Pitfalls in processing near-surface reflection-seismic data: Beware of static corrections and migration

W. Frei[1], R. Bauer[1], Ph. Corboz[1], and D. Martin[1]

Abstract

Near-surface seismic data are a challenge to the processing geophysicist who is familiar only with handling seismic data for target depths larger than 200 to 400 m. Residual static-correction techniques and migration procedures are used routinely for processing deeper data and can destroy data quality in the near surface. Near-surface seismic presents unique problems in processing because it usually is of suboptimal quality and often is recorded in an environment characterized by complex geologic structures. In a presentation of three case histories, one shows less severe consequences, and the other two portray disastrous consequences caused by static corrections and migration not being applied correctly. Graphical examples document the limitations of the residual statics and migration procedures. However, the method of hybrid seismic surveying is a positive and generally applicable solution when dealing with data from the shallow subsurface.

Introduction — Fundamental errors when applying residual statics corrections and migration to near-surface seismic data

Known for his outspokenness, renowned Swiss-German physician Philippus von Hohenheim, known as Paracelsus (1493–1541), delivered his famous and controversial maxim, "It is not the medicine itself but its dosage that cures a patient."

Residual static corrections and migration are common techniques used in processing seismic data. However, these techniques are not jointly applicable for processing near-surface reflection-seismic data because of practical and theoretical reasons resulting from the abrupt and severe variations of seismic-propagation velocities in the vertical and horizontal directions. Even in a moderately complex geologic setting, accurate determination of the velocity distribution using standard reflection-seismic velocity-analysis tools for applying the NMO correction is not practically feasible.

Methods used by the petroleum-exploration geophysicist for the derivation of surface- and subsurface-consistent residual static corrections are based on the assumption that two-way time (TWT) anomalies for reflection events below the surface layers are to be attributed to irregularities of the surface topography and/or to the above-mentioned strong lateral and vertical velocity variations near the surface.

These individual TWT static-correction values applied to each individual trace within a common-depth-point (CDP) gather are instrumental in obtaining the sharpest possible reflection event on the stacked CDP trace. Unfortunately, the collateral damage caused by applying these TWT corrections to the entire seismogram is that all relevant information within the shallow depth range — which is of interest to the engineering geologist — is corrupted.

An ensuing migration step of any kind to be applied on a data set previously subjected to a residual static-corrections procedure is doomed to be highly counterproductive. Migration only aggravates the situation when applied to data previously corrupted by (residual) static corrections derived from deeper depth levels. In the medical world of Paracelsus, it would be equivalent to prescribing a laxative to a patient suffering from diarrhea.

As a maxim, it is to be noted that closer to the surface, unsuitability is greater and the harmful consequences of the migration procedure are more serious (Black et al., 1994). The depth at which migration can be recommended as an appropriate measure — even without previously applied residual static corrections — depends on the particular complexity of the geologic structures and of the general quality of the data.

Data in the seismic section in Figure 1 were recorded in a simple geologic environment with flat subhorizontal depositional structures and practically no lateral velocity variations. The objective of the survey was the detection of buried riverbeds containing minable alluvial ore deposits with a maximum investigation depth of 300 m.

Figures 1a and 1b portray the results of two data-processing versions. In Figure 1a, the reflection-seismic data have been subjected to a conventional processing sequence with several runs of various types of residual static corrections followed by prestack depth migration. The seismic section in Figure 1b is the result of a hands-off type of processing scheme without any residual static corrections and without any sort of migration. A direct time-to-depth conversion with velocity functions derived from refraction-seismic tomography inversion was applied.

Seen from the aesthetic point of view, the section in Figure 1a might be more appealing. As a result of multiple applications of residual static-correction runs, the reflecting interfaces are imaged in a sharper and more continuous manner. However, with the survey's objective in mind, namely, the detection of small structural features down to a depth of 300 m, clearly, more depositional details are revealed by the processing applied to the data of the section shown in Figure 1b. To the left of station number 51,800, the existence of a 30-m-deep riverbed is verified by wells drilled at that location. Because of the combined method-inherent deficiencies of the residual static-correction procedure and migration, this buried riverbed structure is not imaged at all in Figure 1a. More evidence of several possible alluvial ore deposits and additional structural details are marked with circles in Figure 1b.

