Reviewed research article

Plate boundaries, rifts and transforms in Iceland

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Abstract – *The Iceland hotspot has a pronounced effect on the appearance and structure of the plate boundary between the North America and Eurasia Plates that crosses the island. The thick crust produced by the excess magmatism of the hotspot leads to a wider and more complicated plate boundary deformation zone than is observed along normal oceanic plate boundaries. Furthermore, the relative movement of the boundary with respect to the roots of the hotspot leads to unstable boundaries and rift jumps, when crustal blocks or microplates are transferred from one major plate to the other. The plate boundary zone can be divided into segments that are physiographically relatively homogeneous and possess distinct tectonic characteristics. The segments are more or less oblique to the relative spreading direction of the two major plates. The divergent component of the movements is taken up by diking and normal faulting and is usually concentrated in the fissure swarms of the volcanic systems. The transcurrent component of the movements is often accommodated by strike-slip faulting on faults that are transverse to the plate boundary segment, so-called bookshelf faults, witnessing to the transient nature of the segments. In highly oblique segments, such as the Reykjanes Peninsula Rift and the Grímsey Oblique Rift, both types of active structures occur superimposed on each other. In the South Iceland Seismic Zone, that is almost parallel to the local spreading direction, the bookshelf faults dominate the structure, producing earthquakes as large as magnitude 7. More mature transform zones, such as the Húsavík-Flatey faults, have developed strike-slip faults that are sub-parallel to the plate movements. The activity on this transform zone, however, appears to be declining because of transfer of movement over to the Grímsey zone. This is supported by the lack of Holocene volcanism along the Eyjafjarðaráll Rift that connects the transform to the Kolbeinsey Ridge plate boundary off shore. A ridge-jump appears to be in progress in South Iceland, where rifting is occurring in two sub-parallel rift zones, the very active Eastern Volcanic Zone and the less active Western Volcanic Zone. The block between them is seismically and volcanically inert and may be defined as a microplate, the Hreppar Microplate. It is rotating in response to the southward propagation of the Eastern Volcanic Zone and corresponding recess of the Western Volcanic Zone. Poles of relative rotation with respect to the North America and Eurasia Plates are suggested near 65.2°N, 20.1°W, and 62.8°N, 21.3°W, respectively.*

INTRODUCTION

Iceland is a platform of dimensions 300x500 km situated astride a divergent plate boundary and on top of a hotspot presumed to be fed by a deep mantle plume (Einarsson, 1991a, 2001). This land platform is only a part of a much larger platform, also comprising the shelf area, 450 x 750 km wide and bounded by a well defined shelf edge. The eastern part of this mass sits on the Eurasia Plate and the western part sits on the North America Plate.

The mid-Atlantic plate boundary is relatively simple in most parts of the NE-Atlantic, consisting of rifting and transform segments separating the two major plates, Eurasia and North America. The boundary is clearly defined by the epicenters of earthquakes that show a narrow zone of deformation (Figure 1). As it crosses the Iceland platform, however, the deformation zone becomes wider, as shown by the distribution of earthquakes and volcanism in Figure 2. The boundary breaks up into a series of more or less oblique

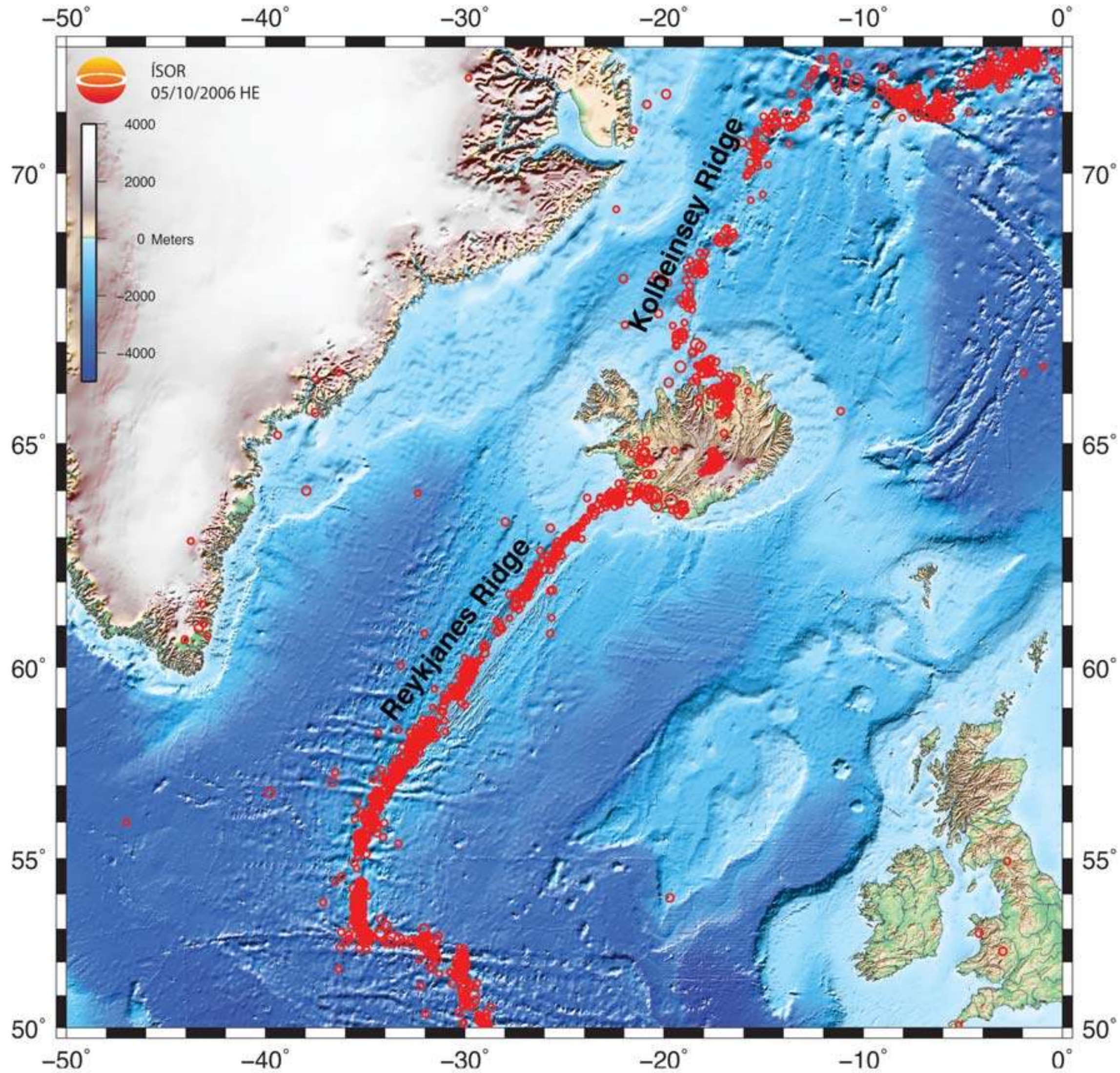

Figure 1. Earthquake epicenters in the Atlantic Ocean 1964–2006. Data are from the epicentral list of the NEIC, US Geological Survey. – *Upptök jarðskjálfta á Atlantshafssvæðinu umhverfis Ísland 1964–2006. Byggt á gögnum frá Jarðfræðistofnun Bandaríkjanna.*

segments. In some places the boundary branches out and small microplates or tectonic blocks are formed that may move independently of the large plates. The Hreppar and Tjörnes blocks are the clearest examples. Both of them seem to move mostly with the North America Plate at the present time. Most of these complexities have been attributed to the presence of the Iceland Plume even though the causal relationship is by no means clear. The center of the plume is generally assumed to be located under Central Iceland (e.g. Wolfe *et al*., 1997). The tectonic fabric and style of deformation along the different segments is largely

