# GEOLOGIC ASPECTS OF SEISMIC HAZARDS ASSESSMENT AT THE IDAHO NATIONAL ENGINEERING LABORATORY, SOUTHEASTERN IDAHO

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## ABSTRACT

The Idaho National Engineering Laboratory (INEL), located on the northwestern side of the Eastern Snake River Plain (ESRP), lies in an area influenced by two distinct geologic provinces. The ESRP province is a northeast-trending zone of late Tertiary and Quaternary volcanism which transects the northwest-trending, block-fault mountain ranges of the Basin and Range province. An understanding of the interaction of these two provinces is important for realistic geologic hazards assessment. Of particular importance for seismic hazards analysis is the relationship of volcanic rift zones on the ESRP to basin-and-range faults north of the plain.

The Arco Rift Zone, a 20-km-long belt of deformation and volcanism on the plain just west of the INEL, is colinear with the basin-and-range Lost River fault. Recent field studies have demonstrated that Arco Rift Zone deformation is typical of that induced by dike injection in other volcanic rift zones. The deformation is characterized by a predominance of dilational fissuring with less extensive development of faults and grabens. Elongate positive magnetic anomalies, closely associated aligned volcanic vents and eruptive fissures, and local perturbations in groundwater flow suggest that basalt dikes are present beneath the deformational features. Although the Lava Ridge-Hells Half Acre Rift Zone, which crosses the INEL south of the Lemhi fault, is not as well preserved or as well studied, its exposed features are similar to those of the Arco Rift Zone.

Available K-Ar ages of lavas in the Arco Rift Zone suggest that volcanism and associated deformation are Pleistocene in age. Cumulative vertical displacements over the past 0.6 Ma are an order of magnitude lower than those associated with the Arco Segment of the Lost River fault to the northwest.

The evidence suggests that the northeast-directed extension that produces the block fault mountains of the Basin and Range is expressed by dike injection and volcanic rift zone development in the ESRP. Seismicity associated with dike injection during rift zone development is typically of low magnitude and would represent only minor hazard compared to that associated with the block faulting. Since the ESRP responds to extension in a manner distinct from basin-and-range faulting, it is not appropriate to consider the volcanic rift zones as extensions of basin-and-range faults for seismic hazard analysis.

## INTRODUCTION

The interaction of basin-and-range (B&R) with Eastern Snake River Plain (ESRP) tectonism has received the recent attention of several researchers. Such studies [1,2,3] show that passage of the Yellowstone hotspot to produce the ESRP has also influenced the movement histories of B&R faults located to the north and south of the plain. The nature of that influence is generation or activation of B&R faulting in front of and adjacent to the hotspot, and gradual migration of fault activity away from the plain in the wake of the hotspot. This has left a gradually widening zone of waning fault activity with distance southwestward from Yellowstone, and a zone of latest Quaternary fault activity that fans away from the ESRP margins. Although it must be related somehow to crustal uplift and profound changes in the thermal structure of the lithosphere with passage of the hotspot, the precise nature of fault control is a subject of debate.

Our study of seismic hazards associated with ESRP and B&R tectonism focuses on one aspect of the interaction of the two provinces: the relationship of ESRP volcanic rift zones to the basin-and-range activity. Since the Arco rift zone and the Lava Ridge-Hells Half Acre rift zone are colinear with the B&R Lost River and Lemhi faults respectively, there has been suspicion that those faults, with their associated seismic hazards, extend onto the ESRP. The Arco rift zone was selected for detailed study because it is the best exposed and most well developed of the rift zones in the vicinity of the INEL.

## DESCRIPTION OF THE ARCO RIFT ZONE

The Arco rift zone can be traced for a total distance of more than 20 km and extends from a point 6 km south of Arco to the Big Southern Butte area (Figure 1). The northwesternmost manifestation of the rift zone occurs within 3 to 4 km of the northwest edge of the ESRP. The Arco rift is characterized both by ground deformation and by constructional volcanic features. This suggests a close genetic association between deformation and volcanism as has been described in other volcanic rift zones.

