Analysis and interpretation of segments of the Koae fault system, Kilauea Volcano, Hawaii

William R. Kahl
Department of Geosciences, Franklin and Marshall College, Lancaster, PA 17604-3003
Faculty Sponsor: Edward C. Beutner, Franklin and Marshall College

INTRODUCTION

The Koae fault system is an east-northeast trending zone of normal faults and groundcracks situated between the East and Southwest rift zones just south of the Kilauea volcano summit caldera (figure 1). The Koae faults are sinuous and steeply dipping. The fault system also has a component of dilation due to the movement of the south flank away from Kilauea. Eruptions occur infrequently in the Koae system because, unlike the adjacent rift zones, there is no direct magma conduit to the area from the summit caldera (Swanson et al., 1976). The lack of local eruptions has left the Koae system with the most clearly exposed faults of Kilauea's rift zones.

FEATURES

The distinguishing feature of the Koae faults is their dominant north-down geometry. The faults are situated on Kilauea's south flank and are part of a gigantic landslide structure, on which gravity-driven movements most commonly drop the south sides of faults relative to their north sides. Duffield (1975) suggests that these north-facing scarps represent master faults bounding asymmetric grabens, which were formed by southward movement of the south flank. To support this theory, Duffield refers to clay modeling by Cloos (figure 2) that shows similar asymmetric grabens with master faults, antithetic faults, and reverse drag.

Two anomalous areas of south-facing fault scarps exist within the Koae system. One of these areas is the easternmost area of the Koae, where symmetric grabens have formed as keystone grabens directly above sites of dike injection (Duffield, 1975). The second area is the north central portion of the Koae system, where a set of arcuate-concentric groundcracks with south facing scarps has formed in response to a circular stress field that has since disappeared. Additional dilation cutting across these faults, according to Duffield (1975), occurred in the general Koae trend of N75°E during the May 5, 1973 eruption.

PROBLEMS

Depth of detachment. If the analogy between the Koae system and Cloos's asymmetric graben model is correct, then the faulting in the Koae system must flatten into a sub-horizontal detachment at depth. Seismic evidence suggests faulting extends to a depth of 10km, but this depth conflicts with a faulting depth of 667m based on Hansen's (1965) graben rule, or conservation of volume. Duffield (1975) offers shallow dike emplacement to account for the discrepancy. Denlinger and Okubo (1995) also postulate the existence of a hot cumulate body beneath the Koae system based on mathematical modeling of flank deformation and on continuous aseismic movement across the Koae system. No dikes, however, have surfaced in the Koae system as might be expected from an underlying shallow intrusive.

Dike related faulting. Diking on the edges of the Koae system has two effects. The first is formation of symmetric grabens on the easternmost Koae system, representing diking at a shallow depth. Lack of symmetric grabens further west in the Koae system indicates that if diking occurs there, it does not occur at the same depth as in the eastern area and has not directly influenced the geometry of the overlying faults.

The second effect is the opening and closing of groundcracks on the system. On May 5, 1973, four fissures with the general Koae trend erupted, opening new cracks and closing old ones. The most notable new cracks formed with the general Koae trend and cut across the anomalous arcuate-concentric area in the north central Koae (Duffield 1975). This conflict with Duffield's previous statement that dilation along the arcuate-concentric cracks moves toward the Koae trend; stress in this eruption was released by formation of new cracks rather than along the pre-existing arcuate cracks.

Lateral movement. Lipman et al. (1985) reported an isolated episode of left-slip movement in the Koae system associated with the December 31, 1974, eruption along the Southwest rift zone. During reconnaissance of the Koae faults, no evidence for strike-slip movement was seen, except on a small scale (depth less than 1m) in a fault transfer zone near Hilina Pali road.

METHODS

Ten vertical profiles were taken across two fault segments in the Koae fault system (figures 3, 4). These profiles were measured using fiberglass tape, steel tape, and Brunton compass. Orientations of groundcracks and amount and dilation direction of groundcracks were measured in the profile sections. Cross-sections (figure 3, lines A,B) based on Duffield's structural map (1975, plate 1) were also drawn for lines for which he reported total dilation but did not give cross-sections.

