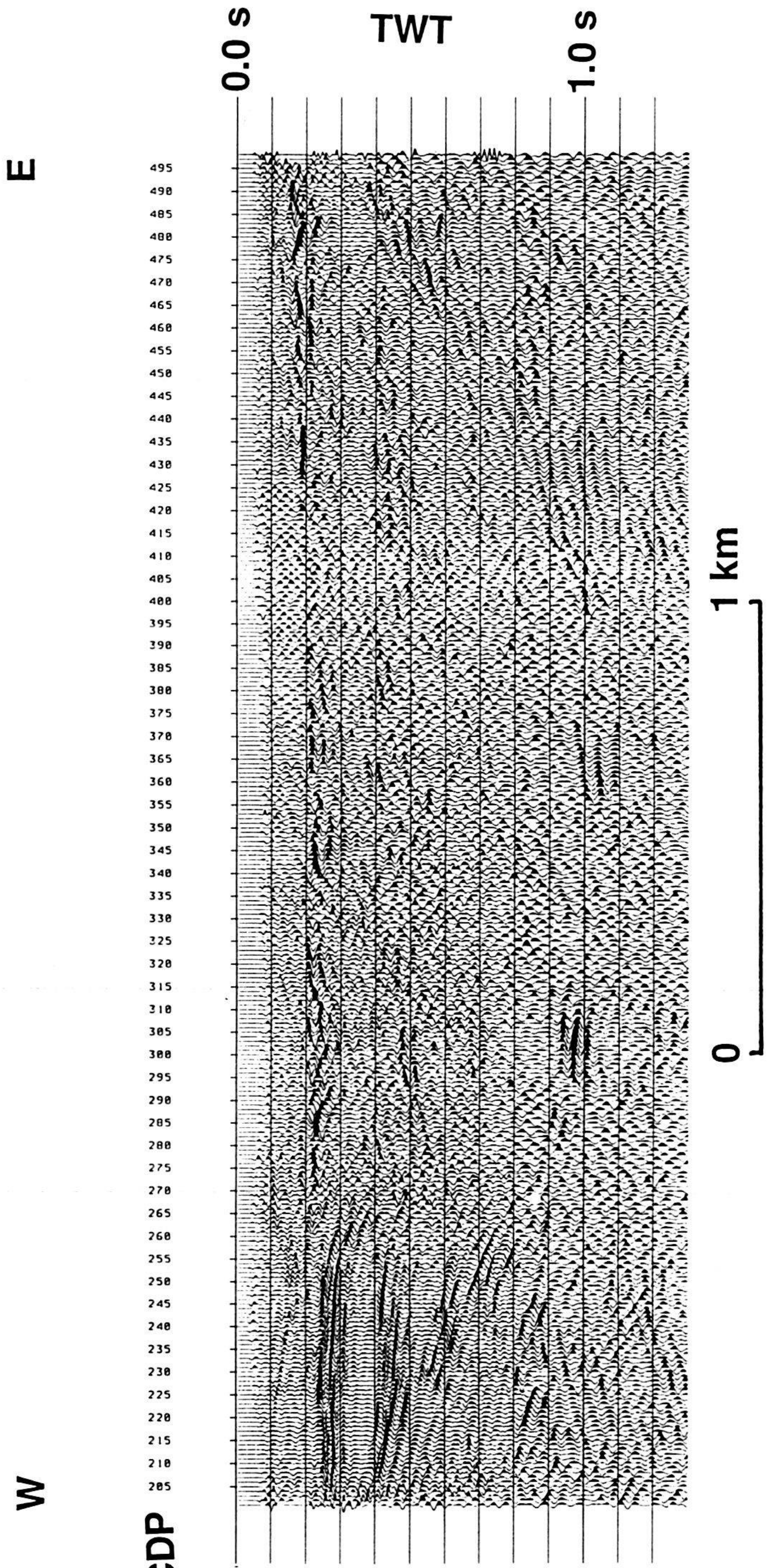

Fig. 2. Unmigrated seismic section of the line Roche-Vouvry. The 300 CDPs on the horizontal axis are spaced at 10 m, the vertical axis is two way travel time in seconds.

energy is reflected at boundaries where the acoustic impedance (i.e. the product of seismic velocity and bulk density) increases or decreases. This is marked on a seismic section with increased amplitudes, represented by large black areas, which vary with location (CDP) and depth (TWT). These boundaries must not necessarily be identical with stratigraphic layering or tectonic boundaries, but a good geological knowledge of the region considered helps the interpreter of a seismic section. Knowledge of other possible phenomena such as multiple reflections, side swipes, processing artefacts and geometric distortion is also necessary.