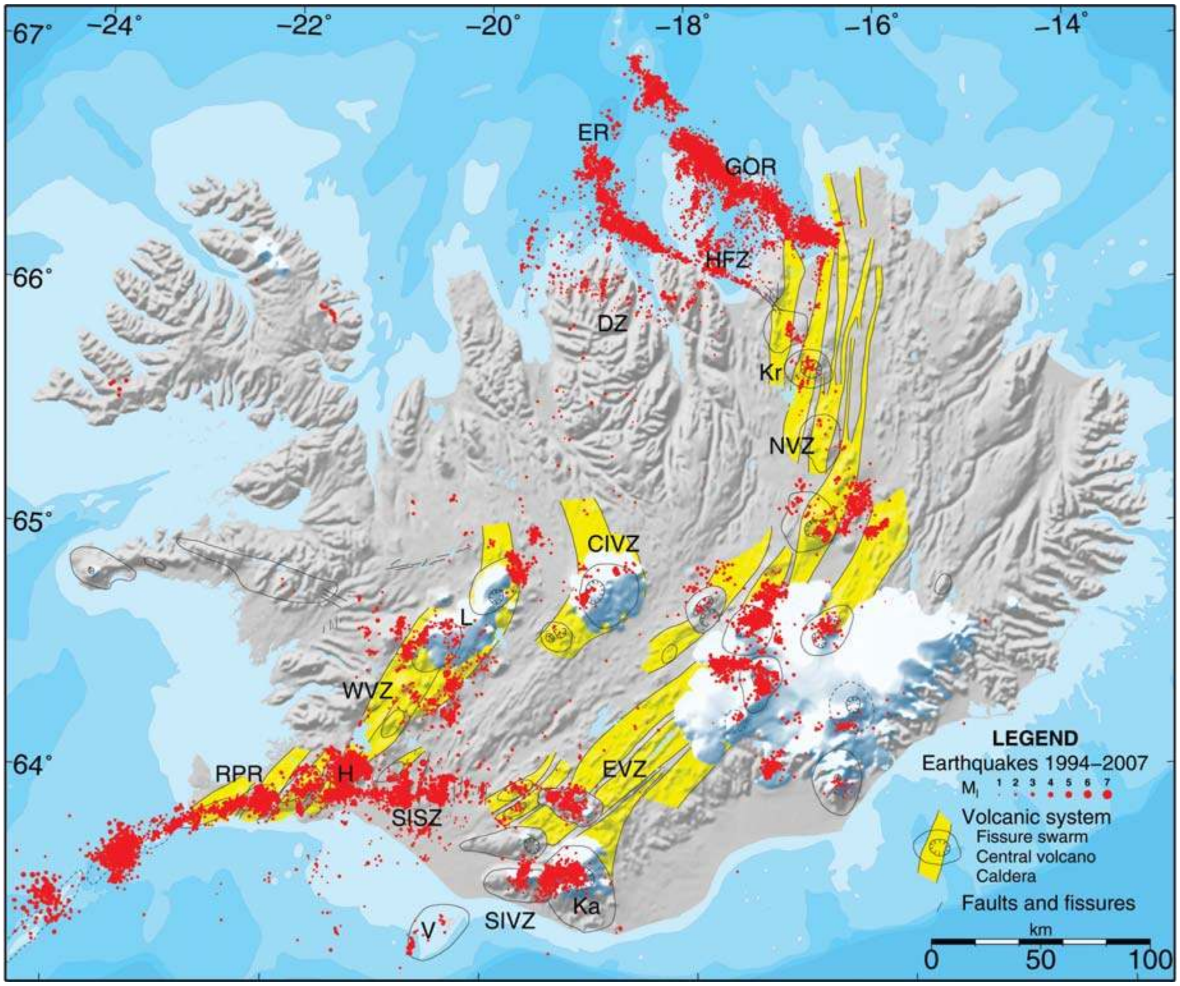

Figure 2. Earthquake epicenters 1994–2007 and volcanic systems of Iceland. Volcanic systems and active faults are from Einarsson and Sæmundsson (1987). Epicenters are from the data bank of the Icelandic Meteorological Office. Individual plate boundary segments are indicated: RPR Reykjanes Peninsula Rift, WVZ Western Volcanic Zone, SISZ South Iceland Seismic Zone, EVZ Eastern Volcanic Zone, CIVZ Central Iceland Volcanic Zone, NVZ Northern Volcanic Zone, GOR Grímsey Oblique Rift, HFZ Húsavík-Flatey Zone, ER Eyjafjarðaráll Rift, DZ Dalvík Zone. SIVZ South Iceland Volcanic Zone. Kr, Ka, H, L, V mark the central volcanoes of Krafla, Katla, Hengill, Langjökull, and Vestmannaeyjar. – *Upptök jarðskjálfta 1994–2007, misgengi og eldstöðvakerfi á Íslandi. Skjálftaupptök eru fengin frá Veðurstofu Íslands.*

determined by the length of the plate velocity vector and its degree of obliqueness along the segment. Some segments are purely divergent. In these segments normal faulting and fissuring are the main types of fracturing and volcanism is pervasive as seen in the Northern Volcanic Zone (NVZ) in North Iceland and the two sub-parallel rift zones in South Iceland, the Western and the Eastern Volcanic Zones (WVZ and EVZ). Other segments are conservative, i.e. are of transform type, such as the South Iceland Seismic Zone (SISZ) and the Húsavík-Flatey Zone (HFZ) in North Iceland. Strike-slip faulting is dominant and volcanism insignificant. Oblique segments contain volcanism and strike-slip tectonism in close proximity to each other. The Reykjanes Peninsula Rift (RPR) and the Grímsey Oblique Rift (GOR) are examples of this type. There is some evidence that the two modes of deformation alternate with time.

This paper gives an overview of the structural characteristics of the the plate boundary segments of Iceland. In most cases these characteristics are consistent with the orientation of the segments with respect to the plate separation vector. Exceptions are seen in South Iceland. Most of the discrepancies can, however, be explained by assuming the Hreppar block is a microplate that rotates with respect to the North America Plate around a pole north of Langjökull.

THE RELATIVE MOVEMENTS OF THE MAJOR PLATES

The pole of relative rotation between the two major plates is located in NE-Siberia at 62.4°N and 135.8°E, and the relative rotation speed is 0.21° per million years according to the Nuvel-1A model of plate motions (DeMets *et al.*, 1994). Holding the North America Plate fixed this gives a plate velocity vector of 18.2 mm/year in a direction of 105° for Central Iceland, slightly faster and more easterly for South Iceland, slightly slower and more southerly for North Iceland. This velocity is valid for the last few millions of years, the time scale of the magnetic and structural data used to constrain the Nuvel-1A model. GPS-data from the continuously recording stations (Figure 3) give results that are consistent with the Nuvel-1A velocity (Geirsson *et al.*, 2006), also results of measurements of the country-wide ISNET network in 1993 and 2004 (Árnadóttir *et al.*, this volume; Geirsson *et al.*, 2005) as well as the results from globally distributed GPS-stations (Sella *et al.*, 2002). This demonstrates that the plate movements are consistent on time scales ranging between years and million years. An example of the constant rate of movements is shown in Figure 3, the time series 1999–2008 for the continuous GPS-station at Höfn in SE-Iceland. When the annual cycle caused by snow load on the highlands (Grapenthin *et al.*, 2007) and the co-seismic effect of the June 2000 earthquakes in South Iceland on the reference station in Reykjavík have been removed, the graphs shows virtually straight lines. The slopes of the lines give an eastward component of 22.1 mm/year and a southward rate of 3.9 mm/year. The vector therefore has a magnitude of 22.4 mm/year and a direction of 100°.

PLATE BOUNDARY DEFORMATION ZONE

Between the major plates there is a zone of deformation where the crustal movements are different from that of the plates. The width of this deformation zone is somewhat variable. In Northern Iceland it is about 100 km wide and coincides more or less with the zone of Holocene volcanism and fissuring. The plate boundary deformation zone accumulates strain during time intervals between significant failure events such as rifting episodes or larger earthquakes. Such gradual accumulation has been documented for the EVZ by Jónsson *et al.* (1997), across the SISZ (Sigmundsson *et al.*, 1995; Alex *et al.*, 1999), and along the Reykjanes Peninsula oblique rift by Sturkell *et al.* (1994), Hreinsdóttir *et al.* (2001), and Keiding *et al.* (2007).

In Southern Iceland the plate boundary has two branches and the block between them does not show evidence of active deformation or volcanism. Earthquake epicenters are almost completely lacking (Figure 2). This block appears to fulfill the criteria of a microplate and has been termed the Hreppar Microplate. The southern boundary of the Hreppar Microplate is marked by the South Iceland Seismic Zone where large, strike-slip earthquakes occur. The northern boundary is marked by diffuse volcanism of the Central Iceland Volcanic Zone (CIVZ) and the relative movement across it seems to be slow.

It has been a matter of considerable debate how the plate movements in South Iceland are partitioned between the two parallel rift zones, the Western Volcanic Zone and the Eastern Volcanic Zone. It is gen-

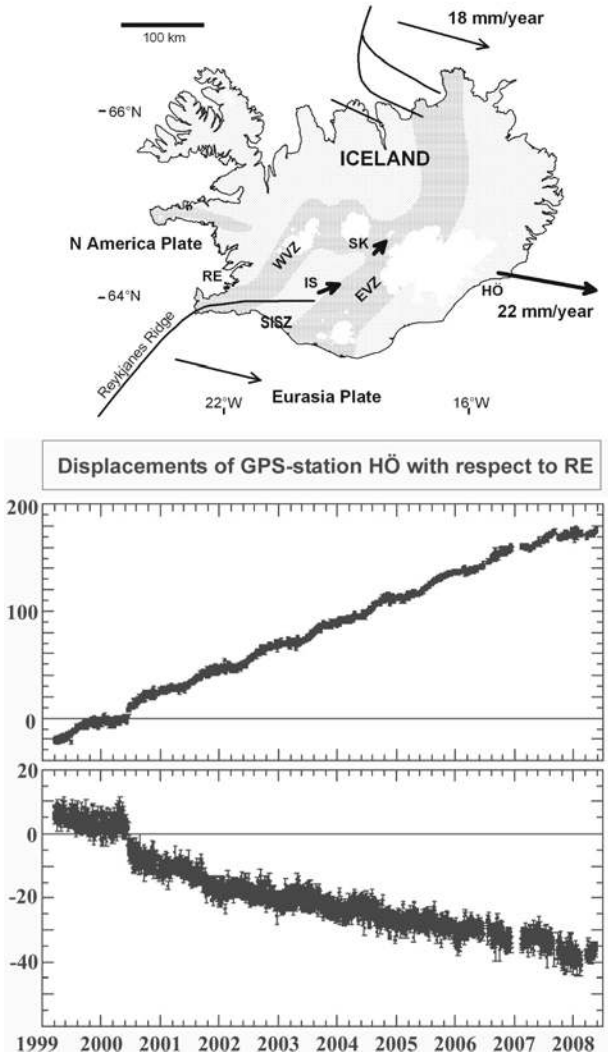

Figure 3. Velocities of the continuous GPS-stations Höfn (HÖ), Skrokkalda (SK), and Ísakot (IS) with respect to Reykjavík (RE) shown as fat arrows. Thin arrows show the calculated velocity of the Eurasia Plate with respect to the North-America Plate according to the Nuvel 1 model. Time-series of the displacements of the station of Höfn with respect to Reykjavík is shown (data from Halldór Geirsson, Icelandic Meteorological Office). Index map shows the plate boundaries. The velocities of the stations SK and IS are 3 mm/a in direction 50° and 5 mm/a in direction 70°, respectively. – *Rekhraði á samfelldu GPS-mælistöðvunum á Höfn í Hornafirði (HÖ), Skrokköldu (SK) og Ísakoti (IS) reiknaður miðað við Reykjavík. Þunnu örvarnar sýna rekhraðann á Evrasíuflekanum miðað við Norður-Ameríkuflekann reiknaðan eftir Nuvel-1-líkaninu fyrir flekarek á jörðinni. Einnig er sýnd færsla sem fall af tíma fyrir stöðina á Höfn í Hornafirði, reiknuð miðað við stöðina í Reykjavík. Kortið sýnir flekaskilin á Íslandi. Hraði stöðvanna tveggja sem eru á Hreppaflekanum er: Skrokkalda 3 mm/ári í stefnu 50° og Ísakot 5 mm/ári í stefnu 70°.*

erally assumed that the two zones are the expression of a ridge jump, i.e. that the WVZ is a dying rift that is being replaced by the currently much more active EVZ (e.g. Einarsson, 1991a). The question is whether the ridge jump occurs by rift propagation, i.e. the EVZ propagating towards the SW while the WVZ recedes, or by activity alternating between the rifts (Sigmundsson *et al*., 1995) and the whole WVZ gradually becoming less active. The lack of evidence for rotated structures within the Hreppar Microplate has been evoked to support the latter hypothesis. Recent modeling studies of GPS data, however, appear to support rotational movements of the Hreppar Microplate (La Femina *et al*., 2005), which is in favour of the propagating rift hypothesis. The model results indicate that near the Hengill triple junction as much as 35% of the plate movements is taken up by the WVZ. This proportion dies out towards the NE and is less than 10% in the Langjökull region. This must indicate a counter-clockwise rotation of the Hreppar

Microplate, considering the lack of evidence for significant irreversible internal deformation of that plate.