Using fiberglass tape, the orientation and length of a set of twenty-six en echelon groundcracks were measured. Direction and amount of dilation were determined at multiple points along each groundcrack (figure 5).

DISCUSSION

Some of the vertical profiles across fault scarps exhibit the reverse drag, or rollover, geometry present in Cloos's clay model. This seems to support Duffield's theory. However, the clay models exhibit a low ratio of faulting depth to rollover width, on the order of 1:1 to 2:1. The rollovers are commonly 50-100 meters in width, which gives a faulting depth of 100-200 meters. This conflicts with both the 10km and the 667m depths mentioned earlier, producing an inconsistency within Duffield's theory. Part of the problem comes from his use of Hansen's graben rule, which requires graben symmetry and uniform dip on the faults. Because the Koae system grabens are asymmetric and their dip at depth is unknown, application of Hansen's rule is not appropriate.

The measured groundcracks offer a interesting contrast to Duffield's curve fit to data on the trend and dilation direction of groundcracks in the arcuate-concentric crack area (figure 5). Duffield's least square linear best fit line indicates dilation perpendicular to the crack azimuth, whereas his S-shaped curve, or visual best fit curve, shows that groundcracks which plot on the tails of the graph tend toward the favored Koae trend of N75°W. In contrast, the groundcracks in the set measured in this study plot as a tail on the opposite side of the graph. Because these groundcracks are west and outside of the anomalous area, they may show that the Southwest rift zone stress field, which is oblique to the Koae trend, is beginning to affect dilation directions in the west.

CONCLUSION

Further research is necessary to gain a better understanding of the Koae fault system. Geophysical or seismic studies of the system at depth or more constrained modeling of the asymmetric grabens might provide insight into the structure of the fault system.

REFERENCES CITED

Cloos, E., 1968, Experimental analysis of Gulf Coast fracture patterns: American Association of Petroleum Geologists, v. 52, p. 420-444.

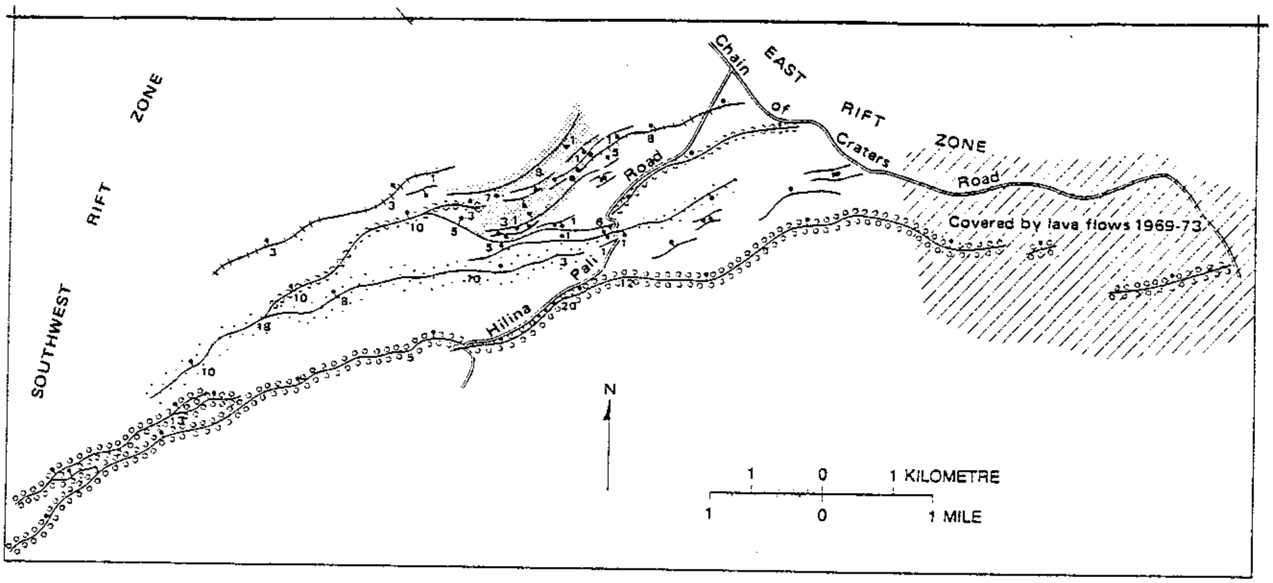
Denlinger, R. P., and P. Okubo, 1995, Structure of the mobile south flank of Kilauea Volcano, Hawaii: Journal of Geophysical Research, v. 100, p. 24,499-24,507.

