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# Styles of surface rupture accompanying the June 17 and 21, 2000 earthquakes in the South Iceland Seismic Zone

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**Abstract**

Two large $M_s$=6.6 earthquakes occurred on June 17 and 21, 2000 in the South Iceland Seismic Zone. The roughly E–W trending zone is undergoing left-lateral shear. However, most known surface rupture has been along north-striking, right-lateral strike-slip faults. Rupture associated with the June 2000 events follows a similar pattern. Although the two earthquakes had similar magnitude, fault plane solutions, and overall rupture lengths of 15 to 20 km, the pattern of rupture from each was notably different in character. The June 17 event ruptured along a series of NNE-trending, left-stepping segments, giving the fault as a whole an almost due north trend. At the largest scale rupture is relatively straight and continuous. At the smallest scale, rupture style seems to vary with small-scale topography and ground texture. Rupture from the June 21 event is more complex and can be divided into five discrete segments. To the north, deformation is distributed across two zones of left-stepping fractures, along which widening and subsidence have occurred. The central segment consists of right-stepping fractures defining a 2 km long, ENE trending zone. Sense of shear is clearly left-lateral strike slip. The two southernmost segments define an NNE trend. In several places along the rupture zones of both earthquakes it can be verified that the ruptures occurred along pre-existing faults. The observed faulting structures are similar to those of earlier earthquakes in South Iceland, both with regard to style and spatial arrangement. However, our observations suggest that some of the historical earthquakes may have been larger than the June 2000 events.


*Keywords:* Iceland; Strike-slip faults; Surface rupture; Earthquakes

## 1. Introduction

Two large earthquakes with $M_s$=6.6, occurred on June 17 and 21, 2000 respectively in the South Iceland Seismic Zone (SISZ). This transform-type plate boundary has been relatively quiet since 1912, but 37 destructive earthquakes have occurred in this

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area since 1164 AD. Most of the historical accounts were compiled by Thoroddsen (1899) who also described the surface effects of the 1896 earthquakes based on reports from local priests and farmers. The surface trace of the 1912 earthquake, a single event near the eastern end of the seismic zone, was described in newspaper reports and has been studied and mapped by Einarsson and Eiríksson (1982) and Bjarnason et al. (1993). However, deterioration of the rupture occurs rapidly in Iceland's climate and it is certain that data, and therefore our understanding of the nature of these events, has been incomplete. The earthquakes of June 2000 have provided us with a first opportunity to fully document the fresh surface rupture from a major earthquake sequence in the SISZ, and to compare its distribution to geophysical models of the underlying fault planes. Angelier and Bergerat (2002) and Bergerat and Angelier (2001, 2003) have produced detailed maps and descriptions of selected small-scale features of both faults and provided analysis of the mechanical behavior of the faults based on those data. The goals of this paper are two-fold. Firstly, we wish to document, with photographs, descriptions and complete maps, the entire extent of co-seismic surface effects (e.g. ground rupture) from the June 2000 earthquakes. We have used real-time differential GPS to provide accurate maps on as fine a scale as possible. Secondly, we wish to describe the relationship between visible rupture at the surface and geophysically determined characteristics of the fault plane at depth. We use GIS software to overlay geophysical data onto our maps in order to compare aftershock distribution and satellite-based deformation data with the location and geometry of surface rupture. This data will better enable us to calibrate the magnitudes of earlier (pre-instrumentation) historical earthquakes whose damage area is known.

## 2. Tectonic setting

The SISZ is a roughly east–west trending transform zone that connects the northeast-trending Western and the Eastern Volcanic Zones in South Iceland. The zone is slightly oblique to the 104° direction of plate motion in south Iceland (DeMets et al., 1994). GPS measurements confirm that left-lateral strain is accumulating along the SISZ (Sigmundsson et al., 1995), but no through-going transform fault has ever been mapped here. Instead, strain is accommodated along many sub-parallel, north-trending, right-lateral strike-slip faults (Fig. 1). The term "bookshelf" faulting has been used to denote shear deformation accommodated by an array of faults trending perpendicular to the shear direction (Sigmundsson et al., 1995). This style of deformation has been proposed to explain the faults that have been mapped in the SISZ (e.g. Einarsson and Eiríksson, 1982; Bjarnason et al., 1993). Einarsson and Eiríksson (1982) suggested that the lack of east–west trending left-lateral faults is due to the transient nature of the zone as it migrates southward in response to ridge propagation. Hackman et al. (1990) used a boundary element model to confirm that north-trending faults can accommodate this left-lateral strain if they are either 10 to 15 km long or "more spatially frequent than mapped". Mapping conducted during the past decade (Fig. 1B) indicates that spacing of faults in the SISZ is indeed close, varying between 500 m to less than 5 km, and averaging less than 2 km. The thickness of the brittle crust decreases within the SISZ from 12 to 15 km in the east to about 5 km in the west (Stefánsson et al., 1993). This thinning of the brittle layer correlates with a general decrease in maximum earthquake size from east to west, and suggests that fault length may also decrease.

## 3. Methods

One important goal of this study was to identify and map as much of the surface rupture as we could as quickly as possible. In the days immediately following each earthquake, cracks in main and secondary roads were reported, while we attempted to map them before they were repaired. Wherever roads were cracked, we followed their trend into farms and fields looking for rupture. Local farmers led us to fractures and sinkholes that opened up on their land which they intended to fill in order to protect livestock from injury. We also conducted reconnaissance in the entire area affected by aftershocks along strike from the epicenters of both earthquakes and along the traces of known surface faults in the immediate vicinity. Because of a shortage of time, some detail in