Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 84 (1991)

Heft: 2

Artikel: Seismic reflection profiling in the Swiss Rhone valley. Part 2, Gravimetric and geological interpretation of the Roche-Vouvry line

Autor: Finckh, Peter / Klingele, Emile

DOI: https://doi.org/10.5169/seals-166779

Eclogae geol. Helv. 84/2: 359–368 (1991) 0012-9402/91/020359-10 $ 1.50 + 0.20/0
Birkhäuser Verlag, Basel

Seismic reflection profiling in the Swiss Rhone valley

Part 2: Gravimetric and geological interpretation of the Roche-Vouvry line[1]

By PETER FINCKH and EMILE KLINGELÉ[2]

ABSTRACT

Stacking velocities obtained in the course of seismic data processing of the seismic reflection line Roche-Vouvry in the Swiss Rhone valley were used to derive seismic interval velocities for the Quaternary valley fill. They range between 1,300 and 2,400 m/s. A velocity versus density correlation from laboratory measurements on core samples from the Quaternary sediments of Lake Zürich was then used to derive the density-depth distribution in the Rhone valley fill, resulting in densities for the deeper sediments ranging between 2.0 and 2.4 g/cm^3. Subsequent gravimetric modelling with these high densities fitted the model values to the field measurements, while taking account for the seismically determined bedrock depth of 1,000 m. The correlation of petrophysical parameters such as seismic velocities, bulk densities and water content with lithological properties such as sedimentary compaction and deformation derived from the Lake Zürich drilling allowed for a geological interpretation of the Rhone valley fill showing uncompacted and compacted sediment packages. Clear seismic reflections near Vouvry reveal a fluvial delta structure and less coherent reflections near the bedrock are interpreted as ground moraines.

ZUSAMMENFASSUNG

Die aus der Datenverarbeitung der seismischen Linie Roche-Vouvry im Schweizerischen Rhonetal erhaltenen Stapelgeschwindigkeiten wurden benutzt, um die Intervalgeschwindigkeiten der quartären Talfüllung abzuleiten. Sie variieren zwischen 1300 und 2400 m/s. Eine Geschwindigkeits-Dichte-Relation, welche aus Labormessungen an Proben der Quartärsedimente des Zürichsees erstellt wurde, wurde benutzt, um die Dichte-Tiefenverteilung der Talfüllung im Rhonetal abzuleiten. Die Dichtewerte für die tieferen quartären Sedimente liegen zwischen 2.0 und 2.4 g/cm^3. Anschliessende gravimetrische Modellrechnungen mit diesen hohen Dichtewerten brachten die Modellrechnungen mit den gravimetrischen Feldmessungen und der seismisch bestimmten Tiefe des Felsuntergrundes von 1000 m zur Übereinstimmung. Die Korrelation von petrophysikalischen Parametern wie seismische Geschwindigkeiten, Dichte und Wassergehalt mit aus der Zürichseebohrung abgeleiteten lithologischen Eigenschaften wie Sedimentkompaktion und -deformation gestatten eine geologische Interpretation der Füllung des Rhonetals, welche nicht kompaktierte und kompaktierte Sedimente enthält. Deutliche seismische Reflexionen bei Vouvry zeigen fluviale Deltastruktur und weniger kohärente Reflexionen knapp oberhalb des Felsgrundes werden als Grundmoräne interpretiert.

Introduction

Seismic reflection surveying in two areas of the Swiss Rhone valley south-east of Lake Geneva reveal thicknesses of the Quaternary sediment infill, which exceed the values predicted by gravimetric modelling (FINCKH & FREI 1991). In the region of Roche-Vouvry the gravimetrically derived maximum bedrock depth of about 420 m by

[1]) Contribution No. 660 of the Institute of Geophysics, ETH Zürich.
[2]) Institute of Geophysics, ETH Hönggerberg, CH–8093 Zürich, Switzerland.