TECTONIC STRUCTURE OF THE PLATE BOUNDARY SEGMENTS

The plate boundary in Iceland can be divided into segments, each with its tectonic and magmatic characteristics and properties. Different authors have used different schemes for the division and there is considerable confusion in the use of names in the literature. In the following text we attempt to clarify this situation.

Crustal formation occurs by magmatism in zones of divergence. Most of the activity is linked with volcanic systems, about 25 of which have been identified on land and 10 more in the shelf areas to the north and south. A volcanic system is defined from its structural and petrologic characteristics (Sæmundsson, 1978; Jakobsson, 1979a,b). It consists of a central volcano and a fissure swarm that transsects it in a direction nearly normal to the local spreading direction. The magmatic activity has a maximum in the central volcano, most of it basaltic but it may contain acidic rocks as well (Walker, 1993). Sometimes calderas develop in the central volcano and most also have geothermal systems. The central volcanoes seldom reach high elevation. Loading of the crust by volcanic production is compensated by subsidence of the weak and warm crust. The volcano therefore grows downwards more than upwards. The fissure swarms are 5–20 km wide and from a few tens to more than 100 km long. They often have the structure of a gentle graben bounded by normal faults of small throw. The volcanic systems are arranged side-by-side in some of the rift zones or are en echelon in the oblique zones.

The volcanic rift zones usually occupy a gentle synform. Strata on their flanks tilt gently towards the zone. This is caused by sagging of the crust in response to loading of volcanic material onto the surface within the zone. This loading in combination with the divergence of the plates across the zone produces the dip according to the model of Pálmason (1980, 1986).

Transform zones form where the plate velocity vector is parallel or sub-parallel to the boundary. The deformation is usually not concentrated on a single transform fault but is instead distributed over a zone of finite width. Transform faulting occurs mainly in two zones, the Tjörnes Fracture Zone near the north coast and the South Iceland Seismic Zone. The accumulated strain in these zones is released during strike-slip earthquakes, as large as magnitude 7, that take place at intervals of decades to centuries (Einarsson, 1991a). The transform motion is commonly achieved by strike-slip on faults that are transverse to the zone. The blocks between the faults are then slightly rotated. A model of books in a bookshelf provides an analogy to this type of faulting. Bookshelf faulting may be taken as evidence for youthfulness of these zones. Icelandic transform zones appear to be young and unstable.

SYSTEMATICS OF THE PLATE BOUNDARY SEGMENTS

The Reykjanes Peninsula oblique rift

The Reykjanes Peninsula in SW Iceland is a structural continuation of the Reykjanes Ridge. The whole ridge north of 56°N is oblique to the spreading direction and resembles faster spreading ridges, both with regard to topography and seismicity (Figure 1, Einarsson, 2001). This has been ascribed to the proximity to the Iceland hotspot. The obliqueness increases as the ridge approaches Iceland. As the ridge axis enters the shelf area SW of Iceland it is expressed as a series of constructional mounds sitting on a flat, eroded surface (Johnson and Jakobsson, 1985) left by the Pleistocene glacier. The tectonic structure here and on the Reykjanes Peninsula is characterized by volcanic systems that are arranged en echelon along the plate boundary. The fissure swarms of the volcanic systems are oblique to the boundary (have a trend of about 35°, Table 1) and extend a few tens of kilometres into the plates on either side.

The plate boundary goes onshore at the SW tip of the Reykjanes Peninsula and extends from there with a trend of 70° (azimuth) along the whole peninsula. The structure of this zone is relatively homogeneous until it joins with the Western Volcanic Zone and the South Iceland Seismic Zone at the Hengill Triple Junction near 64°N and 21.4°W. The most prominent structural elements are extensional, i.e. hyaloclastite ridges formed by fissure eruptions beneath the Pleistocene glacier, postglacial eruptive fissures, normal faults and open fissures. These structures trend mostly between 30°and 40°, i.e. highly oblique to both the plate boundary and the plate velocity vector (Figure 4). The average trend of several of the most prominent features is 35°. The fissures and normal faults are grouped into swarms, 4-5 of which can be identified and are shown in Figure 2. The swarms are usually named after the geothermal areas that occur in their central part: Reykjanes (sometimes divided into Reykjanes and Svartsengi), Krísuvík, Brennisteinsfjöll, and Hengill.

Less conspicuous, but probably equally important, are strike-slip faults that cut across the plate boundary at a high angle. They are expressed as N-S trending arrays of left-stepping, en-echelon fissures with push-up hillocks between them. The left-stepping arrangement implies right-lateral movement along these faults. Typical spacing between the faults is 1 km but in some areas it may be as small as 0.4 km. The strike-slip faults are most prominent in the areas between the fissure swarms but this may be misleading. The pervasive nature of the fissure swarms may conceal eventual strike-slip faults that intersect them. The N-S strike-slip faults may act to accommodate the transcurrent component along the plate boundary in the same way as is explained for the South Iceland Seismic Zone by the bookshelf model, see below (Hreinsdóttir *et al.*, 2001; Clifton and Kattenhorn, 2007).

Seismicity on the Reykjanes Peninsula is high and appears to be episodic in nature with active episodes occurring every 30 years or so. Recent active periods were in the beginning of the 20th century, 1929–1935, 1967–1973, and in 2000. The largest earthquakes in the latest episodes are known to have been associated with strike-slip faulting (e.g. Einarsson, 1991a; Árnadóttir *et al.*, 2004). At the present time, therefore, deformation along the plate boundary appears to be accommodated by strike-slip faulting, possibly with some contribution of crustal stretching (Keiding *et al.*, 2006). No evidence of magmatic contribution has been detected in the last decades, such as inflation sources, volcanic tremor, or earthquake swarms propagating along the fissure swarms.

Magmatic activity within this segment also appears to be highly episodic, but with a much longer period. An active period occurred shortly after the settlement of Iceland, beginning in 950 AD and ending in 1240 AD. During this period all the volcanic systems of the peninsula had an eruptive episode with numerous lava eruptions issuing from their fissure swarms. No eruptions have occurred on the peninsula since then. Similar magmatic periods appear to have occurred earlier, about every thousand years or so (Sigurgeirsson, 1992, 2004; Sæmundsson and Jóhannesson, 2006).

Crustal deformation along the plate boundary on the Reykjanes Peninsula appears to occur in two different modes (Hreinsdóttir *et al.*, 2001): (1) dry or seismic mode, and (2) wet or magmatic mode. Deformation in the dry mode occurs mostly by strike-slip faulting during periods when magma is not available to the crust in any appreciable quantity. The mode of deformation changes when magma enters the crust. Dikes are opened up against the local minimum compressive stress and they propagate into the plates on both sides of the plate boundary and the fissure swarms are activated.

The South Iceland Seismic Zone

The southern boundary of the Hreppar Microplate is marked by a zone of high seismic activity, the South Iceland Seismic Zone, which takes up the transform motion between the Reykjanes Ridge and the Eastern Volcanic Zone (Einarsson, 1991a). It is oriented E-W and is 10–15 km wide N-S. Destruction areas of individual earthquakes and surface faulting show, however, that each event is associated with faulting on N-S striking planes, perpendicular to the main zone. The over-all left-lateral transform motion along the zone is thus accommodated by right-lateral faulting on many parallel, transverse faults and counterclockwise rotation of the blocks between them, “bookshelf faulting“ (Einarsson *et al.*, 1981).

