Transformation of Faults in Seismic Migration and Modelling

Johann Sattlegger

Sattlegger Ingenieurbüro
Für Angewandte Geophysik
P.O. Box 1639
4470 Meppen, West Germany

Summary

Faults, thrust faults and intrusion boundaries as usually picked on seismic data are features quite different from normal reflection horizons.

Their definition is by terminations of reflecting interfaces rather than by discernible reflected energy off the fault or intrusion boundary.

Reflections off faults or intrusion boundaries are, in general, (except for cases of accurate depth migration) not located where the corresponding terminations of horizons line up. Frequently, they are not discernible.

Faults or intrusion boundaries that are not actual reflections may not be migrated or modelled. They have to be transformed from time to depth or depth to time domain. The transform parameters can only be derived from horizons available in both time and depth.

Introduction

In few cases only, reflections off faults or intrusion boundaries are discernible in seismic data. With proper depth migration only, they appear in proper position (Judson *et al.*, 1978).

Most faults are picked where reflecting interfaces run into diffractions (stacked data) or terminate (migrated data). This applies to two- as well as three-dimensional data.

Reflection horizons may be converted to depth by migration, image ray migration or straight depth conversion depending on whether interpretation was on stacked, time or depth migrated data.

In the following, a fault or intrusion boundary that is not discernible as a reflection but has been picked along discernible interface terminations will be referred to as 'non-reflector interface', abbreviated NRI.

Obviously, NRIs may not be migrated or image ray migrated. Think of a steeply dipping NRI, its time gradient would make it move way out of place.

Thus, the only way to transform NRIs from time to depth (migration) or depth to time (modelling) domain is by means of transform parameters derived from reflecting interfaces available in both, time and depth (Sattlegger *et al.* 1984).

In migration, there are two problems. First, an NRI may be required as a velocity boundary for migration of one or more reflecting interfaces which, in turn, are required to transform the NRI. Second, unique computation of transform parameters is possible only when an NRI is available in depth. Because of this and in case of migration, transformation of NRIs may require iteration.

Storage and presentation of NRIs

In the two-dimensional case, in time or depth, migrated or unmigrated domain, an NRI may be stored and displayed as a polygon. In a map, what is commonly called a 'fault trace' may be stored as a polygon.

How do you store and display an NRI (sometimes called a 'fault plane') as a surface in space?

Reflecting horizons (in space) are unique functions of the two coordinates (x, y). They may be grid interpolated, stored by grid values and contoured.

A steeply dipping NRI is hard to grid and even harder to display in a contour map. It may be curved and may no longer be a unique function of (x, y).

The best way of representing and working with complicated, non-unique functions is by parameter representations. With parameters properly chosen, these representations are unique. Think of the earth's surface with an (x, y, z) coordinate system at the centre of the earth. For a given point (x, y) in the equatorial plane, we obtain two values of z for the northern and southern hemisphere. However, with the two parameters (latitude, longitude) = (ϕ, λ) we obtain a unique solution

$$x = x(\phi, \lambda) \quad (2)$$
$$y = y(\phi, \lambda)$$
$$z = z(\phi, \lambda)$$

Lines ϕ = const, λ = const form a coordinate grid in the surface.

Is it possible to find a suitable parameter representation for an NRI?

Above, we have discussed a system of parameter lines already:
- one set of 'parameter lines' could be the lines of intersection of the NRI with the planes of the seismic sections
- the second set of parameter lines could be the lines of intersection of the NRI with the seismic reflectors.

Parameter values, obviously, would be line number, say p, and horizon (interface) number, say q. Instead of horizons, planes of constant time or depth may be used.

The NRI would be given by

$$x = x(p, q) \qquad (3)$$
$$y = y(p, q)$$
$$z = z(p, q)$$

Being unique functions, they may be interpolated.

If

$$p = p(u, v) \qquad (4)$$
$$q = q(u, v)$$

are unique functions, parameter representation (3) may be transformed. Functions (4) may be chosen such that the resulting parameter representation has some valuable or desirable properties.