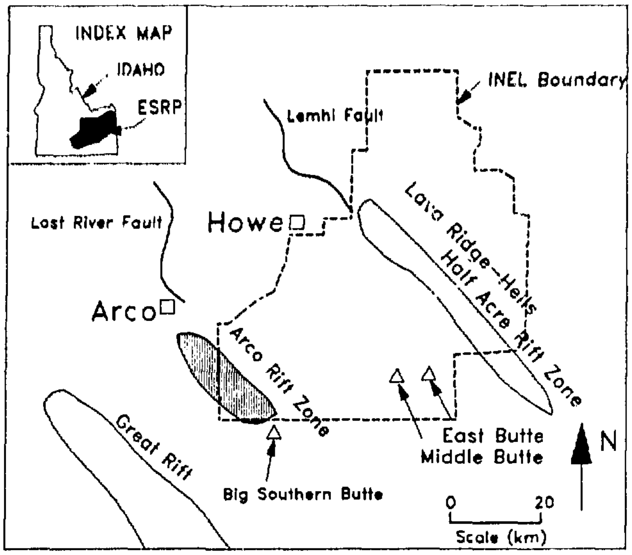


Figure 1. Map of volcanic rift zones near INEL.

### Ground Deformation

Ground deformation in the Arco rift consists of fissures and faults that cut basalt lava flows at the surface. The fissures are open vertical cracks whose walls have experienced only dilational opening, with no apparent dip slip or strike slip displacement (Figure 2). Individual fissures are up to 3 km long, with dilational offsets of up to 1 meter, and observable depths of up to 6 meters. Fissures make up 80% of the total length of ground deformation features in the Arco rift zone [4,5].

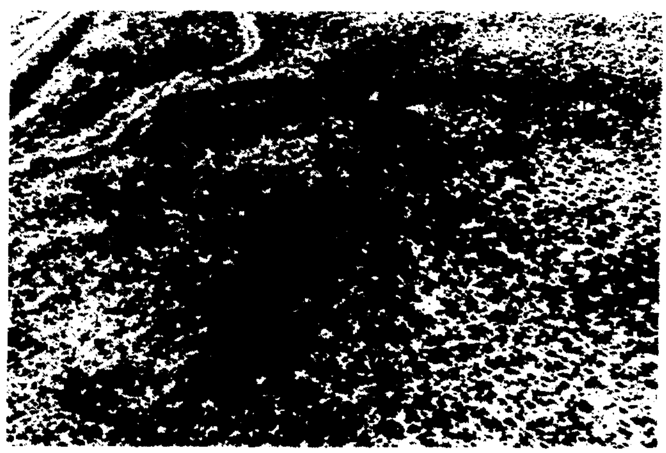

Figure 2. Aerial view of open fissure.