Gonet (1965) contrasts with the seismically determined value of just about 1,000 m. In the Trutmann/Agarn region the discrepancy is somewhat less with values of 300 m derived by gravimetry (Bernauer & Geiger 1986) opposing seismic values of 400 m. The most likely source of this discrepancy is the density distribution in the valley fill assumed in the gravimetric modelling. Gonet (1965) used a value of 1.9 g/cm^3 for the topmost 30 m and of 2.0 g/cm^3 below. Bernauer & Geiger (1986) used a value of 2.1 g/cm^3 for the entire Quaternary infill. Obviously a smaller contrast between bedrock density and infill would allow for greater Quaternary thicknesses in the gravimetric modelling. A bedrock density of 2.67 g/cm^3 was used in both papers as well as in the present work.

Seismic velocities of rocks can be related to rock densities within a certain error margin (e.g. Woollard 1975). Such a relationship is often used for crustal rocks in isostatic modelling (e.g. Bernauer & Geiger 1986) whereas this relationship is not very reliable for low-velocity sediments. It is the purpose of this paper to utilize a velocity-density relationship determined for detrital Quaternary sediments to compute a new model for the density versus depth distribution in the region of the Roche-Vouvry seismic line where the internal velocity distribution can be obtained from stacking velocities. New model calculations should bring about a reduction of the discrepancy between seismic and gravimetric results in this region. Because the Quaternary valley fill of the lines at Trutmann and Agarn does not show very distinct internal reflections stacking velocities were mainly derived for the bedrock reflections. They obviously show considerable slopes Finckh & Frei 1991, Fig. 6) and no attempt to determine a new gravimetric model was made. In the light of the velocity and density models a geological interpretation of the Quaternary infill is attempted.

Gravimetric interpretation

General

Gravimetric modelling generally has two well defined purposes which are basically opposed to each other. The aim is either to determine the geometric parameters of one or several structures starting from a density hypothesis, or, to determine the densities starting from known shapes and structures. Because the seismic survey offers information on both the structures and on density distribution the present case of the line across the Rhone valley at Roche-Vouvry represents a combination of the two approaches.

From seismic reflection surveying it is possible to obtain the interval velocities versus depth distribution in a number of locations (CDPs) along the line. The difficulty resides in the fact that the velocity-density relationship is not unequivocal and that the resulting vertical density distribution results in gravimetric models that are far too complicated. The interpreter thus must work with the geometric parameters as well as with the density models to bring them into agreement.

Velocity-density relationship

In the course of seismic data processing, stacking velocity versus travel time functions were obtained at 5 CDP locations along the line Roche-Vouvry. Using the standard Dix formula (Dix 1955) these V-T functions can be converted to V-Z functions of the interval velocities vs. depth at these locations. The interval velocity is the average velocity of the depth interval in the subsurface between two reflections, i.e. a seismic layer, which represents a usefull petrophysical parameter. The most important limitation to the application of this formula is that the layering must be horizontal, only very weak dips are tolerated (for more details see Cordier 1985). However a look at Figure 3 in Finckh & Frei (1991) shows that with the exception of the fanlike structures near Vouvry this condition is most nearly fulfilled in the east-west direction. Even the upper fan reflections are subhorizontal and thus lead to a neglegible error for the interval velocity. In the direction of the axis of the Rhone valley not much is known about possible dips, however, since this is the direction of water-flow and of sediment deposition. Therefore, it can safely be assumed that in the north-south direction there is horizontal to subhorizontal layering. This assumption is further supported by the fact that the CDP stack reveals structures within the sediments. If the layering would not be horizontal the seismic energy would reflect laterally out of the recording spread. Likewise the function of the interval velocity vs. depth can be established at several locations along the line with some small errors due to small dips at the western end of the line. The derived interval velocity values are in the range between 1,300 m/s and 2,400 m/s.