On Figure 2 on the left hand side (west) a fan of reflections which dips to the east is rather prominent between CDP 205–265 and TWT 0.1–0.8 s. Some energy returns occur at TWT of 0.85 to 1.1 s but they are less coherent. From CDP 270 to the end of the line some strong but not very coherent energy returns are obvious at TWT of 0.15 s to about 0.3 s. From CDP 285 to 310 some reflections are obtained at TWT of about 0.5 s and weaker at 0.7 s. Very prominent are the deep reflections between CDP 280 and 315 at TWT of 0.9 to 0.95 s and slightly weaker between CDP 355 to 375 at a TWT of about 1.0 s. Further coherent energy returns can be noted from CDP 310–470 with TWT between 0.3 s and 0.75 s. Coherent updip reflections appear between CDP 400 at a TWT of 1.0 s and CDP 490 at 0.38 s. The updip reflections between CDP 200 and 250 between TWT from 1.05 to 0.9 s and deeper are discarded from further considerations since the section is not migrated. With migration this energy most likely would collapse into the reflections at CDP 255 and a TWT of 0.89 s. Practically no energy is to be observed in the topmost 0.1 s TWT over the entire length of the section. This is due to the fact that when muting for the first break arrivals, possible shallow reflections are zeroed out. There is no evidence for multiple reflections or lateral echoes.

To determine the reflecting boundary between Quaternary sediments and the Tertiary or Mesozoic bedrock the possible range of the velocity contrast must be considered. Water-saturated Quaternary sediment velocities may vary from 1.5 to 2.3 km/s as determined seismically in a large number of perialpine lakes (Finckh et al. 1984). Laboratory measurements of sonic velocities on cores from a borehole in Lake Zürich show similar values with the strong correlation of the higher values with a higher degree of compaction, probably caused by glacial overriding (Heim & Finckh 1984). On the other hand the Tertiary or Mesozoic bedrock, consisting mainly of completely cemented sediments would have a velocity easily exceeding 4 km/s (Press 1966; Finckh et al. 1984). Reflectivity considerations suggest that at this boundary most of the energy would be sent back to the surface and little would penetrate further into the subbottom. Therefore, it is likely that the strong reflections between CDP 280–315 and CDP 355–375 at TWT between 0.9 and 1.0 s represent reflections from the sediment/bedrock interface. It is highly unlikely to obtain reflections from within the bedrock due to the complex structures and the weak seismic source utilized. From these two lowermost reflective segments the bedrock boundary can be traced to either side, revealing a U-shaped valley form, typical for glacially eroded troughs. This U-shape is actually even more pronounced since a migration would steepen the lateral slopes and move them to the sides and thus widen the flat bottom part. In order to obtain the thickness of the Quaternary sediments it is necessary to convert the travel time of the bedrock reflections into depth with the help of a reasonable velocity. In the