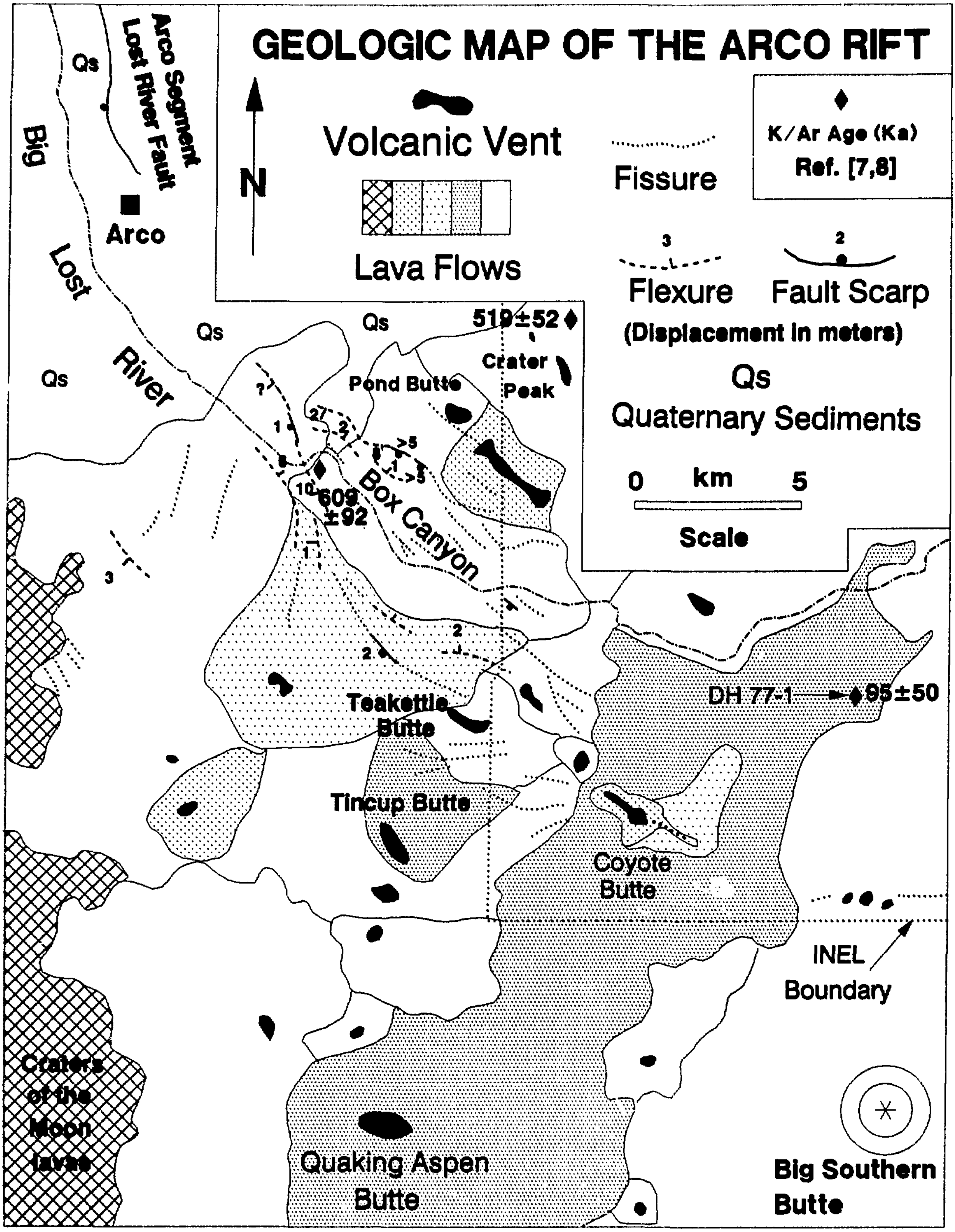


Figure 3. Geologic map of the Arco Rift Zone. (References [4,5,6]).

Faults are expressed on the surface as monoclinal flexures, in which slabs of basalt are draped over underlying faults, and as vertical scarps. The maximum observed vertical displacement on faults in the rift zone is about 10 meters, and the maximum fault length is 5 to 6 km (Figure 3). Most offsets are down-to-the-southwest, but down-to-the-northeast offsets are common (Figure 3). Both flexures and scarps cause vertical displacement of surface lava flows and the expression of faults commonly changes over short distances from flexures to scarps (Figure 4).

Fissures and faults occur in a branching, en echelon, overlapping pattern in a northwest-trending zone approximately 20 km long by 6 km wide. From the northwest end of the rift zone, the fissures and faults branch to the southeast into two subparallel zones, each about 0.6 km wide and separated by about 4 km of relatively undeformed surface rocks (Figure 3).

Figure 4. Aerial view of flexure and scarp.

Each of the branches contains a northwest-trending graben. The most obvious graben (Figure 5) occurs at the head of the Box Canyon of the Big Lost River in the southwesternmost branch of the rift. The floor of the Box Canyon graben has been downdropped up to 10 meters from the block to the northeast but only about 6 to 8 meters from the block to the southwest. The graben in the northeastern branch of the rift zone is even more asymmetric, with a vertical displacement along the northeast side of about 8 meters and along the southwest side of about 1 to 2 meters.

Figure 5. Aerial view of Box Canyon Graben.

## Constructional Volcanic Features

Constructional volcanic features are an important part of the Arco rift. They consist of aligned volcanic vents, elongate volcanic vents, and eruptive fissures. Several northwest-trending linear alignments of volcanoes occur in the rift. The one that extends southeast from Pond Butte and the one that includes Teakettle Butte and Coyote Butte are the most notable examples (Figure 3).

