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Geothermal gradient and hydrothermal systems off North Iceland

Guðmundur Ómar Friðleifsson

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1. Introduction

This report is prepared in relation to an application to the Ocean Drilling Program (ODP) for drillsites within the Tjörnes Fracture Zone Sedimentary Basin (TFZSB). The proponents of this application are scientists at four of the main geological- and oceanographic reasearch institutes in Iceland, i.e. Orkustofnun (National Energy Authority), Science Institute of the University of Iceland, the Marine Research Institute, Reykjavik and the Icelandic Museum of Natural History. In addition, two of the proponents are at the Geological Survey of Denmark and the University of Bergen.

The two drillsite-locations applied for are within the deepest and oldest part of the TFZ-Sedimentary Basin in the Eyjafjardarall region, WSW of Grimsey. The TFZSB-1 site is at 480 m waterdepth within the Eyjafjardarall itself, while TFZSB-2 is due west of TFZSB-1 at 320 m depth. The scientific achiefments anticipated from these two drillsites, with two 1.1-1.6 km deep drillholes, is an undisturbed chronostratigraphic record back to late Miocene (10-15 Ma), i.e. covering most of the geological history of Iceland. As there are no major sedimentary sequences preserved on land in Iceland, apart from the Tjörnes sedimentary sequence, the possibility to unravel a continuous climatological record by sedimentary studies remains with sedimentary sequences possibly preserved on the insular shelf.

The exposed sedimentary sequence at Tjörnes provides a unique record from the Pleistocene, containing at least 14 glacial/interglacial cycles, and a geological record through Pliocene as well. The Tjörnes sediments, however, are all from a coastal proximity or from shallow marine environments. Therefore, unconformities are present and the sequence is in part intervened by lava flows, terrestrial lignite horizons and tephra layers. This in turn makes the Tjörnes sequence a unique site for attempting a land-sea correlation to the deeper oceans, while the coastal proximity exerts some limitations. With the addition of intermediate depth concordant high resolution sedimentary data from the insular shelf, however, a detailed land-sea correlation should result. Such a high resolution sedimentary sequence is likely to rest within the deeper part of the TFZ-Sedimentary Basin. The maximum thickness of the sedimentary sequence in Eyjafjardarall is 3-4 km. Our proposed drillsites aim towards a complete coverage of a high resolution stratigraphic sequence, especially of the younger part by TFZSB-1 (1200-1600 m deep well) probably chiefly of Pleistocene age, and a coverage of the older part of the sedimentary sequence down to the Miocene volcanic basement at the flank of the Eyjafjardarall graben by site TFZSB-2 (1100 m deep well).

The hydrothermal history of the TFZS-Basin is unkown, but from the Tjörnes sedimentary sequence and hydrothermal mineralization in lavas at Flateyjarskagi and at Husavik close to the Husavik-Flatey transform fault zone, only low-temperature hydrothermal mineralization is in evidence. Whether the same applies to the deeper part of the basin closer to the Kolbeinsey Ridge is not known. However, high-temperature hydrothermal activity is known at the Kolbeinsey Ridge itself and the en-echelon arranged volcano-tectonic lineaments linking the Ridge to the NE-Iceland Neovolcanic zone. Evidently a unique opportunity to study the

hydrothermal history of the basin will emerge if our ODP drillsite proposal is accepted and completed, while that topic is subsidiary to the main topic of climatological/oceanographic history.

Relevant data on known geothermal gradient and hydrothermal systems in the vicinity of the Tjörnes Fracture Zone Sedimentary Basin is compiled below from Orkustofnun data.

2. Geothermal gradient

The regional geothermal gradient in coastal areas in North-Iceland closest to TFZSB-1 and TFZSB-2 sites is estimated 50-60°C/km from a number of shallow (< 100 m) and intermediate depth (< 500-600 m) drillholes (fig. 1). The localized low-temperature hydrothermal systems in the same area are, on the other hand, characterized by high values of the temperature gradients at shallow depths (100-300°C/km) but the gradient usually decreases rapidly with depth and at 1-3 km depth the temperature is usually **lower** within the hydrothermal systems than wouled be expected from the regional temperature gradient. This is due to convective heat transport within the hydrothermal systems.