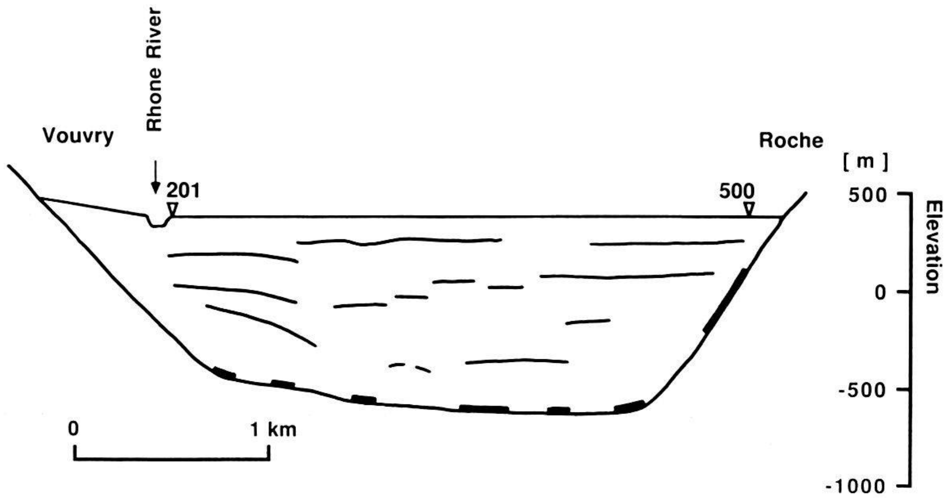

Fig. 3. Cross section of the Rhone valley along the line Roche-Vouvry showing bedrock geometry and some internal sediment structures. The thick lines along the bedrock outline correspond to reflections which were converted to depth using the appropriate stacking velocity. Note the assymetry of the U-shaped valley form.

course of data processing normal move-out (NMO) velocity analysis was performed which provides a velocity versus TWT function for a certain number of CDPs with the most coherent stack. This NMO velocity (or also stacking velocity) is not identical with the sonic velocities discussed above, although there is a certain relationship (for details see e.g. Cordier 1985). However it allows for the time-to-depth conversion since it represents the average velocity with which the seismic waves travel from the source, at the surface, to the reflecting horizon and back. The best stacking velocities obtained for the depth of about 1.0 s TWT is between 1.9 and 2.0 km/s. Thus at CDPs 360 and 400 the sediment thickness is just about 1.0 km which drastically contrasts with the value of 420 m by Gonet (1965), but is in fair agreement with Finger & Weidmann (1987) as well as with Pugin (1988). It will be the purpose of the second part of this paper by Finckh & Klingelé (1991) to investigate this gravimetric discrepancy.

Using the stacking velocities versus TWT function it is thus possible to reconstruct the real shape of the bedrock as well as the true geometric positions of the internal reflectors. This reconstruction is shown as trace drawing in Figure 3, representing a cross section of the Rhone valley between Roche and Vouvry, including the outcropping slopes of the bedrock. The bedrock slopes have been manually migrated to restore their true geometry. The fan-like structure near Vouvry probably corresponds to delta structures of the Fossau creek, a tributary to the Rhone.

b) The lines at Turtmann and Agarn

A similar approach and similar considerations are used to discuss and interpret the lines of Turtmann and Agarn shown in Figures 4 and 5 respectively. Both lines are shown in their unmigrated and migrated versions to show the effect of geometric dis-