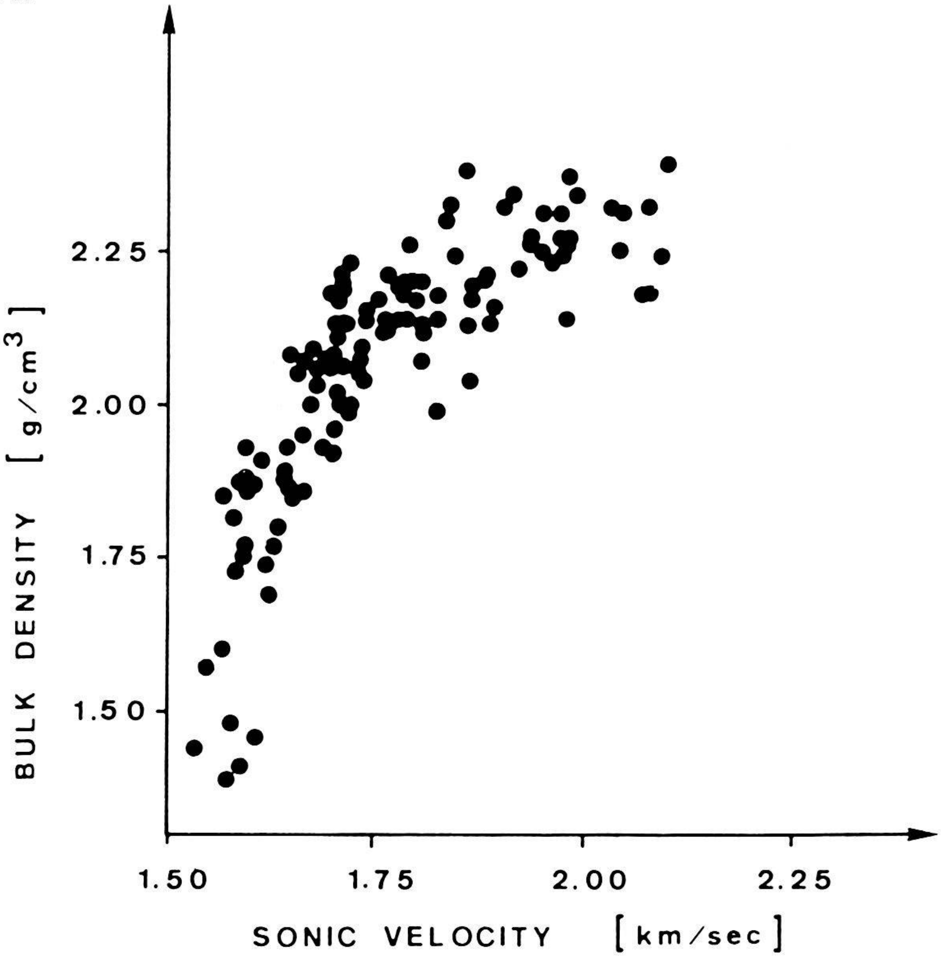


Fig. 1. Correlation between sonic velocity and bulk density from laboratory measurements on samples of unconsolidated sediments of Lake Zürich (from Heim & Finckh 1984).

For converting velocities to density values the function given by WOOLLARD (1975) is not reliable in the range of the interval velocities obtained. A more representative relationship is given by HEIM & FINCKH (1984), shown in Figure 1, which was derived from very detailled sonic velocity and density measurements on cores from a drillhole through the Quaternary sediments of Lake Zürich. The conditions of sedimentation in the Rhone valley are similar to those in the Lake Zürich basin, both regions showing a strong glacial overprint. Since the last glaciation the sedimentation regime first was fluvioglacial, changing to fluviolacustrine with the further retreat of the glaciers. The sediments in both basins are mainly detritic, with muds and oozes as well as sandy or gravelly layers. This similarity between the two basins allows the application of the velocity-density relationship from Lake Zürich to the problem of the Rhone valley.