A more common and more striking feature of the Arco Rift is the northwest elongation of many of the volcanic vents. The most obvious of these elongated vents are Tincup Butte, Teakettle Butte, the unnamed butte northeast of Teakettle Butte, Pond Butte, and Crater Peak (Figures 3 and 6).

Figure 6. Aerial view of Teakettle Butte.

Some of the volcanic vents in the Arco Rift are eruptive fissures. Coyote Butte consists of a conical main vent with a string of spatter cones and spatter ramparts extending for almost a kilometer to the northwest, along a rift-zone fissure. The same fissure extends for about 1.5 km to the southeast of the main cone and hosts minor eruptive spatter along much of that length (Figures 3 and 7). Another example of an eruptive fissure is the vent that lies just to the southeast of Pond Butte.

Figure 7. Aerial view of Coyote Butte.

## AGE OF THE ARCO RIFT ZONE

Fissures in the northwest part of the Arco rift near the Box Canyon cut basalt lavas that have been radiometrically dated at about 609±92 Ka and a lava flow from Crater Peak (Figure 3) has been dated at 516±52 Ka [7]. These two ages furnish an older age limit for the fissuring and show that volcanism from northwest-elongated vents related to rift-zone development was in progress between 500,000 and 600,000 years ago.

Radiometric age determinations have been made on lava flows from drill hole 77-1 (Figure 3, DH 77-1) [8]. The uppermost of these lava flows has been interpreted [6] to have erupted from Quaking Aspen Butte and to have flowed across the Arco rift zone to reach the drill hole site. Our work has shown that the lava flow covers rift zone fissures in older lavas and partially buries the west end of the fissure eruption at Coyote Butte. Its determined age of 95±50 Ka, therefore, imposes a younger age limit on the fissuring and volcanism of the Arco rift.

## MECHANISM OF FORMATION OF THE RIFT ZONE

In Iceland it has been demonstrated that fissuring and faulting is induced by emplacement of shallow dikes from a magma chamber beneath the Krafla caldera into rift zones north and south of the caldera [9]. Each dike-injection episode is accompanied by deflation of the caldera, inflation of the rift zones, seismic activity migrating down the rift zones, widening of fissures and creation of new fissures in the rift zone, and renewed volcanic and geothermal activity in the rift zone.

Recent theoretical derivations and experimental work [10,11] have furnished an understanding of the mechanism of formation of fissures and faults above shallow dikes in volcanic rift zones. This work shows that the injection of magma into dike systems at shallow depths below the surface generates stress fields that produce zones of fissuring and graben development on the surface (Figure 8). As the dike thickens and as additional dikes are injected, two zones of fissuring and faulting fan upward from the top of the dike and a zone of surface subsidence that commonly is expressed as a graben forms directly over the top of the dike.

Comparison of the theoretically and experimentally predicted surface deformation to that actually observed in volcanic rift zones [10,11] shows remarkable agreement. For instance, the magnitude of extension due to fissuring and vertical displacement due to faulting in the Inyo Craters rift zone [11] closely matches that which is predicted by the theoretical and experimental model. Drilling there has intersected a rhyolite dike of appropriate thickness and depth below the surface to produce the observed ground deformation.

The mapped pattern of ground deformation and volcanic features in the Arco rift is also consistent with dike-induced deformation. The magnitude of vertical displacement in the graben faults is within the range of displacement observed at Inyo Craters and the pattern of fissures (Figure 3) is typical of that observed in other volcanic rift zones. The observed deformation is consistent with that to be expected from two dikes that diverge from each other near the northwest end of the rift and converge again near Teakettle Butte. A third dike may be present beneath the Pond Butte area. Based upon the geometry of the theoretical and experimental models (Figure 8), the depth to the top of these dikes should be $\leq$500 meters.