This example shows that for processing near-surface seismic data, two strategies might have to be adopted — one that takes into account aesthetic sensibilities for whatever reasons (Figure

[1]GeoExpert AG.

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1a) and the other which does not jeopardize the survey's objective by excessively applying the procedures of residual static corrections and migration (Figure 1b).

An overdose of residual static corrections and a too strong migration operator — Common pitfalls when processing poor-quality data

In remote areas with no ambient noise and simple geologic conditions such as in the situation described above, collateral damage caused to the imaging accuracy by a conventional deep seismic-processing strategy versus a hands-off processing approach is limited. However, when one is confronted by poor-quality data severely degraded by civilization noise, the temptation to apply a devastating overdose of residual static corrections and a too powerful migration operator is particularly high.

Figure 2a shows a typical raw-data shot record contaminated by traffic noise and industrial background noise from a geologic setting characterized by horizontal layering structures and generally good reflectivity. The data were acquired with an accelerated weight-drop source and a 360-channel spread with

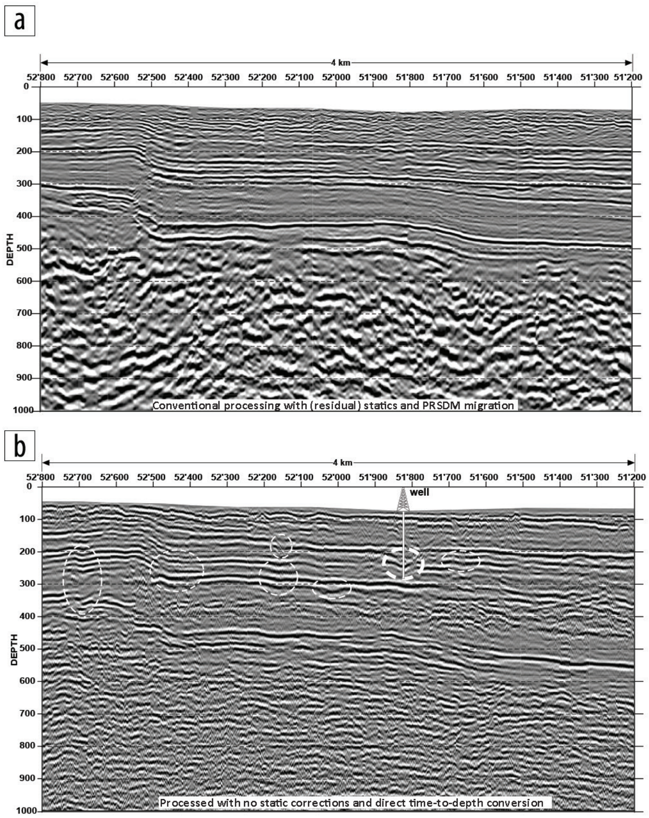

Figure 1. Comparison of the processing strategies for creation of a high-resolution reflection-seismic depth section in an area with subhorizontal depositional structuring and a gradual increase of velocities to a depth of 500 m. Note that two differing sets of velocity functions for the time-to-depth conversion have been applied. (a) Result of conventional reflection-seismic data processing by using residual static corrections and prestack depth migration in an attempt to further improve the continuity and definition of the reflecting interfaces at the expense of accuracy when mapping alluvial ore deposits at depths as great as 300 m. (b) Direct time-to-depth-converted seismic section without any static corrections and using velocities derived from refraction-tomography inversion.