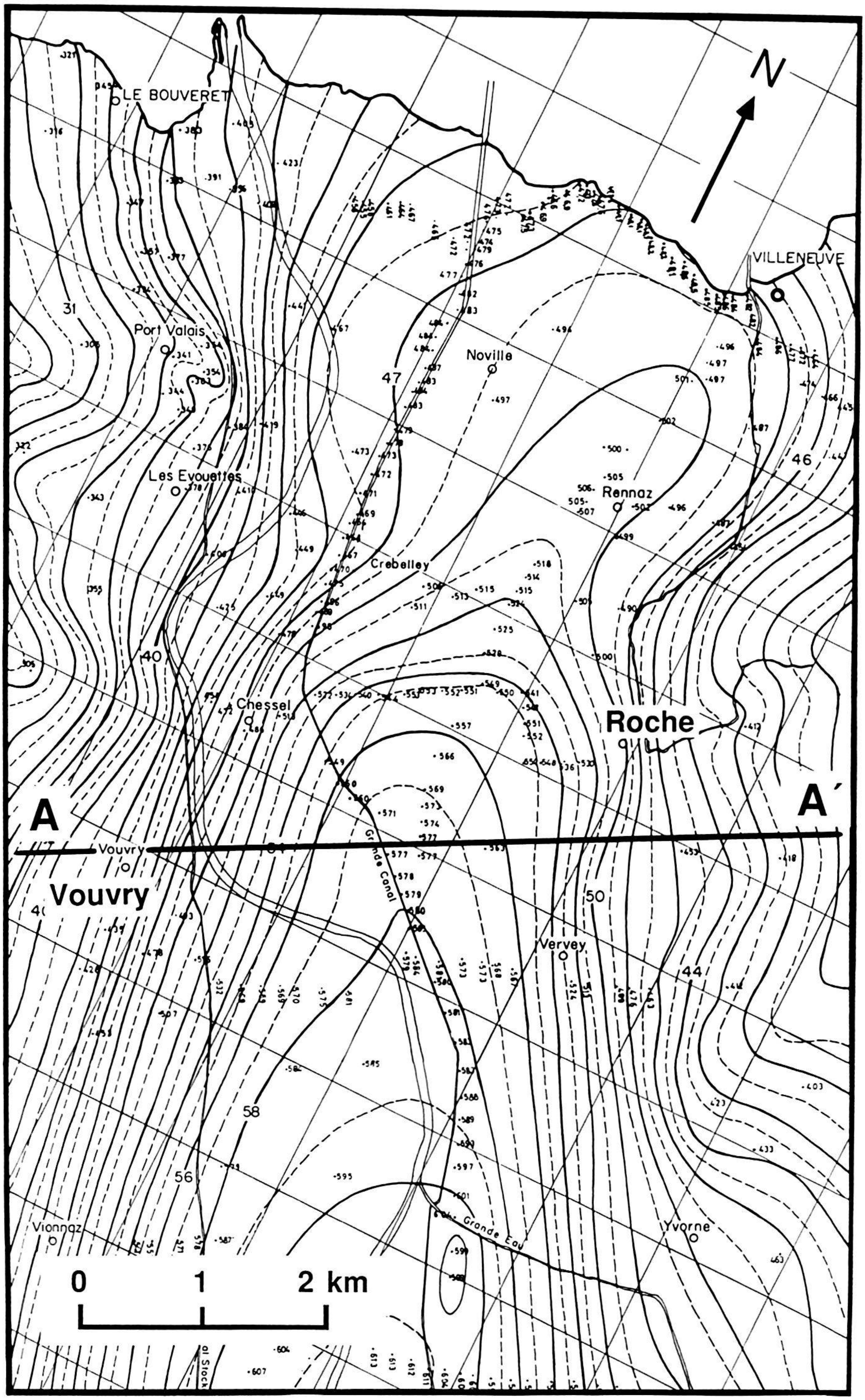
Figure 1 shows a certain scatter in the velocity vs. density distribution. Therefore an average density was picked from the middle of the range for each interval velocity for the determination of the density vs. depth distribution. Table 1 shows the values of the derived velocity vs. depth and density vs. depth model for 5 CDP locations along the line Roche-Vouvry.

CDP 210			**CDP 277**			**CDP 337**			**CDP 397**			**CDP 456**		
d	V	ρ	d	V	ρ	d	V	ρ	d	V	ρ	d	V	ρ
m	km/s	g/cm³	m	km/s	g/cm³	m	km/s	g/cm³	m	km/s	g/cm³	m	km/s	g/cm³
65	1.300	1.3	78	1.300	1.3	130	1.300	1.3	130	1.300	1.3	225	1.500	1.3
51	2.070	2.2	110	1.470	1.4	103	2.070	2.1	130	1.730	1.9	196	1.950	2.2
98	1.950	2.2	268	2.150	2.2	67	2.100	2.4	243	1.950	2.2	363	2.400	2.4
278	2.200	2.3	527	2.200	2.3	682	2.600	2.2	476	2.380	2.4			

Table 1: Selected CDP locations where stacking velocity analyses were performed with the resulting layer thickness d, the corresponding interval velocity V and the picked density ρ. The given density versus depth distribution is the initial gravity model which was iteratively modified until a best fit was obtained.

