



**Examination of seismic profiling data for fault
displacements in Hvalfjörður, Iceland**

Karl Gunnarsson

Greinargerð KG-95-04

EXAMINATION OF SEISMIC PROFILING DATA FOR FAULT DISPLACEMENTS IN HVALFJÖRÐUR, ICELAND

1. INTRODUCTION

By request of Pálmi Kristinsson and Guðlaugur Hjörleifsson of *Spölur h.f.* at a meeting 23 August 1995, Karl Gunnarsson of the N.E.A. (National Energy Authority; "Orkustofnun" in Icelandic) was requested to "re-examine the seismic profiling records for evidence of post-glacial displacements". This subject is labeled as item 6 in the meeting agenda. The area in question is the proposed tunnel route in Hvalfjörður, Iceland. The results of this work are presented here.

According to our understanding, our task is to look for evidence of basement fault movements that have affected the sedimentary overburden. This would be done by locating continuous reflectors in the seismic sections that appear broken and shifted by near-vertical faults. The sediments are of two main types, the older glacial moraine-type sediments, and the younger Recent sediments (i.e. younger than about 10 thousand years). The former display irregular stratification and geometry, so a hypothetical faulted step would be hard to distinguish. The latter tend to show in places more regular horizontal or parallel bedding, suggesting the possibility of fault detection. The discussion will be presented in three distinct parts, as follows:

1. The N.E.A. has already done a special study on the multi-channel seismic reflection data collected by us in 1993 with regard to possible faulting in the overburden sediments. This was done at the request of *Spölur h.f.*, and published first in Icelandic in the short report:

"Athugun á setlögum yfir lághraðasvæðum í berggrunni Hvalfjarðar", Orkustofnun, Jarðhitadeild 1994-03-10, KG-ÓGF-5/94.

An English version of this report was then written for the *Spölur h.f.*:

"An Investigation of faults in sediments in Hvalfjörður, and some critical comments", Orkustofnun, Geothermal Division, 1994-03-23, KG-ÓGF-6/94.

We do not think that further information of this kind can be gained from these particular data, and our present report here is based on our findings from this work.

2. In the above mentioned report (KG-ÓGF-6/94), it was suggested that much of the faulting in the sediments reported by Geoteam could in fact be artifacts in the data and not real faults. We have now re-examined the boomer single-channel data, on which these finds are based, and report our impression.
3. The results are summarized, and the possibility of detecting faults and fractures in the basements are further discussed.

2. RESULTS FROM MULTICHANNEL SEISMIC REFLECTION PROFILES

Our previous (June 1994) investigation of the multichannel seismic sections concentrated on a systematic search at 59 locations, overlying basement low-velocity zones (<4.0 km/s). However, the entire seismic section were scanned for fault-like features at the same time. It should be

noted that the resolution of the air-gun data within the sediments will not likely allow the detection of a fault displacement which less than 1-2 meters. The following conclusions were drawn:

1. No certain steps or escarpments in the sea-bed that could be caused by faults were seen, but a few doubtful instances were encountered.
2. The sediments are mostly inhomogeneous, and unbroken parallel reflection patterns are not often encountered over long distances. This makes it practically impossible for most instances to decide on the possibility of fault movements, and this certainly applies to 29 instances of the 59 investigated. In 27 instances unbroken continuous reflectors were seen over low-velocity zones. In one instance a clear step was seen, and two other cases are possible. These three latter observations are high up in the sedimentary layer where it is quite thick, over irregular basement topography. Such steps in the sediments don't have to be related to basement faulting; faulting or slumping within the sediments and irregular deposition due to currents are also possible causes.

3. RESULTS FROM SINGLE CHANNEL BOOMER DATA

In the 1993 report of Geoteam ("Hvalfjörður Geophysical Survey", Volume 1, 1993, report no. 33165.01) the map no. 2 ("Bedrock contour map with interpreted lineaments and bedrock low velocities") shows the location of "faults extending to seabed". These suggested faults were interpreted by Geoteam staff from the single channel analogue boomer data. In our previous report it was noted that some of the suspected faults in the sediments reported by Geoteam could in fact be artifacts in the data and not real faults. Our re-examination of the single-channel data reinforces this conclusion, and indicates that there is no concrete evidence for faults of this type.

In nearly all of these indicated locations a very slight topographic irregularity is seen in the seabed, steps or undulations. The shapes of these features are not consistently or strikingly "fault-like", nor are their amplitude exceptional or unique for the area. These "bumps" as such can not be taken as a convincing evidence for faulting.