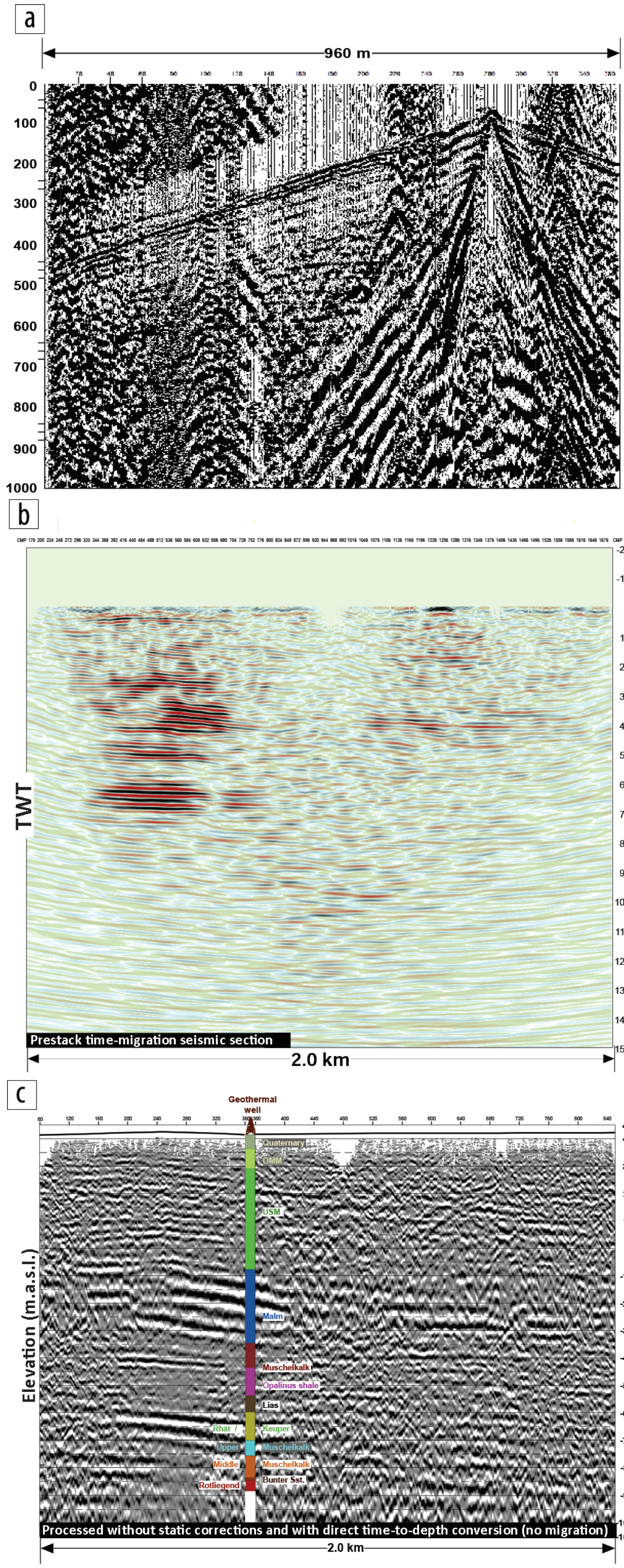

Figure 2. (a) Raw data record contaminated by traffic and industrial noise. (b) Uninterpretable seismic time section resulting from improper use of residual static corrections and a too strong migration operator processed from the data set of poor quality, as shown by the example in part (a). (c) Seismic depth section of the same data as in part (b) without static corrections and migration.

2.5-m receiver-station spacing and a single 10-Hz geophone per station. The objective was to map subsurface structures to a depth of 1500 m in the context of a geothermal drilling project.

The processing step primarily responsible for the significant signal enhancement of the section shown in Figure 2c is spectral balancing with two windows, with corner frequencies of 7, 12, 48, and 72 Hz and 30, 60, 96, and 120 Hz, respectively. For the direct time-to-depth conversion, the velocity function derived from a well-shot survey in the geothermal well was used.

How to process data from an amorphous nonreflective subsurface

The last case history deals with a larger high-resolution seismic survey for the detection of suspected neotectonic faulting in the vicinity of the construction site of a planned nuclear power plant. One of the seismic lines with a length of 1.5 km is situated in terrain of irregular topography on Tertiary bedrock affected by intense tectonic activity overlain by Quaternary deposits 0 to 100 m thick. The required depth of investigation was 150 m.

Data-acquisition parameters for the survey were a 340-channel split spread of variable asymmetry, with receiver-station spacing of 2 m with a single 10-Hz geophone and source-point spacing of 4 m. The source type consisted of 8-kg hammer blows on a steel plate. Vertical stack was twofold to fourfold, and the sampling rate was 0.5 ms.

On the raw data field record in Figure 3a, practically no coherent reflection events are present because of the complexity of small-scale subsurface structures. Ambient noise from external sources is present to a certain extent. Considering the relatively weak seismic energy source of the 8-kg handheld hammer, it is to be noted that well-defined first-break refraction arrivals are present over source-receiver offsets of more than 350 m.