The largest earthquakes in the South Iceland Seismic Zone have a tendency to occur in sequences, beginning with the largest event located in the eastern part of the zone and followed by smaller events farther west (Einarsson *et al.*, 1981). Sequences of this

Table 1. Characteristics of plate boundary segments. – *Einkenni einstakra belta flekaskilanna.*

Plate Boundary Segment	Plates	Trend A (° Azim.)	Trend B (° Azim.)	Velocity (mm/a)
Reykjanes Peninsula Rift, RPR	NA-EU	70	35	19
Western Volcanic Zone, WVZ	NA-HR	30	30	1-5
South Iceland Seismic Zone, SISZ	HR-EU	90	0	14
Eastern Volcanic Zone, EVZ	HR-EU	43	43	14-18
Central Iceland Volcanic Zone, CIVZ	NA-HR	90	varied	1
Northern Volcanic Zone, NVZ	NA-EU	0	8	18
Grímsey Oblique Rift, GOR	(TJ)-EU	310	350	(13)
Húsavík-Flatey Zone, HFZ	NA-(TJ)	300	305	(5)
Eyjafjarðaráll Rift, ER	NA-(TJ)	10	10	(5)

Plates: NA North America, EU Eurasia, HR Hreppar Microplate, (TJ) Tjörnes Microplate. Trend A: Overall trend of the zone. Trend B: Trend of principal structures

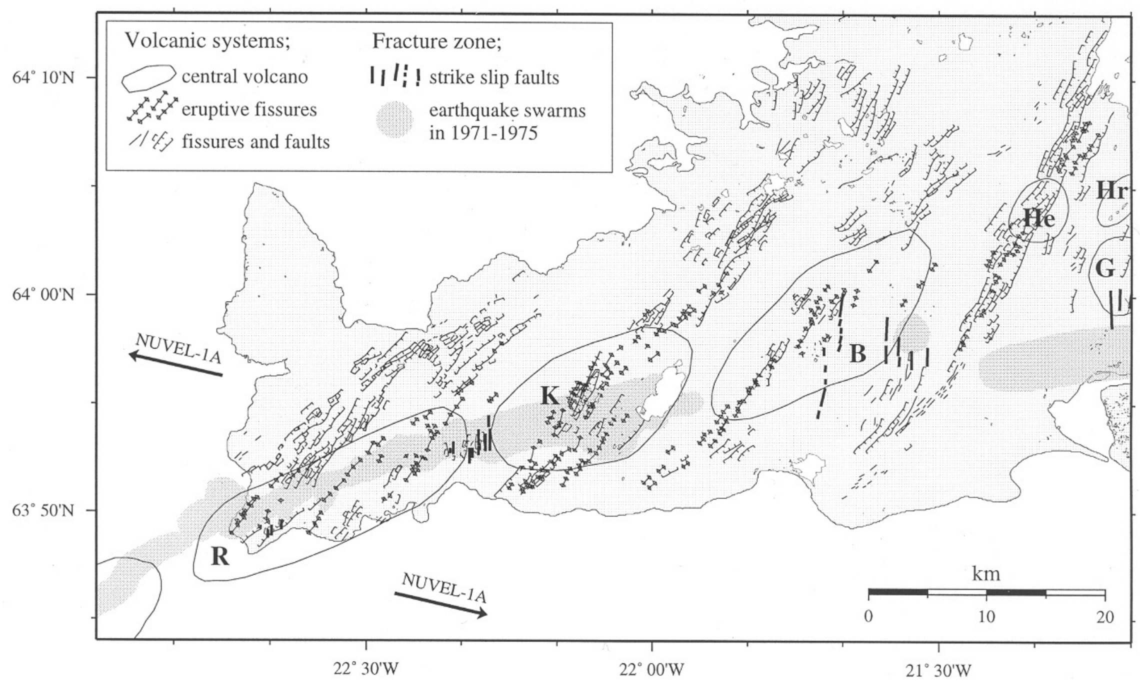

Figure 4. Faults and fissures on the Reykjanes Peninsula, modified from Hreinsdóttir *et al.* (2001) and Clifton and Kattenhorn (2007). – *Misgengi og sprungur á Reykjanesskaga.*

type are documented in 1630–1633, 1732–1734, 1784 and 1896, and historical evidence seems to indicate that similar sequences also occurred in 1294, 1339, and 1389–1391. The inter-sequence time intervals are thus in the range 45 to 112 years. The return period of total strain release of the zone has been estimated about 140 years (Stefánsson and Halldórsson, 1988; Stefánsson *et al.*, 1993).

The South Iceland Seismic Zone, shows widespread evidence of Holocene faulting. Glaciated surfaces, alluvial plains and Postglacial lava flows are fractured along the 15 km wide, 70 km long, E-W trending seismic zone (Einarsson and Eiríksson, 1982; Einarsson *et al.*, 1981, 2002; Clifton and Einarsson, 2005). An effort has been made to map all recognisable Holocene fault structures in this zone (Figure 5). A large majority of all fractures strike NNE to NE and form left-stepping, en echelon fracture arrays with a northerly trend. They are associated with right-lateral faulting at depth. Right-stepping arrays also exist, apparently associated with faulting on conjugate faults with ENE strike, but they are mostly of secondary nature. Other fault trends also occur, but are rare. Push-up structures are prominent in association with the en echelon arrays, sometimes reaching heights of several meters. The mapped fractures associated with a few of the large, historical earthquakes in this region (e.g. the 1630, 1784, 1896, and 1912 earthquakes) are confined to narrow, N-S trending zones crossing the SISZ at a high angle. The magnitude of these earthquakes is in the range 6.5–7.

The South Iceland Seismic Zone was hit by a series of earthquakes in June 2000, two of which caused considerable damage (Stefánsson *et al.*, 2003). The earthquakes follow a pattern of large historic earthquakes in this zone and began on June 17 with a mag-

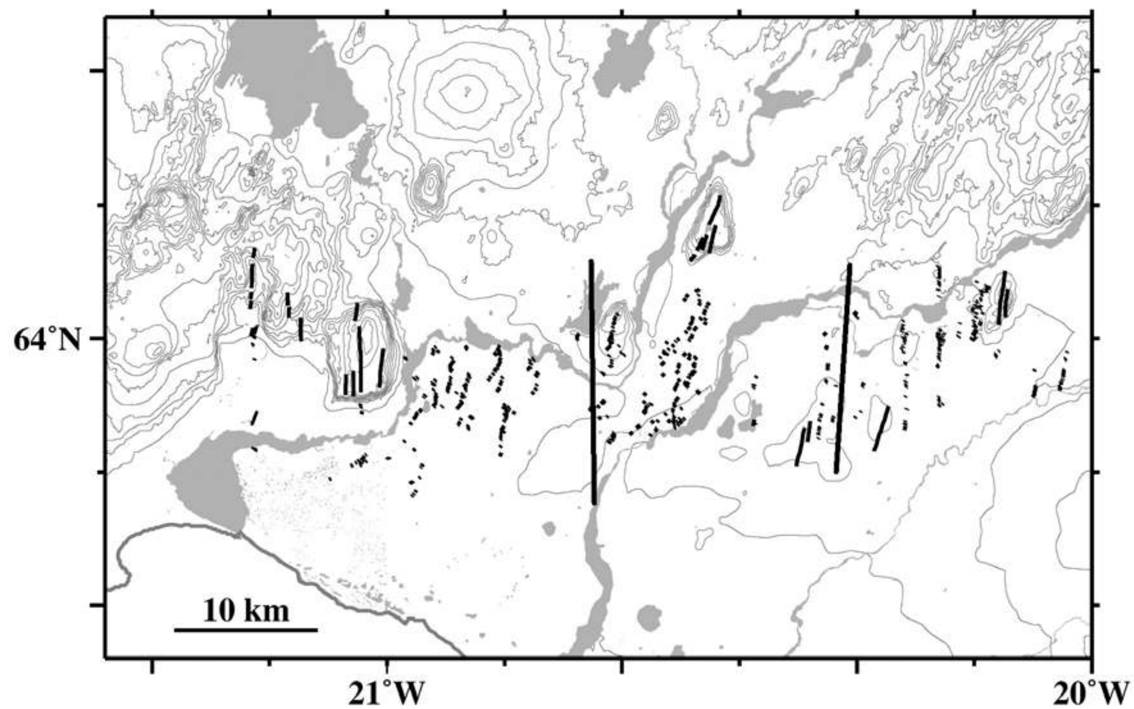

Figure 5. Mapped Holocene faults in the South Iceland Seismic Zone. The heavy N-S lines show the source faults of the June 17 and 21, 2000, earthquakes. – *Kortlagðar sprungur frá nútíma á Skjálftabelti Suðurlands. Stóru N-S línurnar merkja misgengin sem virk voru í skjálftunum 17. og 21. júní 2000.*

nitude 6.5 event in the eastern part of the zone. This immediately triggered a flurry of activity along at least a 90 km-long stretch of the plate boundary to the west. This activity included three events with magnitudes larger than 5 on the Reykjanes Peninsula oblique rift (Clifton *et al.*, 2003; Pagli *et al.*, 2003; Árnadóttir *et al.*, 2004). A second mainshock, also of magnitude 6.5, occurred about 20 km west of the first one on June 21. The mainshocks of the sequence occurred on N-S striking faults, transverse to the zone itself. The sense of faulting was right-lateral strike-slip. One of the events of the sequence has the characteristics of a "slow earthquake", i.e. the radiation of seismic waves is comparatively weak for the amount of faulting observed by InSAR or GPS.

The two largest events of the sequence occurred on pre-existing faults and were accompanied by surface ruptures consisting primarily of en echelon tension gashes and push-up structures (Clifton and Einarsson, 2005). The main zones of rupture were about 15 km long, and coincided with the epicentral distributions of aftershocks. Fault displacements were of the order of 0.1–1 m at the surface. Faulting along conjugate, left-lateral strike-slip faults also occurred (Bergerat and Angelier, 2003), but was less pronounced than that of the main rupture zones. The co-seismic displacement field of the earthquakes was captured by InSAR and GPS-measurements (Pedersen *et al.*, 2001; Árnadóttir *et al.*, 2001). According to modeling of these data (Pedersen *et al.*, 2003) faulting extends from the surface to a depth of 10 km in both events. Maximum displacements are 2.6 m and 2.9 m, respectively.

The sense of faulting during this 2000 earthquake sequence conforms to the model of "bookshelf faulting" for the South Iceland Seismic Zone. It was furthermore demonstrated that bookshelf faulting continues to the west, along the Reykjanes Peninsula oblique rift (Árnadóttir *et al.*, 2004).