In Flatey island, which is situated within the TFZ-Sedimentary Basin, the gradient in a 554 m deep well is 47°C/km. In Grímsey, closer to the Kolbeinsey Ridge, only 2 temperature profiles are available from shallow wells, yielding a poor quality gradient estimate of 80-95°C/km. Near Hofsos in Skagafjordur a gradient of 61°C/km is considered truthworthy.

Elsewhere, like in Sigulfjordur, which is the nearest harbour due south of the TFZSB-1 and -2 sites, one gradient estimate values outside low-temperature hydrothermal systems gives 34°C/km. The reservoir temperatures within the hydrothermal systems there is about 80°C/km +/- 10°C above 1 km depth. In Olafsfjordur, Dalvik and Hrisey, the nearest low-temperature utilized hydrothermal systems in Eyjafjordur, similar reservoir temperatures, about 60-80°C are observed. In Husavik at the Husavik-Flatey transform fault, just south of the Tjörnes Plio-Pleistocene sedimentary sequence, the highest reservoir temperature is 110°C at 1200 m depth.

Assuming similar condition to prevail at TFZSB-1 and TFZSB-2 sites at present we would expect a regional thermal gradient from 40-80°C/km. If that is the case a relatively smooth drilling operation is foreseeable. A higher thermal gradient on the other hand would probably relate to an active low-temperature hydrothermal system in the fault system of the Eyjafjardarall graben. In that case drilling delays due to circulation loss or gain could be expected at deeper levels, probably with poorer drillcore recovery. In the ODP proposal we will suggest an approximately 150 m deep pilot hole (1-2 days) to be drilled at site TFZSB-1 during ODP Leg-162, if possible, in order to predict the geothermal condition. This we find rather tempting as the ODP-drillship may revisit site 907 (?) on the Icelandic Plateau north-east of the TFZSB. Hydrothermal gas composition in a pilot hole could in turn point to a higher temperature geothermal system than we expect, and eventual problems due to hydrocarbon gas emmission might be foreseeable as well. A pilot hole could influence the siting of TFZSB-1 as a suitable target for high resolution sedimentary studies. In turn it could also strengthen our proposal by predicting a smooth deep drilling operation and provide a glimpse to the likely resolution of the unusually thick sedimentary sequence within the Tjörnes Fracture Zone Sedimentary Basin.

3. Hydrothermal manifestations on the seafloor

Manifestations of hydrothermal activity are known from several locations south and southeast of the Kolbeinsey Ridge (fig.1). All of these are well outside our proposed drillsite. The nearest one, at 66°34.93'N and 18°41.71'W at 315 mbsl depth, is about 7 nautical miles NE of TFZSB-1. A dredge sample collected by a fishingboat in 1988 contains opaline silica, gypsum and calcite. Sulphur odor was smelt when the sample emerged.

A better known geothermal site at the southern end of the Kolbeinsey Ridge is at 67°05.4'N and 18°42.7'W at 100 mbsl. A dredge sample collected by the Marine Research Institute, Reykjavik, contains cubanite, gypsum, barite, pyrite, marcasite, galena, quartz and halite. Its temperature is unknown, but boiling temperature at that depth would be close to 180°C.

Other hydrothermal manifestions on the ocean floor known in the region are in the Skjalfandi-deep east of Grimsey. The locations of these and the two discussed above are shown in table 1, from data compiled by the Museum of Natural History (S.P.Jakobsson, pers. com.):

TABLE 1

66°34.93.N , 18°41.71'W	Eyjafjardarall-deep	315 mbsl
67°05.4' N , 18°42.7' W	Kolbeinsey Ridge	100 mbsl
66°38' N , 17°48' W	Skjálfandi-deep	100 mbsl
66°36.23'N , 17°38.20'W	Skjálfandi-deep	
66°36.05'N , 17°39.70'W	Skjálfandi-deep	385 mbsl
66°34' N , 17°46' W	Skjálfandi-deep	330 mbsl
66°32.41'N , 17°39.87'W	Skjálfandi-deep	440 mbsl

Apart from this data on hydrothermal manifestations, data on geothermal systems, heatflow or geothermal gradients on the ocean floor in the Tjörnes Fracture Zone Sedimentary Basin is nonexistent to the best of my knowledge.