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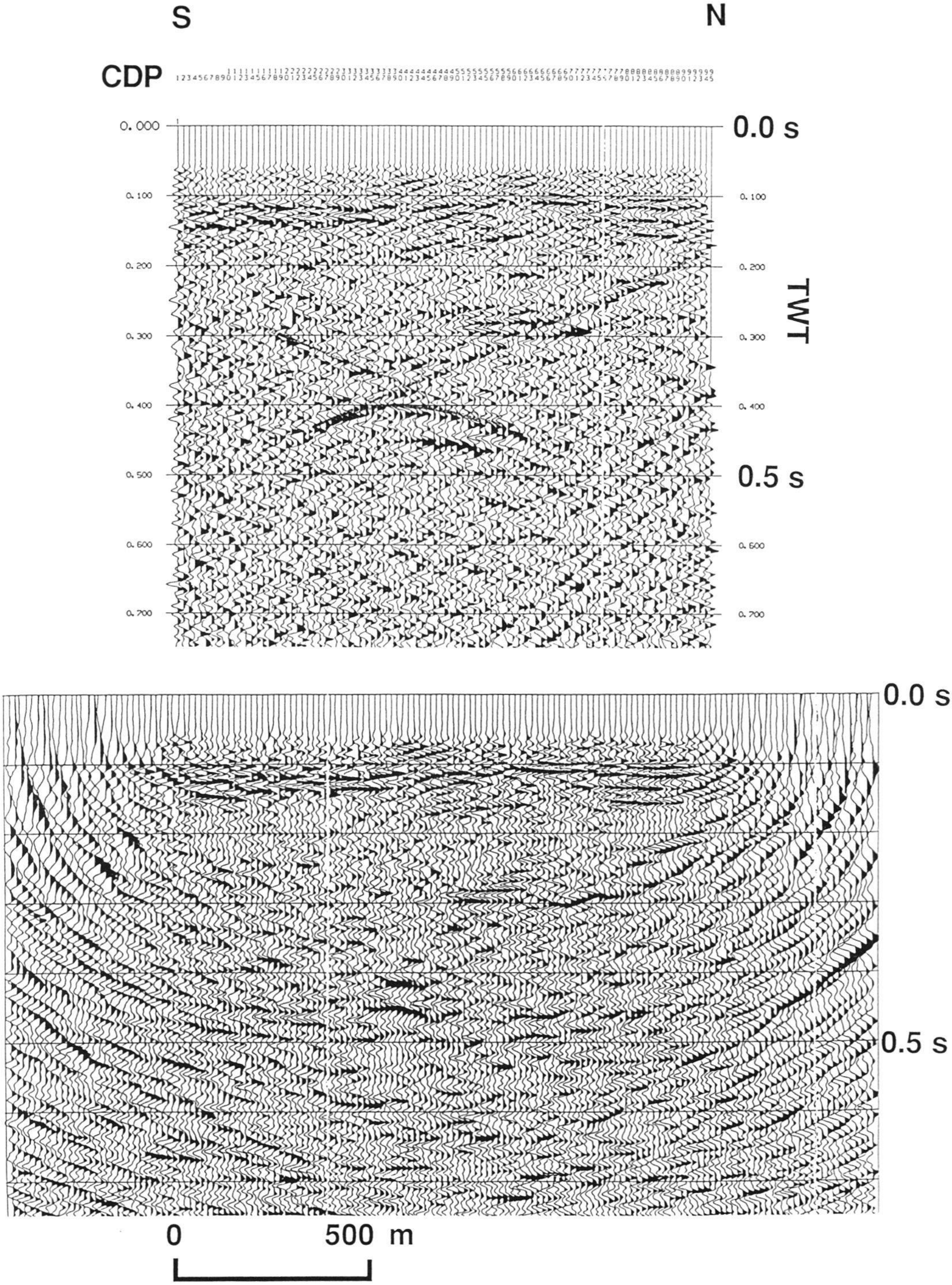
Fig. 4. Unmigrated (top) and migrated (bottom) seismic section of ther line at Turtmann. CDP spacing is 10 m. Note the bow-tie structure in the unmigrated section which collapses into a clear reflection in the migrated section.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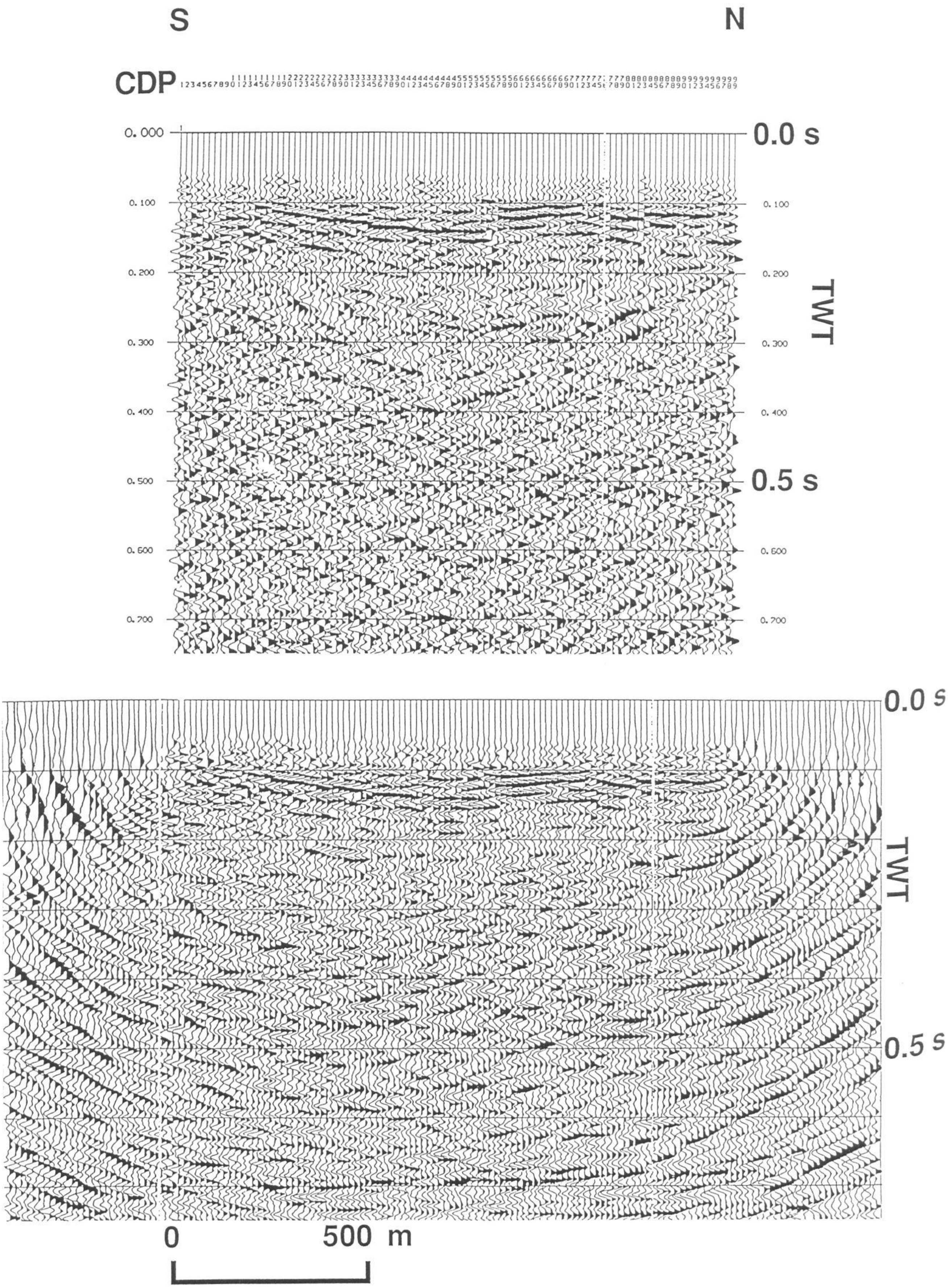
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tortion and its removal. The line of Turtmann in Fig. 4 before migration (top section) shows less distinct reflections when compared to the line Roche-Vouvry. Again in the uppermost 0.1 s TWT no distinct reflections are to be seen due to muting. However, clear, although not very coherent reflections, are obvious between 0.1 and 0.2 s TWT over the entire section. Further down, at about 0.28 s TWT, some energy returns can be seen between CDP 48 and 75. Very noticeable are the signals forming a double arc between CDP 24 and 70 with the apex at CDP 40 and a TWT of 0.41 s. This is almost a textbook example of a bow-tie structure indicating the necessity to migrate the section to restore true geometries. After migration with a velocity model with 80% of the stacking velocities the picture is considerably improved as shown in the bottom section. The hyperbolic arc has collapsed into a horizontal reflection between CDP 40 and 49 at 0.41 s TWT, originating from the strongly reflecting sediment/bedrock boundary. Some internal structures become visible between CDP 50 and 95 between TWT of 0.2 and 0.3 s. Some coherent wiggles can also be made out at CDP 6–25 at a TWT of about 0.2 s. Altogether the migrated section shows more structures and less noise than the unmigrated section. It is not quite clear whether the absence of any well defined sedimentary structure is due to the lack of energy of the seismic source or whether there are no such reflecting structures. Note that the migrated section is wider by 30 traces on either end which is necessary to allow the migration of events out of the original line.