Note that the density in the deeper part of the basin often has values greater than 2.1 g/cm^3 with maximum values of 2.4 g/cm^3. Single measurements by EBERLI (1984) show values of 2.5 g/cm^3 and larger; they stem from the highly compacted muds in the lower parts of the drillhole and support the fact that the density values assumed in earlier gravimetric modelling were too small.

Fig. 2. Gravimetric map of the Rhone valley between St. Maurice and the mouth of the Rhone into Lake of Geneva. The total gravimetric anomaly is shown. The line AA′ indicates the location of the cross section and the seismic profile Roche-Vouvry (from GONET 1965).


N
LE BOUVERET
VILLENEUVE
Port Valais
Noville
Les Evouettes
Rennaz
Crebelley
Chessel
Roche
A
A´
Vouvry
Vouvry
Grande Canal
Vervey
Vionnaz
Grande Eau
Yvorne
31
47
46
40
50
44
58
56
0
1
2 km

Gravimetric modelling

Using the density versus depth information shown in Table 1, a density distribution was constructed for the sediment infill underneath the seismic line. This 2D-model was extrapolated to the east and west into the outcropping bedrock assuming the most probable densities. By comparison of the calculated with the observed gravity anomaly

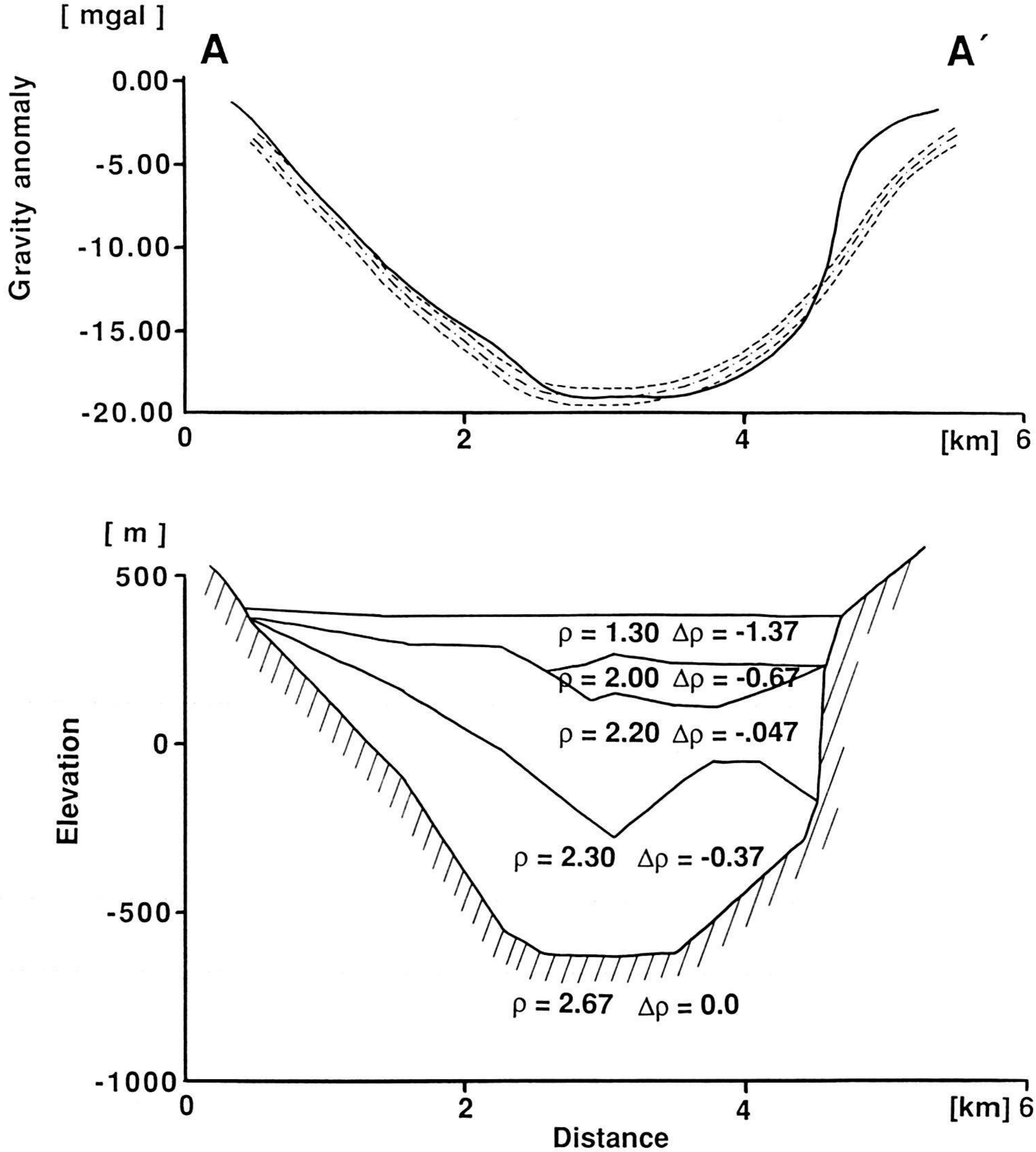


Fig. 3. Top: Calculated (thick line) and measured gravimetric (dashed band) anomaly due to the Quaternary infill along the cross section AA′ with reduced density. The width of the dashed band indicates the error band width of the field measurements after regional corrections. Bottom: Final model of the density distribution for the Quaternary valley fill along the cross section AA′ in Figure 2. Vertical exageration 2.5 fold.

the model was iteratively altered until a best fit was obtained. In consequence the density boundaries may have shifted somewhat horizontally and vertically and no longer correspond to possible seismic reflections. This model is shown at the bottom of Figure 3. The top of Figure 3 shows the calculated gravimetric effect of this structure in a thick line and for comparison the gravimetric anomaly is shown by the dashed triple line. The later data were obtained from a cross section AA′ of the Bouguer anomaly map of the Rhone valley given by GONET (1965) and shown in Figure 2. It is corrected for the regional isostatic field of −32 mgal, a value also given by GONET (1965). This cross section coincides with the seismic line Roche-Vouvry.