In a first round, the data processing was awarded to a seismic contractor with many years of experience in processing petroleum-industry seismic data. A considerable amount of time was spent in applying numerous runs of static and residual static corrections followed by migration. Because of the absence of coherent and adequately defined reflection events, neither a reliable NMO velocity analysis nor an improvement in the coherency of selected reflection events by various types of residual static corrections was achieved. Figure 3b presents the resulting seismic time section.

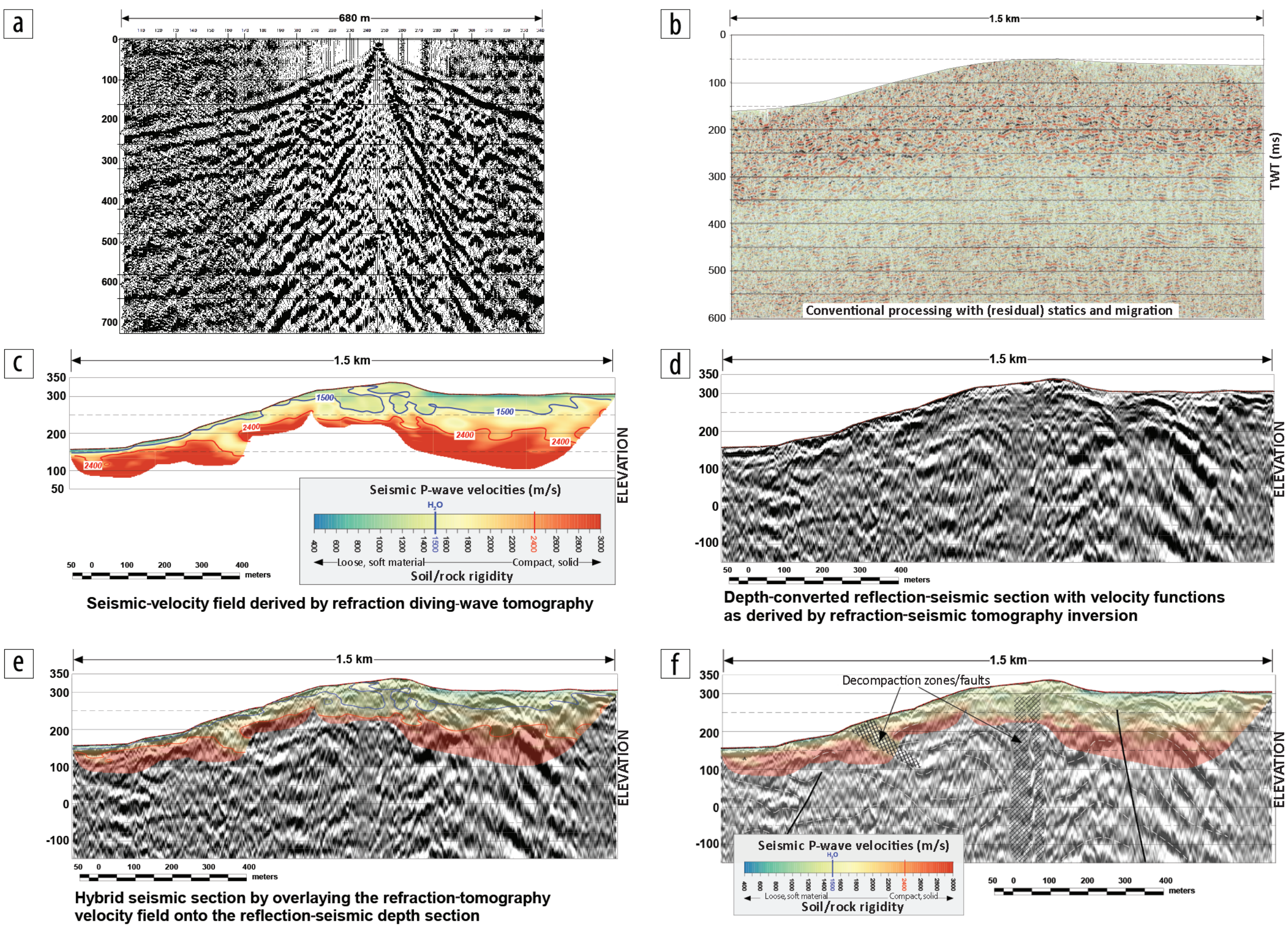

Figure 3. (a) Typical raw data shot record of a poorly reflective subsurface. (b) Noninterpretable reflection-seismic time section derived from the same data set as in part (a) resulting from inappropriate application of static corrections and migration (processed by a seismic contractor familiar with handling seismic data from the petroleum-exploration industry only). (c) Seismic-velocity field derived from refraction-tomography inversion. The surface of the unweathered Tertiary bedrock is assumed to be represented by the 2400-m/s isovelocity contour line. (d) Reflection-seismic depth section with velocities derived from the velocity field in part (c). (e) Hybrid seismic section to be presented for interpretation to the engineering geologist or geotechnical engineer. (f) Proposed seismic interpretation of the hybrid seismic section.

The conclusion based on the three examples of inappropriately applied static corrections presented above is that for near-surface seismic profiling, the standard data-processing sequence commonly used in the petroleum industry, which includes residual static corrections and migration, is not to be recommended.

Better near-surface results are obtained invariably by using the method of hybrid seismic surveying presented by Frei and Keller (2000) and by Frei (2012). That method combines high-resolution reflection-seismic profiling with refraction-tomography inversion. In hybrid seismic surveying, the disadvantages of one method are compensated for by the benefits of the other. The major advantage is to be seen in the enhanced interpretation reliability gained by joint presentation of the results of the two techniques, which are completely independent of each other. For this reason, they are truly complementary to each other and thus instrumental for reciprocal calibration purposes. An additional financial advantage comes from the substantially lower cost of doing a single seismic survey to acquire both the refraction and reflection information.

As the first step in hybrid seismic evaluation of the data in Figure 3a, the seismic velocity field is derived from refraction-tomography inversion. Because the refraction arrivals are well defined, the seismic velocities can be derived up to a depth of 200 m (Figure 3c).