An effort to observe broken and shifted strata below the bumps failed to provide a single convincing case. There are in fact a number of instances where there are apparent shifts in the reflection pattern immediately below the sea-bottom, but these are most likely artifacts in the data. This is due to the long signature of the seismic signal that developed intermittently during the survey. This phenomena causes interference of real and false reflections just below the seabed reflection, suggesting in some cases false faults below surface irregularities. This has not been taken into consideration by the Geoteam interpreter, and it is probably no coincidence that the "fault"-indications are concentrated in that part of the survey area where the long signature character of the seismic source was most pronounced.

It is, however, not safe to say that our interpretation of the data has conclusively proved that no faulting has taken place in the the sediments, but hypothetical displacements must be to small and subtle for the resolving power of the applied survey methods.

For a further discussion of some details the surface features, we refer to the attached figure, which is a copy of a part of the Geoteam map discussed to above (no. 2). The black dots show the locations of the faults or sea-bed features. The distribution suggests that some of these might form elongated nearly linear features on the sea-bed. We have indicated three such possible connections, marked by thick lines and written circled capital letters. Feature (A) is located at the inner edge (south-east edge) of a sand-reef deposit. Other possible causes than faulting could be sea currents shaping the reef, or marks made by sand dredging ships, that operate frequently in

the vicinity. Feature (B) is over a step in the basement. Differential compaction or slumping of sediments over that step could conceivably cause displacements. Feature (C) close to the south shore of the fjord is not shown in the Geoteam map and is added by us. It is slight step in the sea-floor, down on the east side, and has a northerly trend. No suggestions of displacements can be seen in the underlying sediments, which are, however, not suitably stratified. This feature is as likely as any to be a fault.

4. SUMMARY OF RESULTS AND COMMENTS

In conclusion, no definite indications of faulting in the sedimentary layer have been observed in either the the multichannel or single channel boomer profiling data. It can also be stated that due to the irregular layering and structure of the mass of the sediments, such indications would probably not be detected in most instances, even if they exist. It is also evident that the resolution of the seismic signal is a limitation. On the basis of these observations, it is our opinion that further investigations in this field are not likely to lead to firm conclusions.

Even if deformations do exist in the sediments, they do not have to be caused by basement faulting. Slumping and differential movements because of compaction within the sediments are also possible. To demonstrate the problem of detecting open conductive basement fractures in the Hvalfjörður area, a recent field case of hydrothermal exploration conducted by the N.E.A. can be cited. This is relevant to the present discussion, as young tectonically active faults and cracks are the typical source for warm groundwater in the older areas of Iceland, such as the Hvalfjörður area, where the bedrock is relatively tight and has little permeability. Such faults are self-sealing unless the tectonic activity continues to break cracks open.

The exploration effort located a hydrothermal field in the inner reaches of Hvalfjörður, some 15 km NE from the proposed tunnel route. The field is believed to be fed by a narrow zone of north-south trending fractures that extend across the fjord. This zone was found by measuring the geothermal gradient in a net of shallow (about 50 m) boreholes, giving a temperature anomaly about 1-2 km wide. This type of geothermal signature is in fact typical of many geothermal localities in this part of Iceland. No geological evidence were found on the surface for recent tectonic activity, and it is thought that these deformations can in fact be minor and easily missed.

Very little geothermal gradient data is available in the vicinity of the proposed tunnel route. A data point in a borehole at the southern end (Hjarðarnes) suggests a normal regional value, but another hole a short way to the south-west (Saurbær) gives a value significantly higher than the regional. It is an open question if this is an indication of a geothermal field, but to our mind, these are the only data presently available that indicate the possibility of recent tectonic activity and permeable fractures at the tunnel site. It should also be noted that experience shows that such recent fractures frequently follow the trend of the older dominant fault and dyke systems. These major structural elements of the plateau basalts are typically best traced by magnetic mapping.

Reykjavík, August 29, 1995,

Karl Gunnarsson

A section of map no. 2, "Bedrock contour map with interpreted lineaments and bedrock low velocities", from the 1993 Geoteam report: "Hvalfjörður Geophysical Survey", Volume 1, 1993, report no. 33165.01

The part nearest to the south shore is shown, containing all indications of "faults extending to seabed" (large dots). The thick lines suggesting lineations through the dots, labeled by circled capital letters, are added by the present author. These are interpreted as sea-bed features, not demonstrably caused by faulting. (Orkustofnun, K.G., August 1995)