Reykjavík 15. júní 1994,

Guðmundur Ó. Friðleifsson

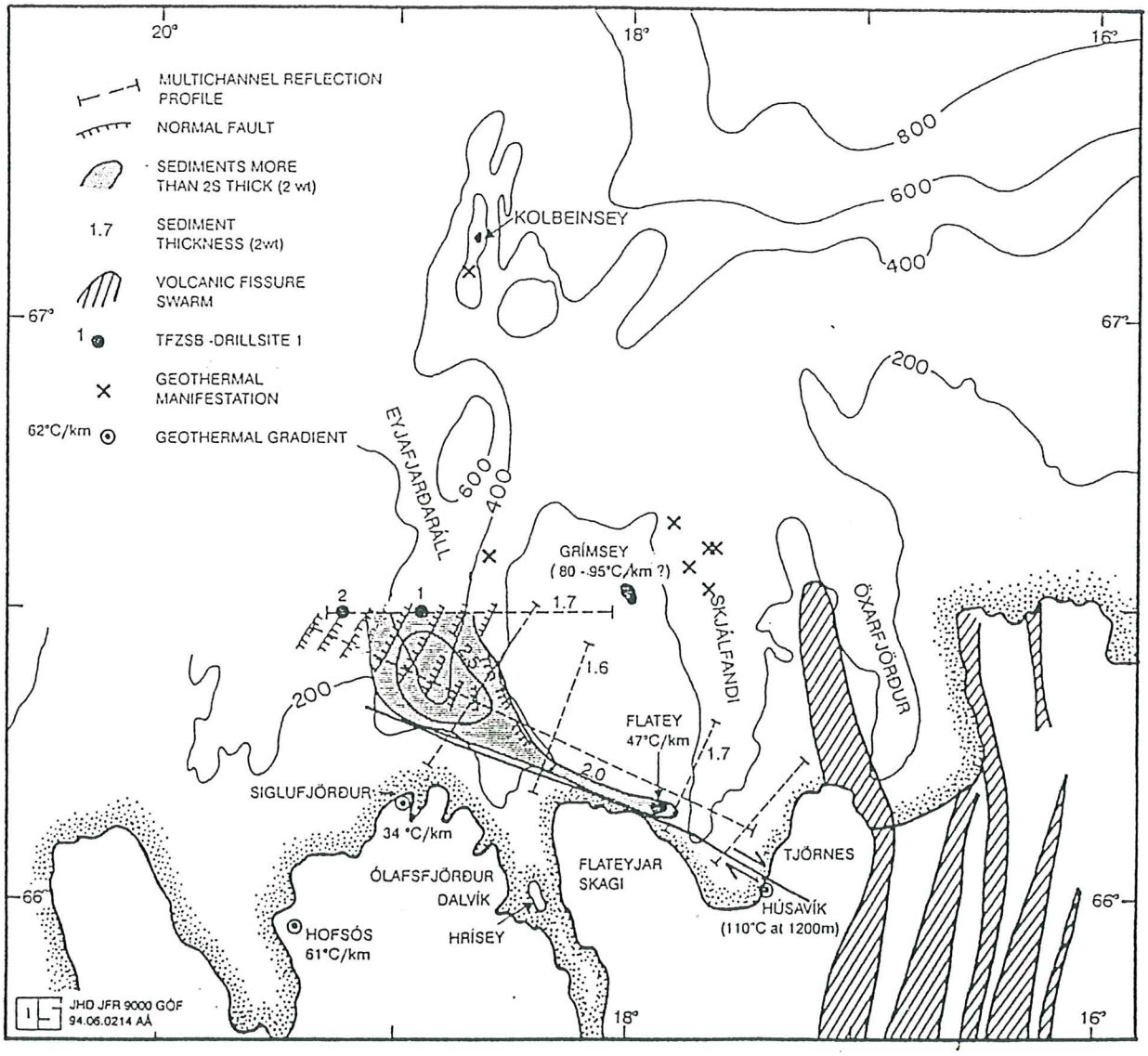

Figure 1. Map showing geothermal gradients in coastal areas, the approximate locations of known hydrothermal systems at the seafloor and the locations of TFZSB-1 and TFZSB-2 ODP-drillsites within the Tjornes Fracture Zone Sedimentary Basin.