The Western Volcanic Zone

This rift zone branches from the Reykjanes Peninsula and the South Iceland Seismic Zone at the Hengill Triple Junction. It contains the Hengill volcanic system with its fissure swarms, part of which is the Þingvellir Graben partly filled by the lake Þingvallavatn. It then extends NE to the Langjökull area. The volcanic systems there are partly covered by the Langjökull glacier which obscures the structures. The Western Volcanic Zone seems to have been the main rift in the southern part of Iceland in the last 7 million years (e.g. Kristjánsson and Jónsson, 1998). The activity has been dwindling in the last few million years and only a minor part of the total spreading is occurring in this zone at the present. Open fissures and eruptive fissures are common in the southern part of the zone, in the Hengill volcanic system, but become less prominent towards the north. Normal faulting is, on the other hand, quite prominent throughout the zone and fault throws as large as 150 m have been reported (e.g. Gudmundsson *et al.*, 1992), which is rather unusual for Icelandic divergent zones. The fissure swarms of the volcanic systems are almost parallel to the trend of the zone itself (see Figure 2) indicating spreading direction perpendicular to the zone. The average trend of the most prominent extensional structures is 30° (Figure 6), excluding the trend of the Jarlhettur hyaloclastite ridge, that is located at the eastern margin of the zone and has a significantly more easterly trend than the others (38°). Lava shields are common in this zone. Volcanic activity has been low in the last 1000 years (Sinton *et al.*, 2006).

The rather spectacular extensional structures of the WVZ, the Þingvellir Graben in particular, have frequently been taken as the type examples and proof of plate divergence in Iceland. It now seems, however, that the large topographic relief here is the telltale sign of a magma-starved rift (Sæmundsson, 1986, 1992). The plate divergence is taken up by crustal stretching and normal faulting rather than by dike intrusions and lava effusion.

The crustal dilation across the WVZ has been estimated by many authors and by many methods. Decker *et al.* (1976) measured a distance profile across the WVZ for the period 1967–1973 and concluded that insignificant lengthening had occurred, or about 3 mm per year. Guðmundsson (1987) estimated the crustal stretching by measuring the total widening of dilatational cracks in the 9000 years old lava that covers the Þingvellir area. He estimated that about half of the total spreading was taken up by the zone. GPS-

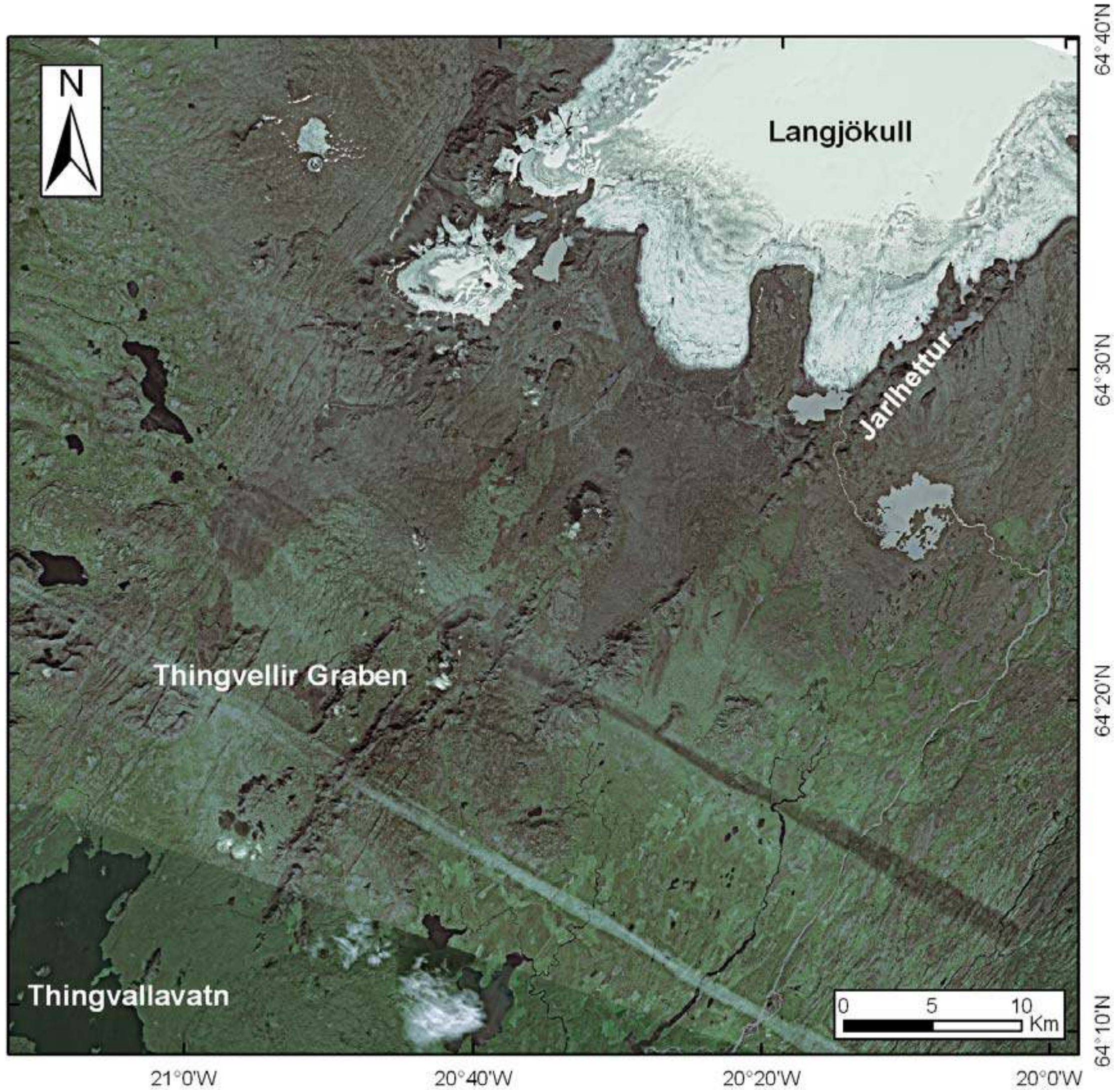

Figure 6. A ©SPOT-image of the Western Volcanic Zone. – *SPOT-gervitunglamynd af vestara gosbeltinu.*

measurements in the last two decades offer more reliable estimates. Sigmundsson *et al*. (1995) estimate that (15±15)% of the spreading is taken up by the WVZ. La Femina *et al*. (2005) find the proportion to be 35% at the southern end, i.e. in the Hengill area, and decrease towards the NE. A profile just south of Langjökull shows only 10% of the full spreading rate. This rapid fall-off in spreading rate with distance along the boundary indicates that the pole of relative rotation between North America and Hreppar is to the north and nearby, or within a distance of 100 km at most.

The Eastern Volcanic Zone

This rift zone extends from the eastern end of the South Iceland Seismic Zone and about 100 km to the NE, to Central Iceland where it joins with the Northern Volcanic Zone and the Central Iceland Volcanic Zone in a triple junction (Figure 2). It is characterised by long, linear structures (Thorarinsson *et al.*, 1973), eruptive fissures and normal faults. The fissure swarms of the volcanic systems are largely parallel to the zone itself and define a strong NE trend.

Although extensional structures are characteristic for the two volcanic rift zones in South Iceland (WVZ and EVZ) their structure is remarkably different. The most prominent structures in the Eastern Zone are constructional, i.e. volcanic fissures and their subglacial equivalents, long hyaloclastite ridges (Figure 7). In the Western Zone normal faults are most prominent. Volcanic fissures and hyaloclastite ridges exist but they are generally shorter and subordinate.

The central volcanoes of the EVZ are grouped in Central Iceland, to a large extent covered by the Vatnajökull glacier (Björnsson and Einarsson, 1990). They are connected to fissure swarms that issue from the glacier to the SW (Figure 7). Eruptive activity is very high, and large basaltic eruptions have occurred here in historic times, often on long fissures such as the Laki fissure active in 1783, the Veiðivötn fissure active in about 1480 AD, the Eldgjá fissure active in 934 AD, and the Vatnaöldur fissure active about 872 AD (Thordarson and Larsen, 2007). All these historical eruptions were of large volume, 2–15 km^3. Lava shields are virtually unknown in this zone. The Grímsvötn volcanic system includes the Laki fissure, and the Bárðarbunga system comprises the Vatnaöldur and Veiðivötn fissures, as well as the Heljargjá graben. The Eldgjá fissure is a part of the Katla volcanic system that is located in the South Iceland Volcanic Zone south of the plate boundary.

The Eastern Volcanic Zone appears to be young, taking over as the main rift in South Iceland from the receding Western Volcanic Zone in the last 3 million years. Both Jónsson *et al.* (1997) and LaFemina *et al.* (2005) have demonstrated that elastic strain accumulation is in progress across the EVZ. Seismic background activity is very low.

The Central Iceland Volcanic Zone

The Hofsjökull volcanic system and possibly also the Tungnafellsjökull system in Central Iceland do not fit readily into the rift zones defined above. A separate zone may be defined that is highly oblique to the spreading direction. Volcanic activity has been low in the Holocene. This zone, together with the South Iceland Seismic Zone and the Western and Eastern Volcanic Zones, demarcate the Hreppar Microplate. Two fissure swarms radiate from the Hofsjökull central volcano, one to the SW and the other to the NNW (Figure 2). The latter is more pronounced and consists mostly of normal faults. The fissure swarms of the Tungnafellsjökull volcano are not very pervasive. Movements of faults there, of the order of a few cm, were detected by InSAR during the Gjálp eruption of 1996 (Pagli *et al.*, 2007).

The Northern Volcanic Zone

This rift zone extends from central Iceland to the north coast where it joins with the Tjörnes Fracture Zone. Volcanic systems are well defined and their fissure swarms are arranged in a left-stepping, en echelon pattern along the zone, consistent with the slightly oblique orientation of the plate boundary and the resulting right-lateral component of the spreading vector. There is a gentle change in the trend of extensional structures along the zone, becoming more northerly towards the north. Rifting structures and eruptive fissures are common but lava shields are responsible for a good part of the Holocene volcanism (Sigvaldason *et al.*, 1992). The main volcanic systems within the zone are named after their respective central volcanoes, Kverkfjöll, Askja, Fremrinámar, Krafla and Þeistareykir (Sæmundsson, 1974). Sometimes a separate system, Heiðarsporður, is defined south of Krafla (Sæmundsson, 1991), and lately a separate system, Hrúthálsar, is also defined north of Askja (Sæmundsson *et al.*, 2005).