A comparison between the Bouguer anomalies produced by GONET (1965) and KLINGELE & OLIVIER (1980) shows differences ranging from 56 mgal to 60 mgal. This can be explained by the fact that the reference ellipsoids are not the same in the two works. GONET (1965) used an Elmert Ellipsoid with no absolute reference whereas KLINGELE & OLIVIER (1980) based their computation on the Swiss gravity net and on the International Ellipsoid. Beside this, some discrepancies remain especially at the flanks of the valley. These can be attributed to differences in topographic corrections applied in the two works. However, a more detailed check of the data has shown that in the central part of the Roche-Vouvry profile the discrepancies do not exceed 1 mgal.

The accuracy of the gravity residuals thus derived from Figure 2 is about ± 0.5 mgal due to intrinsic errors, the hand drafting of the map and the absence of measurements in the eastern part of the cross section. This error is indicated by the triple dashed band at the top of Figure 3.

The comparison of the two curves at the top of Figure 3 shows good agreement except in the eastern part of the profile where the model result deviates by about 4 mgal. This discrepancy might stem from the fact that at the place of the profile a small local gravimetric axis with a negative value is present and thus the slope of the residual curve is too gentle (see Fig. 2). On the other hand the excess of the model curve at this point might perhaps be caused by the very steep bedrock wall at the eastern end of the profile. If the topmost layer with a density contrast of -1.37 g/cm^3 extends into the loose sediments of the slope covering the bedrock, the calculated curve would reveal a smoother shape. However, there is no further information from the seismic section to design the gravimetric model more precisely and the boundary effect at the contact of the sediments with the bedrock wall remains.

Discussion

Gravimetric modelling using a density vs. depth distribution derived from laboratory measurements on lake sediments and seismic surveying show good agreement with the observed gravimetric anomaly. Also the sediment structure with a maximum thickness of about 1,000 m and the bedrock topography as derived from the seismic section agree with the density distribution. This agreement of seismic surveying and gravimetric investigations is due to the fact that in the lower part of the sediment infill densities of 2.2 and 2.3 g/cm^3 were entered into the gravimetric model. Such high densities for unconsolidated Quaternary sediments are somewhat unusual and gravimetric modelling hesitates to use such high values (e.g. BERNAUER & GEIGER 1986; GONET 1965). The work by EBERLI (1984), however, shows clearly that such high values are not unreasonable and may constitute a realistic range of density values for the lower part of Quaternary valley fills.