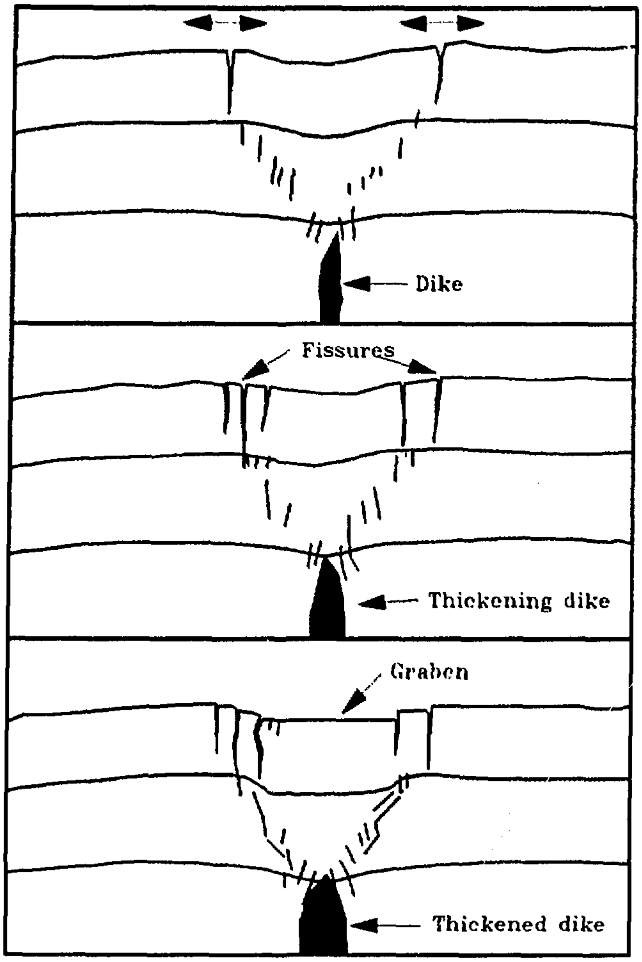


Figure 8. Mastin and Pollard's (1988) idealized depiction of fault and fissure growth above a growing shallow dike (Modified from reference [11]).

The evidence that such dikes exist at depth beneath the Arco Rift is threefold. The strongest evidence is the existence of fissure eruptions and elongate, aligned volcanic vents along the rift. The analogy with fissure eruptions along the Great Rift and the presence of the Craters of the Moon lava field at the north end of the Great Rift is strongly compelling. These eruptions must be supplied by flow of magma through dikes which reach the surface in some areas and remain at depth in others. The areas of graben formation and faulting correspond to areas where the dikes are deepest and the areas of fissure eruptions correspond to areas where the dikes reach the surface.

The second indication that basaltic dikes are present beneath the Arco rift is the northwest-elongated positive aeromagnetic anomaly that exists over the rift [12]. It is very similar in magnitude to, but smaller in size than, the one that exists over the north end of the Great Rift at Craters of the Moon (Figure 9).

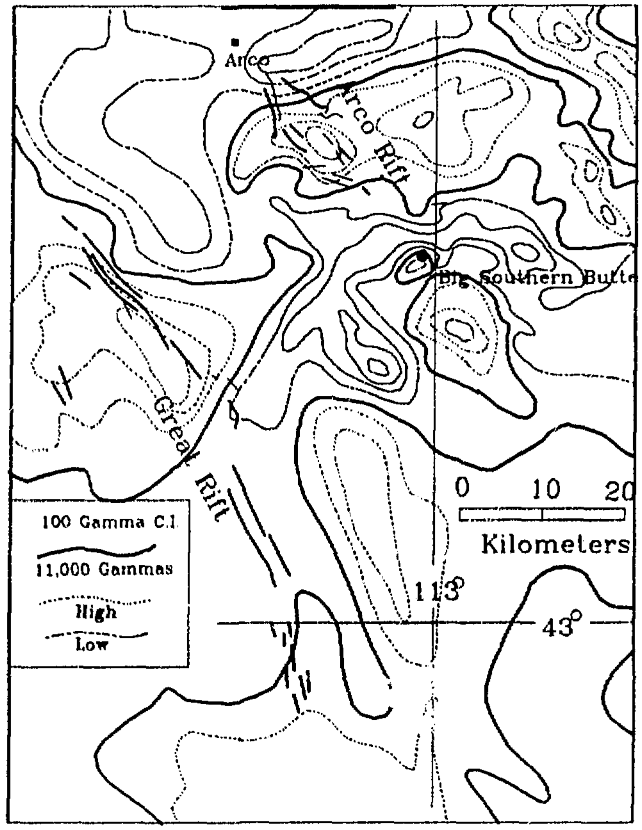


Figure 9. Aeromagnetic anomalies over the Great Rift and the Arco Rift Zone (Modified from Reference [12]).