Although the volcanic systems of the NVZ all have some of the characteristics of volcanic systems, they are remarkably different from each other. The Þeistareykir system, e.g., has a very strong and well developed fissure swarm but no caldera, and silicic rocks are insignificant. The Krafla system has a

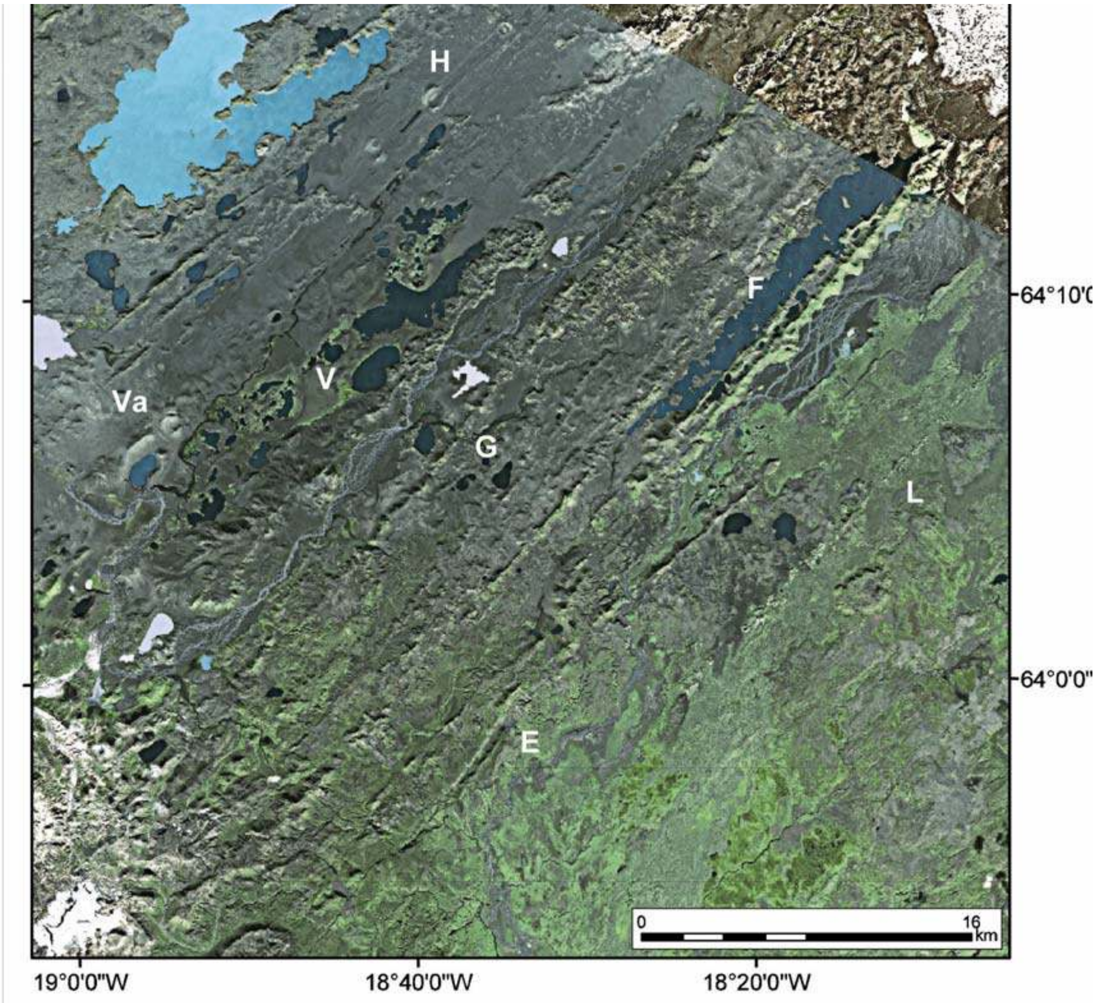

Figure 7. ©SPOT-image of the Eastern Volcanic Zone. The structure is dominated by volcanic fissures such as the Laki fissure (L), the Veiðivötn fissure (V), the Eldgjá fissure (E), and the Vatnaöldur fissure (Va). The hyaloclastite ridges Fögrufjöll and Giljabrúnir and the Heljargjá Graben are also marked (F, G, and H). – *SPOT-gervitunglamynd af Eystra gosbeltinu. Beltið einkennist af löngum, tiltölulega beinum gossprungum, móbergshryggjum og sigdölum.*

caldera that has been partly filled and is cut by a strong and pervasive fissure swarm (Figure 8). Contribution of silicic magma is considerable and the geothermal system is powerful. The fissure swarm of the Askja system is very long but the high activity of the central volcano almost completely obliterates it in the caldera region (Hjartardóttir, 2008). The central region of the Fremrinámar central volcano is covered by two large lava shields. No calderas are visible. Lava shields are generally very prominent in the NVZ. Many of them were active in the first few millenia of the Holocene (Sigvaldason *et al*., 1992).

Figure 8. ©SPOT-image of the Krafla volcanic system and surroundings in the northern part of the Northern Volcanic Zone. The indistinct Krafla caldera is marked with a line, also the most prominent extensional structures Austaribrekka normal fault (A), Sandvatnsbrekka normal fault (S), Þrengslaborgir eruptive fissure (T), and the Krafla 1984 eruptive fissure (K). – *SPOT-gervitunglamynd af eldstöðvakerfi Kröflu og næsta umhverfi. Kröfluaskjan er sýnd, einnig nokkur áberandi siggengi og gossprungur.*

The activity in the volcanic systems appears to be episodic. An episode of magmatic and tectonic events may last several years or a decade, and be separated from the next episode by centuries or thousands of years. Only the Askja and Krafla systems have had episodes involving eruptions in Historic times (Björnsson *et al.*, 1977), Askja in 1874–1876 and 1921–1929, and Krafla in 1724–1746 and 1974–1989. There are indications that the Þeistareykir system had a rifting episode without eruptive activity in 1618 (Björnsson *et al.*, 1977).

The Krafla rifting episode of 1974–1989 provided a dramatic demonstration of crustal deformation along a divergent plate boundary where strain had been accumulating for more than two centuries. It involved a sequence of magmatic and tectonic events along the plate boundary in N-Iceland. It was accompanied by the largest earthquake sequence so far recorded along the divergent plate boundaries of the Atlantic (Einarsson, 1986). The events took place mainly within the Krafla volcanic system between latitudes of 65°34'N and 66°18'N (Figure 1). During most of the episode, magma apparently ascended from depth and accumulated in the magma chamber at about 3 km depth beneath the central volcano (e.g. Tryggvason, 1980; Ewart *et al.*, 1991). The inflation periods were punctuated by sudden deflation events lasting from several hours to 3 months when the walls of the chamber were breached and magma was injected laterally into the adjacent fissure swarm where subsequently large-scale rifting took place. Rifting, fissuring and graben subsidence took place in the fissure swarm but the flanks were uplifted and contracted laterally as the rift widened (e.g. Sigurdsson, 1980; Torge and Kanngiesser, 1980; Kanngiesser, 1983). A total of about 20 discrete rifting events were identified, each one affecting only a portion of the fissure system (Björnsson *et al.*, 1979; Tryggvason, 1980; Einarsson, 1991a,b). Subsidence within the Krafla caldera was concurrent with rifting and widening of segments of the Krafla fissure swarm (Björnsson *et al.*, 1977, 1979; Tryggvason, 1980, 1984, 1994). Early deflation episodes were primarily associated with subsurface movements of magma and little or no lava extrusion. Later in the sequence most of the magma removed from the magma chamber reached the surface in fissure eruptions lasting from 5 to 14 days. Maximum cumulative extension of 8–9 m was measured across the fissure swarm slightly north of the Krafla volcano. A large segment of the plate boundary was affected by the Krafla events, extending at least 20 km south of Krafla and 70 km north of the volcano, at least to the rift-transform intersection in Axarfjörður (Figure 2). The rifting during the Krafla volcano-tectonic sequence can be modeled as elastic reaction to the failure of the elastic part of the crust under stress that had accumulated in the plate boundary region during the previous decades and centuries (Buck *et al.*, 2006).

The sudden stress change in the elastic layer leads to increased differential stress in the underlying viscoelastic layer and viscous reaction, which in turn induces movements in the elastic surface layer. These movements decay with time in an exponential way. Post-rifting movements were measured after the Krafla events (Jahn *et al.*, 1994; Foulger *et al.*, 1992; Heki *et al.*, 1993; Völksen and Seeber, 1998) but appear to be over according to the 1993–2004 ÍSNET results (Árnadóttir *et al.*, this issue).

The Tjörnes Fracture Zone

The Tjörnes Fracture Zone is a broad zone of seismicity, transform faulting and crustal extension that connects the southern end of the submarine Kolbeinsey Ridge to the Northern Volcanic Rift Zone (Einarsson, 1991a; Stefansson *et al.*, 2008). The plate motion is taken up by several sub-parallel NW-trending seismic zones, the Grímsey seismic zone, the Húsavík-Flatey fault zone and the Dalvík seismic zone (Einarsson, 1976, 1991a) and a few northerly trending rift or graben structures.

The Grímsey Oblique Rift is suggested as a name for the northernmost seismic zone, which is entirely off shore. It has an overall NW-SE trend (Einarsson, 1976) but is composed of several volcanic systems with N-S trend. Evidence for Holocene volcanism is abundant (McMaster *et al.* 1977; Brandsdóttir *et al.*, 2005). At its SE end the zone connects to the Krafla fissure swarm, but the NW-end joins the Kolbeinsey Ridge just south of Kolbeinsey Island. The larger earthquakes of the Grímsey Zone seem to be associated with left-lateral strike-slip faulting on NNE-striking faults (Rögnvaldsson *et al*., 1994). The zone has the characteristics of an oblique rift. There is a striking similarity between the Reykjanes Peninsula and the Grímsey Zone. The two zones are symmetrical with respect to the plate separation vector. The similarity is seen in the overall trend, the en echelon fissure swarms, transverse bookshelf faults, and the occurrence of geothermal areas. Earthquake swarms are common in both zones.