Geological Interpretation

We now attempt a complete geological interpretation of the reflection structures shown in the seismic section and tentatively derive some petrophysical implications from stacking velocities. This interpretation must be consistent with the main geological setting of Quaternary glacial and postglacial valley fills in the alpine environment.

With this condition in mind the attempt is made to combine the purely seismic structures shown in Figure 3 of Finckh & Frei (1991) with the density and interval velocity information discussed above. The density distribution from the best gravimetric fit is shown in Figure 3 at the bottom. Both figures show in their western part features dipping to the east, i.e. reflecting structures as well as increased depth of the density boundaries. In the middle and eastern part they show a complexity in the reflection events as well as varying thicknesses of the density layers, but altogether the reflections are mainly horizontal if the vertical exaggeration of the density model in Figure 3 at the bottom is taken into account. It is thus likely that the horizontal to subhorizontal reflections correspond to the density layering, indicating increased density with depth. As Eberli (1984) has shown the high densities in the Quaternary sediments of Lake Zürich correlate excellently with their low to very low water contents ranging from 20 to 10% which is caused by glacial overriding through squeezing out the interstitial water. This is confirmed by the very strong deformation evident in these sediments.

Because of the similarity of the sedimentation condition and of the similarity of the glaciation history, a resemblance of the sediment infill of the Rhone valley along the line Roche-Vouvry to the sediments in the Lake Zürich basin is postulated, although the thicknesses of the various units in the Rhone valley exceeds that of Lake Zürich mainly because of the higher sedimentation rates due to the much larger catchment area. Therefore a subdivision of the sediment infill of the Rhone valley into an uncompacted and undeformed upper unit with low densities and a deeper unit with glacially compacted and deformed sediments with higher densities and a low water content is proposed. The work by Eberli (1984) reveals that the transition zone from undeformed to deformed sediments is not clearly indicated either by a clear change of the density distribution or by the ensuing water content. However the lithological structures in the sediments of Lake Zürich basin described by Lister (1984) clearly show the change from undeformed to deformed sediments. This feature might indicate polycyclic glacial overriding and loading which obviously would affect deeper sediments more frequently. Whereas the gravimetric model has limited resolution, the seismic reflection provides more structural information. The strong and continuous reflector at about 0.2 to 0.3 s (see Fig. 2, Finckh & Frei 1991), corresponding to a depth of 150 to 220 m depending on the location along the line and indicating a strong velocity contrast, is thus proposed to form the boundary between undeformed and deformed infill. The comparison of seismic velocities with the lithology of the Lake Zürich sediments by Heim & Finckh (1984) show a marked increase at this boundary which thus gives rise to reflections. The deeper seismic structures in the middle and eastern part of the

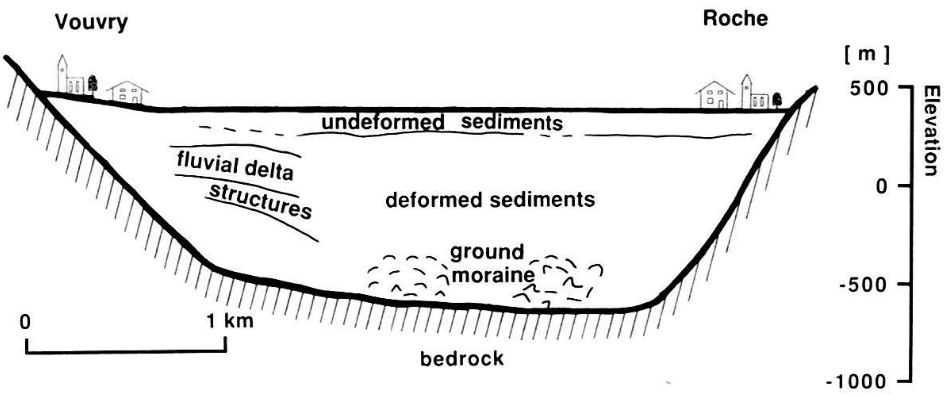


Fig. 4. Geological interpretation of the Quaternary infill of the Rhone Valley along the cross section AA′ based on seismic, gravimetric and petrophysical considerations showing the boundary between undeformed and deformed sediments as well as delta structures near Vouvry and ground moraines above the bedrock. No vertical exageration.