Duffield, W. A., 1975, Structure and origin of the Koae fault system, Kilauea Volcano, Hawaii: U.S. Geological Survey Professional Paper 856, 12 p.

Hansen, W.R., 1965, Effects of the earthquake of March 27, 1964, at Anchorage, Alaska: U.S.Geologic Survey Professional Paper 542-A, p. A1-A68.

Lipman, P. W., Lockwood, J. P. , Okamura, R. T., Swanson, D. A., Yamashita, K. M., 1985, Ground deformation associated with the 1975 magnitude-7.2 earthquake and resulting changes in activity of Kilauea Volcano, Hawaii: U.S. Geological Survey Professional Paper 1276, 45 p.

Swanson, D.A., Duffield, W. A., Fiske, R. S., 1976, Displacement of the south flank of Kilauea volcano: the result of forceful intrusion of magma into the rift zones: U.S. Geological Survey Professional Paper 963, 39 p.



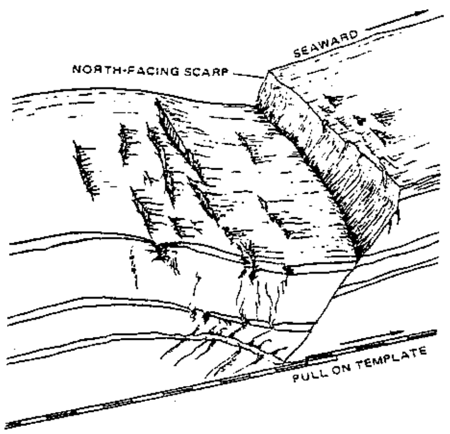
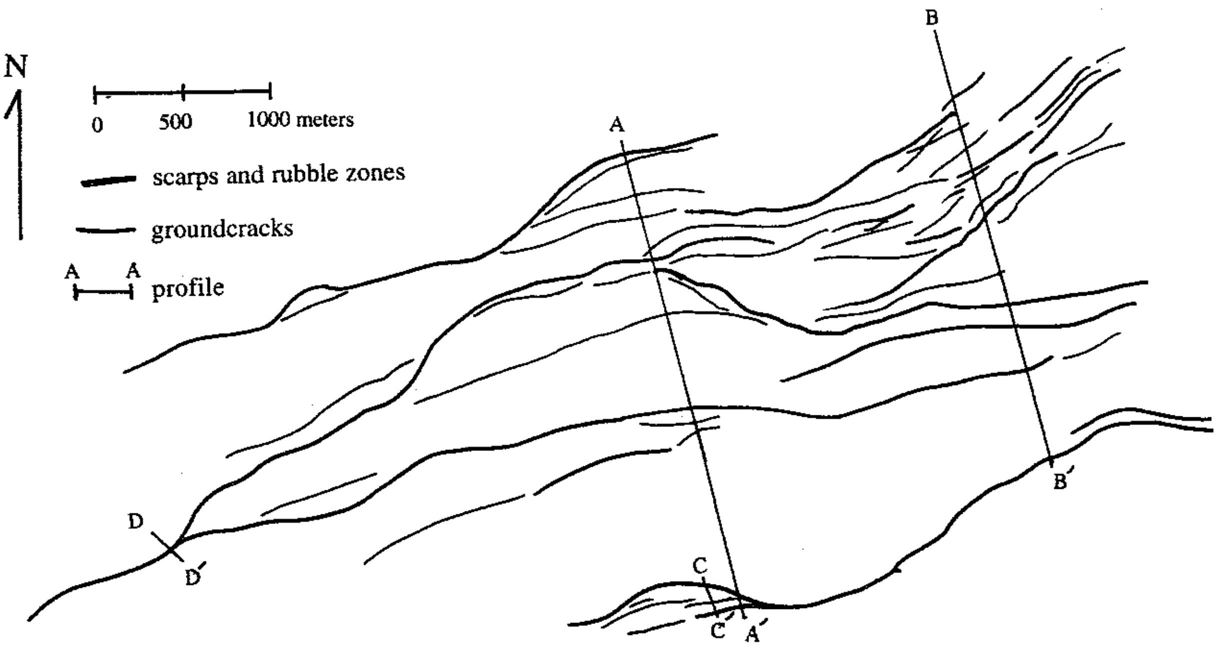