Transformation of fault surfaces

As outlined in the introduction, interface points available in time and depth must be used to transform NRIs.

Figure 1 depicts part of a base map along with migration displacement vectors and migrated depth values posted. A salt boundary is displayed in both, time and depth position. Migration displacements have been used to transform boundary from time to depth.

Salt boundary as displayed may be considered one parameter line q = const.

Figure 2 depicts the various steps of transformation of a salt boundary. Of course, transformation can be performed only where migrated interfaces are available. Thus, the salt boundary changes shape and 'grows' as migration proceeds. The salt boundary may be considered a parameter line p.

Velocity creeping

Obviously, faults and their transformation are non-problematic for migration if we have one continuous velocity field.

A continuous velocity field may allow approximate migration.

Approximate migration provides approximate positions of interfaces and NRIs. Hence, it provides an enhanced velocity field.

In turn, enhanced velocity field allows improved migration.

Experiments indicate switching from the continuous to the non-continuous velocity field immediately following the first approximate migration step may lead to instability. Gradual modification of the velocity field in small increments, from the continuous to the non-continuous velocity field and simultaneously with iterative migration, provides a stable answer in most cases.

For practical migration (in two or three dimensions) this is of great importance. It frees the geophysicist from having to decide on the sequence of migration of interfaces and transformation of faults, which is hard to do in complicated cases with many NRIs (faults, thrust faults, etc).

Conclusions

Non-reflector interfaces (NRIs) are important features as part of the subsurface model as well as velocity boundaries for migration and modelling.

Modelling is not a problem. The model along with the NRIs is available in depth and modelling may be performed. NRIs may be transformed after completion of modelling.

Migration is a problem. NRIs are required in depth for velocity boundaries. They may be obtained in depth only by transformation with transform parameters obtained from horizons and NRI transformation sequence and iteration (repeated migration) in some cases.

'Velocity creeping' is a method to solve this problem generally and in most cases, making migration and NRI transformation sequence rather irrelevant.

References

Judson, D., Lin, J., Schultz, P. & Sherwood, J. (1978)—'Equalizing the stacking velocities of dipping events via devilish', paper presented at the 48th Annual International SEG Meeting in San Francisco, Brochure published by DIGICON Geophysical Corporation.

Sattlegger, J. & Kües, B. (1984)—'Simultaneous interactive migration and modelling of seismic reflection horizons and fault systems', paper presented at the 46th Meeting of the European Association of Exploration Geophysicists in London.

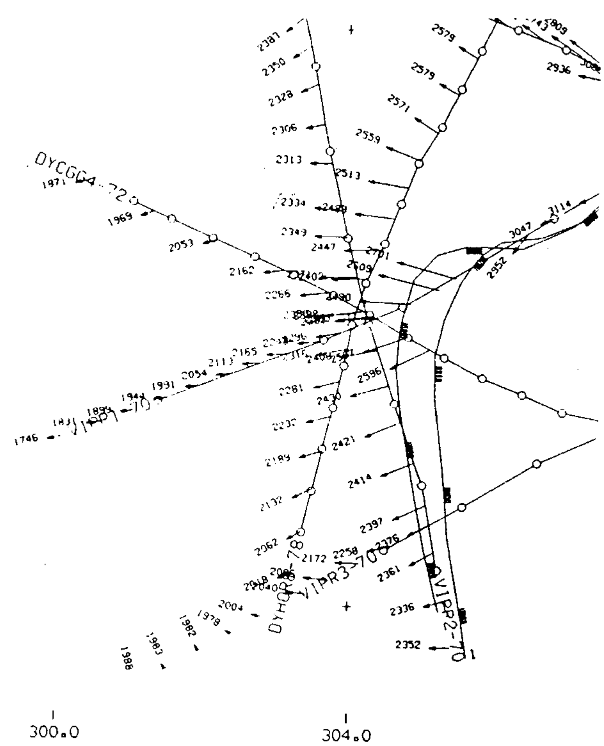

FIGURE 1

Migration displacements with salt boundary in time and depth.