Rhone valley are less continuous and might represent changes in the degree of compaction and deformation. The eastern part of the basin is characterized by the fan structures which most likely stem from fluvial deltaic deposits of the Fossau creek near Vouvry. Finally some clear but not very coherent energy returns can be seen at about 0.8 s TWT (about 750–800 m depth) between CDPs 315 to 370 and CDP 385 to 420. In analogy to Lake Zürich this is interpreted as reflecions from structures corresponding to ground moraines. The final geological interpretation of the Rhone valley near Roche-Vouvry is shown in Figure 4.

It is necessary to discuss the results of this paper in view of the results obtained by Finger & Weidmann (1987). The seismic investigations, from which their velocity vs. depth model was derived for static corrections was not aiming to resolve in detail the Quaternary valley fill. This model is too simplistic to be used for gravimetric modelling and for a geological interpretation, a fact which is acknowledged by the authors. However, their maximum thickness of the valley fill of about 900 m determined in the region of Roche-Vouvry is remarkably close to the value of about 1,000 m presented in this paper.

Conclusions

The integrated seismic and gravimetric interpretation using a velocity-density relationship valid for the geological environment of an alpine Quaternary valley fill allowed us to resolve the discrepancies between seismically determined bedrock depths and the gravimetrically derived values from earlier authors. Clearly the densities occurring at greater depths in such valley fills exceed those assumed earlier and future gravimetric modelling in similar environment will have to take account of this fact. The lithological correlation to petrophysical properties such as sonic velocity, bulk density and water content derived from the Lake Zürich drill cores and applied to the Rhone valley allow a geological interpretation and a differentiation into undeformed and deformed fluvioglacial sediments. From seismic reflection data additional fluvial delta structures as well as ground moraines can be derived. Reflection seismology results in a more detailed resolution of the subbottom structure. However, gravimetric information and a good knowledge of the geological environment is needed to obtain a reasonable geological interpretation of these geophysical data.

Acknowledgments

Jörg Ansorge greatly helped to improve a first draft. We thank W. Wildi and A. Pugin as well as an anonimous reviewer for helpfull comments.

REFERENCES

BERNAUER, I. & GEIGER, A. 1986: Lokale Schwerefeldbestimmung und gravimetrische Modellrechnungen im Satelliten (GPS)-Testnetz «Turtmann» (Wallis). Geodätische-geophysikalische Arbeiten in der Schweiz 38, Schweizerische Geodätische Kommission, 106.

CORDIER, J.-P. 1985: Velocities in Reflection Seismology. Reidel Publishing Company, Dordrecht, 201.

DIX, C.H. 1955: Seismic velocities from surface measurements. Geophysics 20, 68–86.

EBERLI, G.P. 1984: Water content and bulk density of Zübo sediments. Contr. Sedimentology 13, 115–124.

GONET, O. 1965: Etude gravimetrique de la plaine du Rhone; Région St. Maurice – Lac Léman. Matériaux pour la Géologie de la Suisse, Géophysique No 6, Commission Géotechnique Suisse, 50.

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. Helv. 84, 345–357.

FINGER, W. & WEIDMANN, M. 1987: Quelques données géologiques nouvelles sur la vallée du Rhone entre Sierre et le Léman. Bull. Murithienne 105, 27–40.

HEIM, C. & FINCKH, P. 1984: Sonic velocity measurements on cores from Zübo. Contr. Sedimentology 13, 125–134.

KLINGELE, E. & OLIVIER, R. 1980: Die neue Schwerekarte der Schweiz. Beitr. Geologie der Schweiz, Serie Geophys. no. 20.

LISTER, G.S. 1984: Lithostratigraphy of Zübo sediments. Contr. Sedimentology 13, 31–58.

WOOLLARD, G.P. 1975: Regional changes in gravity and their relation to crustal parameters. Bureau gravimetrique Int. Bull. d'Information 36, 106–110.

Manuscript received 24 August 1990
Revision accepted 22 September 1991