The second step in producing the reflection-seismic depth section is a more time-consuming affair. The most challenging part is derivation of the velocities for the NMO correction and for the direct time-to-depth conversion. Note that no static corrections of any kind and no migration are applied (Figure 3d).

Step three consists merely of joint presentation of the results of the refraction-seismic and reflection-seismic surveys by transparently superpositioning the velocity field onto the reflection-seismic depth section (Figure 3e).

Figure 3f presents a proposed interpretation of the hybrid seismic section. Note the good correlation at some locations between the structures imaged by the refraction velocity field and the reflection depth section, for example, the sub-horizontal zone of decompaction outcropping at the surface on the left half of the profile. The visual crosscorrelation is instrumental for a reliable interpretation.

Summary of the advantages of hybrid seismic surveying

Hybrid seismic surveying offers these advantages:

- Reflection-seismic data processing and refraction-tomography inversion can be applied on the same data set recorded in a single acquisition procedure.
- The weaknesses of one method are compensated for by the advantages of the other.
- The results of the seismic-reflection and seismic-refraction data processing are completely independent of each other.
- The combined results of the two methods provide a significantly more reliable interpretation.. TLE

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Corresponding author: w.frei@geoexpert.ch

References

Black, R. A., D. W. Steeples, and R. D. Miller, 1994, Migration of shallow seismic data: Geophysics, **59**, no. 3, 402–410, http://dx.doi.org/10.1190/1.1443602.

Frei, W., 2012, Methodology and case history of hybrid seismic surveying in combination with multichannel analysis of surface waves (MASW): A useful tool for the detection of rock and soil instability zones: Proceedings of the International Conference on Geotechnical and Geophysical Site Characterization 4 (ISC-4): CRC Press.

Frei, W., and L. Keller, 2000, Hybride Seismik — Eine verbesserte Methode des Aussagepotentials seismischer Daten [Hybrid seismic surveying — A method to better view the information content in seismic data]: Bulletin für angewandte Geologie, **5**, no. 2, 229–236 (in German).

Suggestions for further reading

A comprehensive and easily understandable introduction to seismic prospecting methods: www.parkseismic.com.

Barton, N., 2006, Rock quality, seismic velocity, attenuation, and anisotropy: Taylor & Francis.

Osypov, K., 2000, Robust refraction tomography: 70th Annual International Meeting, SEG, Expanded Abstracts, 2032–2035, http://dx.doi.org/10.1190/1.1815841.