The second seismic zone, **the Húsavík-Flatey Zone**, is about 40 km south of the Grímsey zone, and is well defined by the seismicity near its western end, where it joins with the Eyjafjarðaráll Rift. This transform zone can be traced on the ocean bottom to the coast in the Húsavík town, continuing on land into the volcanic zone, where it merges into the Þeistareykir fissure swarm (Sæmundsson, 1974; Gudmundsson *et al*. 1993), (Figure 9). This is a highly active seismic zone. The last major earthquakes occurred in 1872 when the town of Húsavík suffered heavy damage (e.g. Björnsson and Einarsson, 1981). Volcanism only plays a subordinate role if any.

A third zone, **the Dalvík zone**, is indicated by seismicity about 30 km south of the Húsavík-Flatey Zone (Einarsson, 1976, 1991a). Earthquakes as large as M_S 7 have occurred in this zone, but it lacks clear topographic expression. In spite of rather clear alignment of epicenters, the Dalvík zone is not seen as a through-going fault on the surface (Långbacka and Gudmundsson 1995; Gudmundsson, 1995). A common feature of all three seismic zones is the occurrence of earthquakes on transverse structures (Rögnvaldsson *et al*., 1994), see also Figure 2, similar to that observed in the South Iceland Seismic Zone and the Reykjanes Peninsula.

A well-developed rift, the Eyjafjarðaráll Rift, has been identified in a southward continuation of the Kolbeinsey Ridge. This zone is characterised by normal faulting on faults perpendicular to the spreading vector indicating crustal extension. Signs of volcanic activity are scarce (Brandsdóttir *et al*., 2005), however, suggesting that this rift is starved of magma at the present time. The rift is connected with the Húsavík-Flatey Zone in the south. Together with the Grímsey Oblique Rift and the northernmost extension of the Northern Volcanic Rift Zone these zones demarcate a crustal block. It remains to be tested if it is possible or practical to define this block as a microplate with its own kinematics.

Flank zones

Volcanism also occurs in zones outside the immediate plate boundary. These zones are sometimes called volcanic flank zones, off-rift volcanic zones or intraplate volcanic zones (e.g. Jakobsson, 1979b, Sæmundsson, 1978, 1986). The South Iceland Volcanic Zone is a direct continuation of the Eastern Volcanic Zone beyond its junction with the South Iceland Seismic Zone (see Figure 2). It contains several very active volcanic systems, including the Hekla and Katla volcanic systems. Rifting structures are, however, not prominent, consistent with this zone's intraplate setting. The zone has been interpreted as the propagating tip of the Eastern Volcanic Zone into the Eurasia Plate (e.g. Óskarsson *et al*., 1985; Meyer *et al*., 1985).

The Snæfellsnes Volcanic Zone is entirely intraplate and is not connected to the presently active plate boundary. It contains three volcanic systems that rest unconformably on Tertiary crust and have been active in the Holocene, Snæfellsjökull, Lýsuhóll and Ljósufjöll. Their fissure swarms have a WNW-trend, almost parallel to the spreading vector. At its eastern end it continues as a moderately active seismic zone, last active in the Borgarfjörður earthquakes of 1974 (Einarsson *et al*., 1977; Einarsson, 1989). The origin of the Snæfellsnes zone remains enigmatic even though most authors seem to agree that it is related to the location of the center of the Iceland hotspot at this latitude.

The Öræfajökull Volcanic Zone is located well east of the presently active plate boundary. It comprises three volcanic systems that must be considered active, Öræfajökull, Esjufjöll and Snæfell, although only the first one has had confirmed eruptions in the last few thousand years. The structure of this zone is only poorly known as most of it is hidden beneath the Vatnajökull glacier. It has been speculated that this zone is the first sign of an impending ridge jump, accommodating the westward movement of the Eurasia Plate with respect to the Iceland mantle plume.

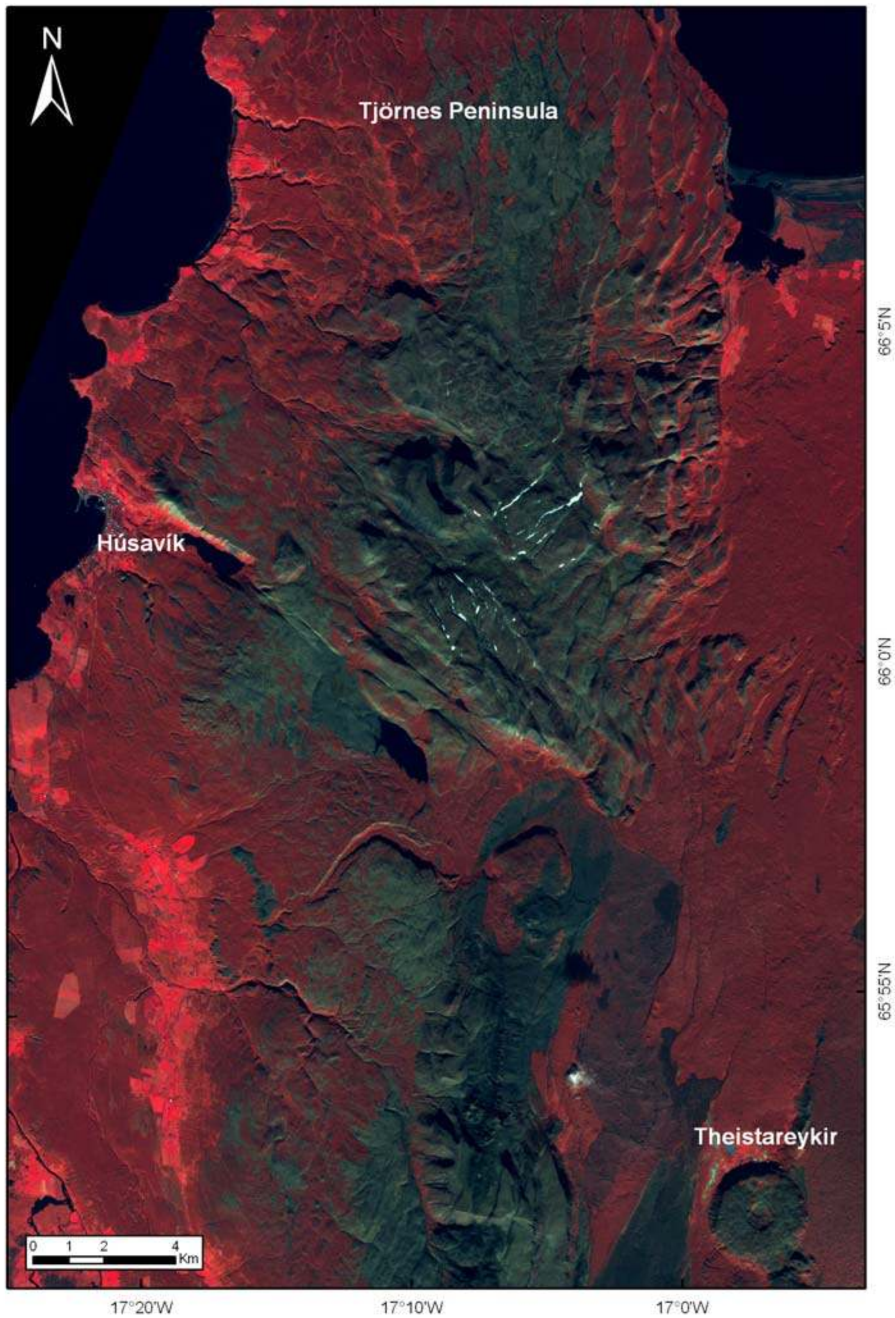

Figure 9. ©SPOT-image of the triple junction formed where the Húsavík-Flatey Zone merges with the Þeistareykir fissure swarm. – *SPOT-gervitunglamynd af þrípunktinum þar sem Húsavíkur-Flateyjar-sprungubeltið mætir sprungusveim Þeistareykja.*

THE HREPPAR MICROPLATE AND ITS POLES OF RELATIVE ROTATION

In two areas of Iceland the plate boundary branches out and appears particularly complicated, i.e. in South Iceland where rifting occurs in two sub-parallel rift zones, and at the north coast where two or three branches of the Tjörnes Fracture Zone appear to take up the transform motion. The question arises whether these complications can be better understood by defining microplates. Two conditions must be fulfilled: 1) The plate must be well defined, i.e. a block of little or no internal deformation surrounded by active boundaries. 2) A consistent set of poles of relative rotation with respect to adjacent plates must be found.

The general idea that the two sub-parallel rift zones in South Iceland delimit a crustal block of little deformation is not new. It appeared in the first papers on the plate tectonic interpretation of the geology of Iceland (e.g. Ward, 1971; Pálmason and Sæmundsson, 1974) and it was inherent in the design of the first attempts to measure the rate of separation, e.g. the two distance profiles of Decker *et al.* (1971, 1976) across the two rifts. The use of the term "Hengill triple junction" by e.g. Foulger (1988) furthermore assumes three plates meeting at a triple junction. The term "microplate" for this block, however, appeared in the literature only recently (e.g. LaFemina *et al.*, 2005; Einarsson *et al.*, 2006; Sinton *et al.*, 2006) as have direct GPS-measurements of the rate of movements along its boundaries (LaFemina *et al.*, 2005; Geirsson *et al.*, 2006). LaFemina *et al.* (2005), furthermore, confirmed that its internal deformation rate was consistent with a microplate model.