The third indication is related to perturbations in the southwestward flow of groundwater in the Snake River Plain aquifer. At the Great Rift the water table elevation drops steeply from appoximately 4400 feet above sea level northeast of the rift to about 4100 feet southwest of the rift [13]. This "damming" of the aquifer flow (aquiclude) is interpreted to result from the presence of nearly vertical, relatively unfractured basalt dikes beneath the rift [14]. A similar but smaller magnitude perturbation of water table elevations occurs at the Arco Rift and can be explained by a dike system similar to that at the Great Rift.

## IMPLICATIONS FOR SEISMIC HAZARDS

The crustal extension that affects southeastern Idaho is accomodated by block faulting in the B&R to the north and south of the ESRP. That block faulting, on the north side of the plain, has produced north-northwest-trending mountain ranges with elevations as high as 3600 meters and structural offsets of as much as 2.7 km within the past 10 Ma. Estimated rates of fault movement in the Arco and Thousand Springs segments of the Lost River fault are 0.1 m/1000 years and 0.3 m/1000 years respectively [15].

The fact that no large-displacement normal faults offset lavas as old as 0.5 Ma on the ESRP indicates that the mechanism of accomodation of extension is different on the plain. Fault slip rates as high as those associated with the Lost River fault would have produced structural relief on surface lava flows as great as 50 to 150 meters if the mechanism were the same. The vertical displacement of some surface lava flows is a near-surface phenomenon and probably dies out at very shallow depths (Figure 8).

The style of deformation observed in the Arco rift zone indicates that the mechanism of accomodation of extension in the ESRP is dike injection and volcanic rift zone formation, probably with associated seismicity typical of that occurring in Icelandic rift zones. The north-northwest trend of the rift zones is controlled by the northeast-southwest direction of extension, and the location of some of the rift zones seems to be controlled by the positions of adjacent B&R faults. Extension is almost entirely accomplished, however, by dike injection in the rift zones.

At least three seismogenic mechanisms could have been associated with dike injection in the Arco rift zone. (1) Shear failure on nearly vertical faults produced the grabens above the dike tops (Figure 8). (2) Conjugate fault planes connecting en echelon dikes and fissures [16] may have allowed for shear failure in short sections between dikes. (3) Tensile failure of rocks during fissure and crack propagation [17] ahead of and above advancing dike tips preceded the dilational displacement necessary for dike emplacement. All of these mechanisms are associated with relatively small failure surfaces. For instance, the faults responsible for mechanism (1) are limited in vertical extent to about 1 km or less (Figure 8) and their length does not exceed about 5 km (Figure 3). In comparison, the failure surfaces associated with magnitude 7 or greater earthquakes in the B&R to the north of the ESRP are typically in the range of 20 km in vertical extent by >20 km in length [18]. Seismicity associated with Arco Rift Zone dike injection would, therefore, be expected to be of much smaller magnitude than that associated with B&R tectonism. These observations are consistent with documented maximum earthquake magnitudes of 4 to 5 associated with magmatism in Hawaiian rift zones [19].

## CONCLUSIONS

Although some ESRP volcanic rift zones are colinear with normal faults in the adjacent B&R province, they have a distinctly different style of deformation and mechanism of formation. They cannot be considered as extensions of B&R faults for seismic hazard analysis. They form in a dilational manner, are associated with dike injection and volcanic activity, and are not capable of generating large B&R-style earthquakes.

## ACKNOWLEDGEMENTS

This work was supported by the United States Department of Energy under DOE Contract No. DE-AC07-76ID01570. We are grateful for thoughtful reviews by Ivan Wong, W. E. Harrison, and J. C. Walton. H.T. Ore assisted with aerial photography.

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