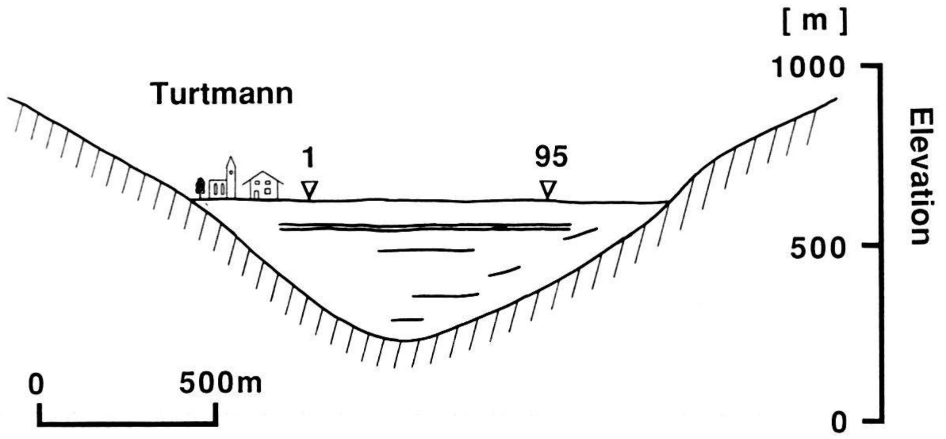
Again this section now can be used for a geometrical reconstruction into depth instead of travel times. This is shown in Figure 6 (top section). The shape of the bedrock does not clearly have a U-form and the sediment thickness amounts to about 400 m.