The segments comprising the plate boundary in South Iceland have presented irregularities or inconsistencies that have not been satisfactorily explained so far:

1. The Western and Eastern Volcanic Zones trend obliquely to the over-all spreading vector. Yet the structure of the zones does not reflect this, such as by en-echelon arrangement of the fissure swarms. The volcanic systems, with their fissure swarms trend parallel to the zones themselves. This indicates that the spreading across the zones is perpendicular to their trend and oblique to the spreading of the major plates.
2. The Western and Eastern Volcanic Zones are not quite parallel and there is a significant difference between the trend of extensional structures within them (Table 1). Eruptive fissures, normal faults, and hyaloclastite ridges have trends of 40–46° in the eastern zone, but 26–33° in the western one.
3. The South Iceland Seismic Zone does not show evidence of crustal extension. It appears to behave as a transform zone and yet it trends obliquely to the over-all spreading vector of the two major plates.
4. The spreading rate changes along the rift zones. It decreases towards NE in the WVZ and increases in the EVZ. This implies rotation of the block between the two rifts.
5. The activity of the Central Iceland Volcanic Zone is low, both volcanic and seismic.

We propose that these discrepancies can be resolved by assuming the Hreppar block behaves as a rigid plate that moves independently of the two major plates. We then attempt to constrain its poles of rotation and its rates of rotation with respect to the Eurasia and North America Plates.

The first criterium for a plate, i.e. that internal deformation is negligible, is supported by seismicity maps, e.g. that of Einarsson and Sæmundsson (1987) and Einarsson (1991a) for the period 1981–1985 and Figure 2 for the period 1991–2006. These maps show an aseismic block surrounded by volcanically and seismically active boundaries. This block is wider than typical deformation zones around the adjacent boundaries. We can therefore assume that the block has a core of very little irreversible deformation. This is supported by recent GPS results (LaFemina *et al.*, 2005).

We use the following constraints to locate the poles of rotation:

1. The spreading across the Western and Eastern Volcanic Zones is perpendicular to their trends, i.e. the poles must be located on lines extending from the ends of the zones and with the same trend.
2. All three poles of relative rotation of plate pairs must lie on the same great circle. The direction of this great circle across Iceland must therefore be close to an azimuth of 15°, i.e. the direction to the Eurasia-North-America pole of rotation.

3. The South Iceland Seismic Zone must be approximately on a small circle around the pole of relative rotation between Eurasia and Hreppar.
4. The direction of motion of the CGPS-stations on the Hreppar block, those of Isakot and Sporðalda, as shown in Figure 3 must be on a small circle around the North-America-Hreppar pole of rotation.

It is a rather simple geometrical exercise to locate the poles from these constraints. The exact location depends on how literally one takes the constraints. They must be near the following points: 1. The North-America-Hreppar pole is in the area north of the Langjökull glacier, near 65.2°N and 20.1°W. 2. The Hreppar-Eurasia pole is SW of the Vestmannaeyjar Archipelago, near 62.8°N and 21.3°W.

DISCUSSION AND CONCLUSIONS

Iceland has a plate boundary deformation zone that is wider and more complicated than is observed along normal oceanic plate boundaries. This is clearly seen, for example, in the distribution of seismicity in Figure 1. It is generally assumed that this is, at least partly, due to the thick crust produced by the excess magmatism of the hotspot. Part of the complexity is also caused by the relative movement of the major plates with respect to the root of the hotspot, the mantle plume underlying the lithosphere. The activity of the plume produces a zone of weakness that eventually develops into a plate boundary. This paper gives an overview of the present configuration of the plate boundary, its structural characteristics and how it is segmented. The main conclusions can be summarised as follows:

1. Recent volcanic and tectonic activity in Iceland is consistent with the basic assumption of the plate tectonics theory, i.e. that the surface of the Earth is divided into plates with insignificant internal deformation, separated by plate boundary deformation zones. It has been shown that the global model of plate movements applies well in Iceland. Measured plate movements of the last few years conform with the globally determined plate movements of the last few million years.

2. The plate boundary can be traced through Iceland as a chain of active zones, volcanic rift zones, seismically active transform zones and oblique rifts. The boundary can be divided into segments, each with a set of characteristics typical for that segment and different from that of the neighbouring segments (Table 1). The main characteristics are orientation of the zone with respect to the plate velocity vector, trend of principal structural elements with respect to the zone, type of volcanism, seismicity and type of faulting.

3. The two major plates, the Eurasia and North America Plates, move apart in the Iceland area with a velocity of about 19 mm/year and the relative vector has a direction of about 105°.

4. A small plate fragment (90 x 90 km), the Hreppar Microplate, can be defined between the two volcanic rift zones in South Iceland. A consistent set of poles of relative rotation can be defined for this microplate assuming perpendicular rifting within the two bounding rift zones. The poles are at small distance from the microplate, which is consistent with the observation that spreading rates across the bounding rift zones changes considerably along strike. This is also consistent with a propagating rift origin of the microplate, the EVZ being the propagating rift and the WVZ the receding rift.

5. An additional microplate or crustal block may possibly be defined within the Tjörnes Fracture Zone, but its poles of rotation remain to be determined. Distributed seismicity within the block indicates considerable internal deformation.

6. The two segments with a large angle of obliqueness, the Reykjanes Peninsula Rift (RPR) and the Grímsey Oblique Rift (GOR), have several similarities that may be common to all highly oblique plate boundaries. They have extensive volcanism and high seismic activity characterised by strike-slip faulting. The volcanic systems with their fissure swarms are arranged en-echelon along the zone and a good part of the seismicity occurs by bookshelf faulting, with the faults transverse to the zone. The RPR and GOR are symmetrical with respect to the plate velocity vector.

7. The two transform boundary segments, the South Iceland Seismic Zone and the Húsavík-Flatey Zone, contrast sharply in their structural characteris-

tics. The structural grain in the HFZ is strong and parallel to the zone itself. Faults in the SISZ, on the other hand, are mostly transverse to the zone and only slightly affect the structural grain. Most large earthquakes in the SISZ are related to bookshelf faulting. This difference in tectonic style may be caused by the different stage of maturity of the two zones. The SISZ is in the stage of birth as a consequence of the ridge jump from the WVZ to the EVZ. The HFZ is a mature transform, and dying as the rifting in the Eyjafjarðarál Rift is becoming magma-starved.

8. Considerable activity, both seismic and volcanic, occurs outside the plate boundary segments. This activity implies intraplate deformation and plate modification and may be responsible for some of the apparent minor discrepancies between measured movements and movements predicted by simple rigid plate assumptions.

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ÁGRIP

Íslenski heiti reiturinn hefur afgerandi áhrif á lögun og gerð flekaskilanna milli Norður-Ameríku- og Evrasíuflekanna sem liggja yfir landið. Jarðskorpan undir Íslandi er þykkari en úthafsskorpan umhverfis landið vegna mikillar eldvirkni heita reitsins. Þykkari skorpa leiðir til breiðara aflögunarsvæðis umhverfis flekaskilin. Jarðskjálftar og eldvirkni eiga sér því stað á breiðara svæði á Íslandi en víðast finnst við flekaskil á hafsbotni. Auk þess færast flekaskilin til miðað við rætur heita reitsins í möttlinum undir niðri. Ný flekaskil verða til þegar miðja heita reitsins hefur fjarlægst gömlu flekaskilin um of. Flís eða smáfleki klofnar þá frá öðrum meginflekanum og límist við hinn. Slík flekaskilastökk hafa orðið nokkrum sinnum í jarðsögu Íslands og virðast einmitt núna vera í gangi á Suðurlandi.

Skipta má flekaskilunum niður í búta eða belti sem hvert um sig hefur ákveðin einkenni sem greina það frá öðrum beltum. Flest beltin eru skásett með tilliti til heildarrekstefnunnar milli meginflekanna. Gliðnunarþáttur rekvigrans leiðir til myndunar ganga og siggengja sem oftast tengjast sprungusveimum eldstöðvakerfa. Sá þáttur rekvigrans sem er samsíða flekaskilunum leiðir til sniðgengishreyfinga. Oft stefna sniðgengin hornrétt á beltið og raða sér hlið við hlið eftir því líkt og bækur í bókahillu. Bókahillusprungur virðast vera fylgifiskar vanþroskaðra hjáreksbelta. Þar sem rekið er mjög skásett, t.d. á Reykjanesskaga og Grímseyjarbeltinu, koma báðar tegundir sprungusvæða fyrir, þ.e. sniðgengi og sprungusveimar með siggengjum og gosvirkni. Skjálftabelti Suðurlands er næstum samsíða rekvigranum og þar eru sniðgengishreyfingar á bókahillusprungum ríkjandi. Sniðgengishreyfingunum fylgir skjálftavirkni og geta skjálftar þar náð stærðinni 7. Á þroskaðri hjáreksbeltum, eins og t.d. Húsavíkur-Flateyjar-misgengjunum, hafa myndast sniðgengi sem eru nánast samsíða beltinu sjálfu. Virkni á þessu hjáreksbelti fer þó minnkandi vegna færslu flekaskilanna til austurs. Grímseyjarbeltið virðist vera um það bil að taka við hlutverki Eyjafjarðaráls sem helsta fráreksbelti við Norðurland og tenging við rekhrygginn fyrir norðan land, Kolbeinseyjarhrygg. Á Suðurlandi er Eystra gosbeltið um það bil að leysa Vestara gosbeltið af hólmi sem aðalfráreksbeltið. Bæði beltin eru virk en það eystra þó mun virkara. Flísin á milli þeirra er nánast óvirk, bæði hvað varðar eldgos og skjálfta. Aflögun er óveruleg og má því skilgreina flísina sem smáfleka, Hreppaflekann. Hreppaflekinn snýst, því rek um Eystra gosbeltið er meira norðan til en sunnar. Á móti er rek um Vestara gosbeltið meira sunnan til en norðar. Skilgreina má rekpóla fyrir hreyfingar Hreppaflekans. Rekpóll miðað við Norður-Ameríkuflekann er skammt norðan Langjökuls, nálægt 65.2°N, 20.1°W. Rekpóll hreyf-

inga miðað við Evrasíuflekann er staðsettur sunnan við landið, nálægt 62.8°N, 21.3°W.

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