Figure 1. Principal normal fault zones of the Koae fault system. Four main zones are patterned. Vertical offset is in meters. In the north-central Koae there is an area of anomalous arcuate-concentric fissures (shaded area). (from Duffield, 1975)

Figure 2. Asymmetric graben in tabular clay model (from Cloos, 1968, fig. 18). The fault zone produced in the model has been correlated with the north facing scarps in Koae fault system.

Figure 3. Generalized fault scarps and groundcracks of the central Koae system (after Duffield, 1975, pl. 1). Profiles A-A' and B-B' refer to text; profiles C-C' and D-D' refer to figure 5.



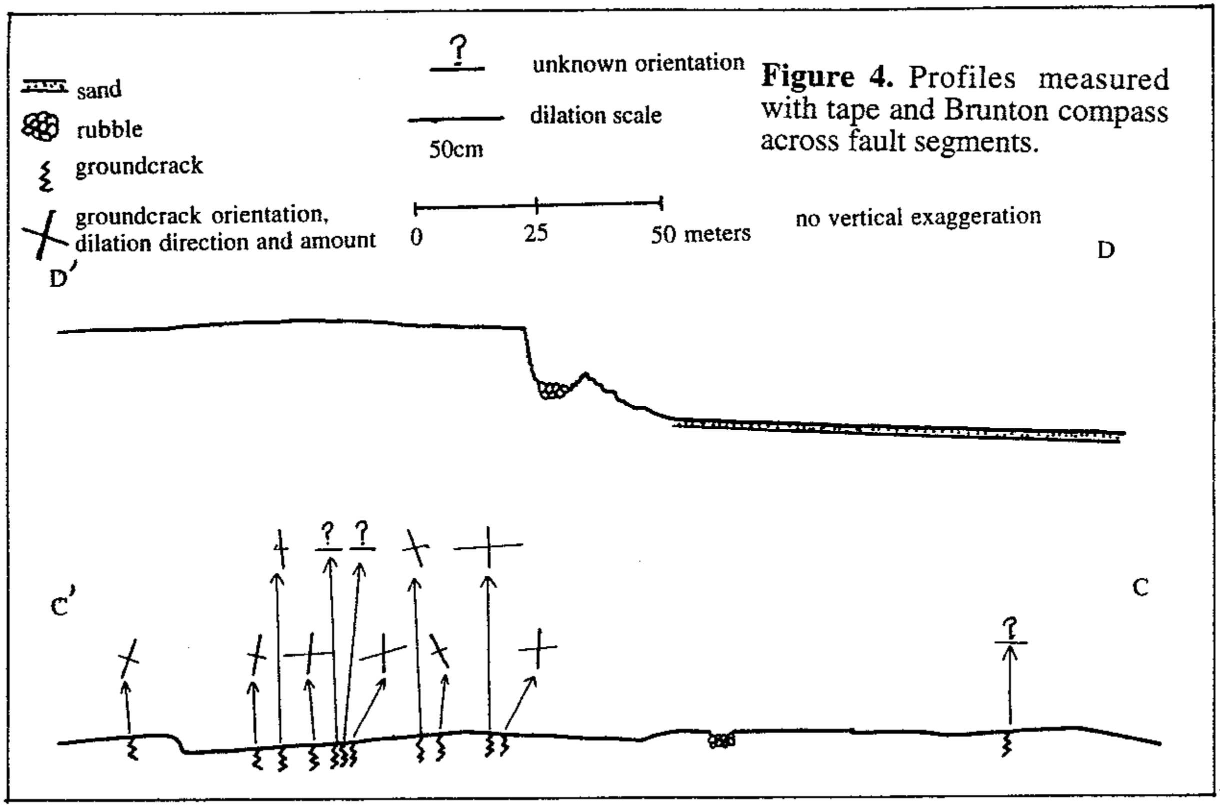


Figure 4. Profiles measured with tape and Brunton compass across fault segments.

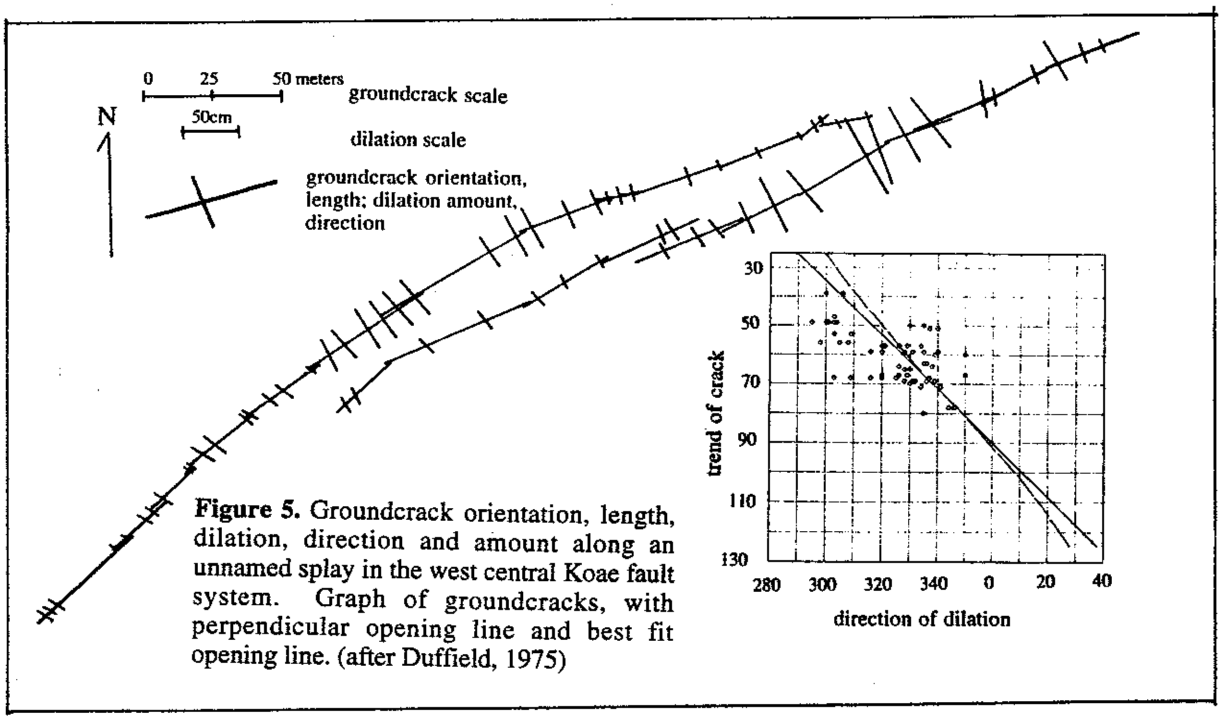


Figure 5. Groundcrack orientation, length, dilation, direction and amount along an unnamed splay in the west central Koae fault system. Graph of groundcracks, with perpendicular opening line and best fit opening line. (after Duffield, 1975)