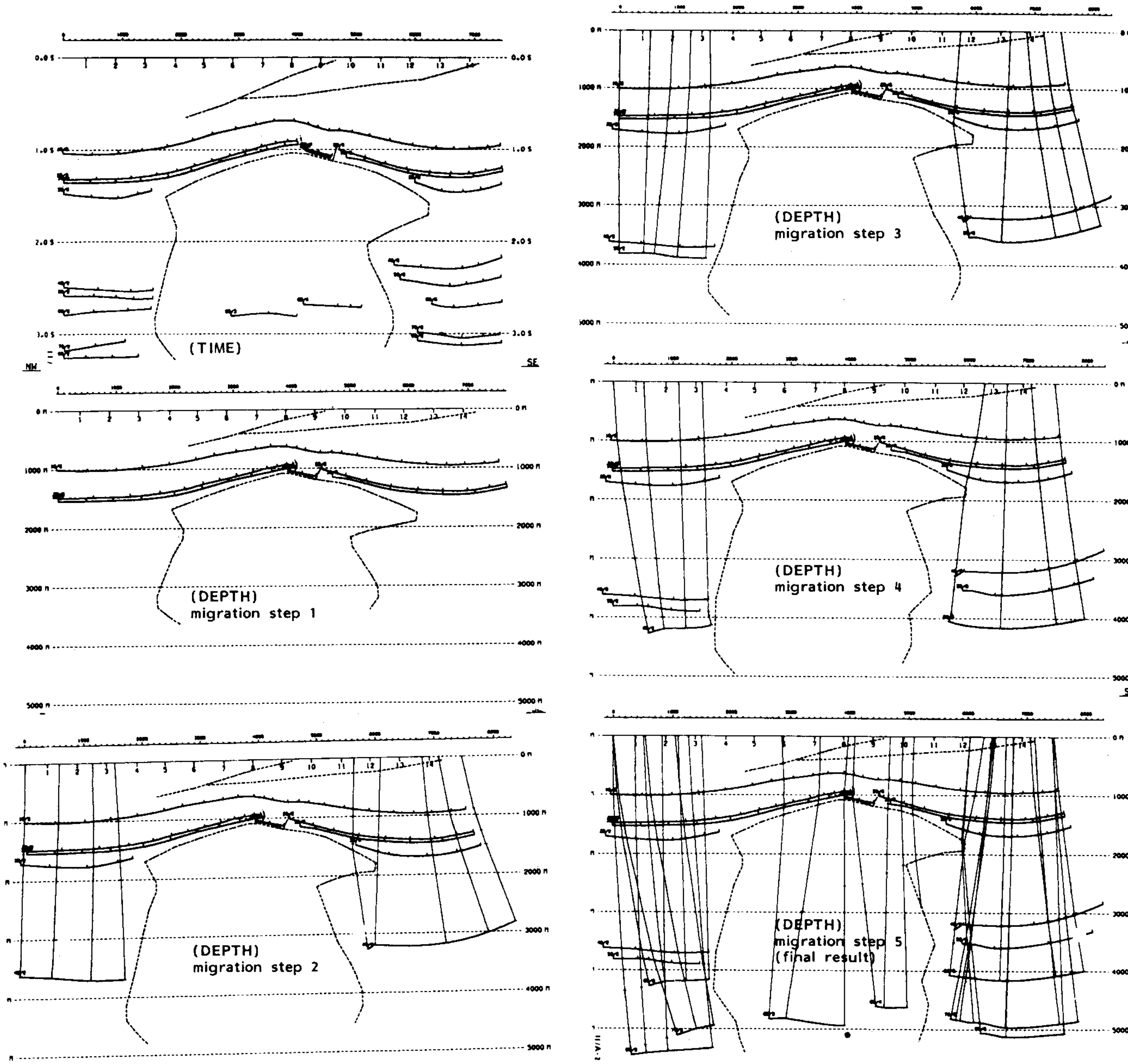

FIGURE 2
Steps of migration and transformation of salt boundary.