Much the same can be said about the Agarn line before and after migration except that the bow-tie structure before migration is not clear. After migration however the reflections from the bedrock sides are more clearly visible, particulary between CDP −5 and +20 in the lower section of Figure 5 at an increasing TWT from 0.23 to 0.36 s. Time-to-depth conversion indicates a sediment thickness again of about 400 m. Geometric reconstruction (Fig. 6, bottom section) shows a smooth, round bedrock shape, which is more in accordance with glacial erosion.

Conclusions

This contribution shows that the tool of reflection seismology developed for hydrocarbon exploration can also be applied to smaller scale studies such as resolving Quaternary valley fill and some internal structures. The lines presented here reveal these structures and bedrock forms with unprecedented precision. This technique can be brought to the scale of engineering problems if the necessary care is taken in field work and in the subsequent data processing. The recent technological development of the recent years brought less expensive portable field instruments onto the market and the number of available channels is increasing. A similar evolution is taking place with seismic data processing systems. Moreover, an increasing number of non-explosive

Fig. 5. Unmigrated (top) and migrated (bottom) seismic section of the line at Agarn. CDP spacing is 7.5 m.



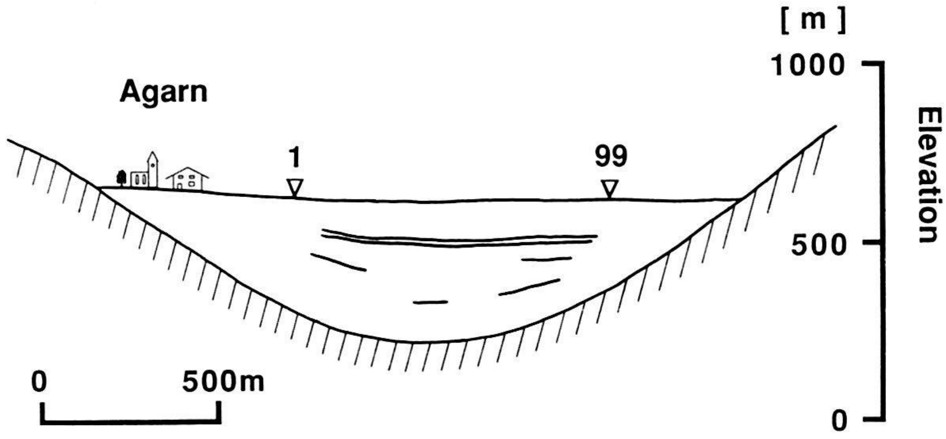


Fig. 6. Cross-sections of the Rhone valley near Trutmann (top) and Agarn (bottom) and the location of the respective lines. The bedrock forms are shown as well as some internal sediment structures.

seismic sources are appearing on the market, a fact which reduces the problems of permitting and handling explosives. In order to improve the resolution of such surveys some efforts can be made such as to reduce the geophone station spacing to 2, 3,5 or 10 m, to decrease the sampling rate to fractions of milliseconds (for recording higher frequencies) and to eliminate low frequencies during recording by adequate field filters or by utilizing high-frequency geophones. In conclusion we believe that reflection seismology will become a practical tool to solve coming geological, environmental and engineering problems.

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