APPENDIX D

VOLCANO HAZARD ANALYSIS

SITE-SPECIFIC VOLCANIC HAZARD ANALYSIS

For this analysis, the probabilistic approach of Hackett et al. (Hackett, 2002) is adopted, using surficial and subsurface geologic data from the INL area, together with observations of active volcanism from the analog regions of Iceland and Hawaii. Critical references providing much of the supporting data for this analysis include Champion, 2002; Hackett, 1992; Hackett, 2002; Hughes, 1999; Hughes, 2002; Kuntz, 1992a; Kuntz, 1992b; Kuntz, 1994; Kuntz, 2002; and the Volcanism Working Group, 1990. The interpretation of late-Quaternary volcanism in the INL area is the basis for analyzing the characteristics, frequency and magnitude of any future volcanic events, following the paradigm that "the recent geologic past is the key to understanding the future."

SILICIC VOLCANISM AND HAZARDS

Quaternary silicic volcanism of the axial volcanic zone occurred as four mapped or inferred rhyolite domes: Big Southern Butte, Middle Butte, East Butte and an unnamed dome near East Butte. Localized silicic volcanism also occurred at the polygenetic Cedar Butte volcano (Kuntz, 1994; McCurry, 1999). Thus, five silicic volcanic centers formed 1.4 to 0.3 Ma along the axial volcanic zone. This yields a recurrence interval for silicic volcanism within the axial volcanic zone of 220,000 years (5 events per 1.1 Ma = 4.5×10^{-6} per year). This is more than an order of magnitude less frequent than the estimated recurrence of basaltic volcanism within the axial volcanic zone. Furthermore, the spatial distribution of Quaternary silicic volcanism in the Idaho National Laboratory (INL) area, and the areas inferred to have been impacted by individual eruptions, are far smaller than for basaltic volcanism. Therefore, the hazards associated with near-field silicic volcanism are considered to be far less important than those of basaltic volcanism and no further analysis is pursued here. This is consistent with the conclusions of previous workers (Kuntz, 1979; Volcanism Working Group, 1990; Hackett, 2002).

Pyroclastic flow and tephra fall deposits associated with silicic volcanism from all possible sources are considered to pose no significant hazard in the INL area (Volcanism Working Group, 1990; Hackett, 2002; INL, 2007). Such potential sources include future explosive silicic volcanism from new or reactivated caldera volcanoes on the Eastern Snake River Plain (ESRP); explosive volcanism from the Yellowstone Plateau volcanic field located 230 km (143 mi) to the northeast of the INL (Christiansen, 2000); and ash-fall deposits from the Cascade volcanoes located more than 700 km (435 mi) west of the INL.

BASALTIC VOLCANISM AND HAZARDS

Inundation by basalt lava flows is the most significant volcanic hazard at the proposed site. During the past 4.3 Ma the ESRP has been repeatedly inundated by basaltic lava flows, which today are exposed over about 58 percent of the INL area and are found in subsurface wells and boreholes across most of the ESRP. Volcanic vents are not randomly distributed on the ESRP but occur mainly within several volcanic zones as shown in Figure D-1, Volcanic Rift Zones, Volcanic Vents, and Dike-Induced Fissures and Faults. The characteristics of volcanism in the INL area, including the volcanic source zones, are summarized in Table D-1, Characteristics of Volcanism in the INL Area. The axial volcanic zone is a northeast-trending, constructional volcanic highland with many vents and lava fields. Basalt vents and lava fields are also abundant in the southern segments of several northwest-trending volcanic rift zones where they merge with the axial volcanic zone. The volcanic rift zones are the surface expressions of underlying basaltic feeder dikes. Ascending dikes orient themselves perpendicular to the direction of least horizontal compressive stress. Magma overpressure forces the overlying rocks apart, forming northwest-trending belts of extensional deformation above the subsurface dikes. Surface-deformation features include tensile fissures up to 1 m (3.3 ft) wide and several hundred meters (feet) long, normal-fault scarps and monoclines of several meters (feet) offset and several km (mi) long, and linear arrays of fissure-fed basaltic lava flows. The typical volcanic landform of the ESRP is a small monogenetic shield volcano, 5 +/- 3 km^3 (1.2 +/- 0.7 mi^3) in volume, with small pyroclastic cones and collapse craters near the summit, and surrounded by an extensive lava field. The volcanic and structural features of the ESRP in the INL area are similar to those of the Hawaiian and Icelandic rift zones.

The main style of Quaternary ESRP basaltic volcanism is Hawaiian, involving local firefountaining from eruptive fissures and the deposition of coarse scoria at eruptive vents, and the mild effusion of fluid, gas-poor pahoehoe lava flows from eruptive fissures and small shield volcanoes. Many of the flows are fed by lava tubes (Greeley, 1982) and have hummocky surfaces with many small collapse depressions. Tuff cones and rings, formed during phreatomagmatic steam explosions due to the interaction of basaltic magma with shallow ground water, are found elsewhere on the ESRP (Womer, 1982; Hackett, 1988) but do not occur in the INL area, probably because the water table is too deep.

Table D-2, Hazards Associated with Basaltic Volcanism on the Eastern Snake River Plain, describes the principal hazards associated with ESRP basaltic volcanism. Effusion of pahoehoe lava flows is the most frequent late-Quaternary volcanic phenomenon, pahoehoe lava flows are exposed at the surface over nearly two thirds of the land surface, and occur in the subsurface wells and boreholes across most of the ESRP (Hackett, 2002). Basalt lava flows therefore pose the most significant volcanic hazard to facilities. Observations of active lava flows in Hawaii (Tilling, 1994) suggest that basalt lava moving across the gentle terrain of the INL area would advance slowly, generally < 1 km (< 0.6 mi) per day, and would mainly threaten property by inundation or burning. Other hazards associated with basaltic volcanism, with or without lava effusion, include: release of corrosive gas from eruptive fissures or lava tubes, which would mainly affect areas within a few hundred meters (feet) of active vents; coarse tephra deposition within a few hundred meters (feet) of active vents; surface fissuring and minor faulting above ascending dikes, within narrow zones up to about 10 km (6 mi) long; and small- to moderate-magnitude earthquakes induced by the ascending dikes (Hackett, 1996; Hackett, 2002).

EVENT DEFINITION

A basaltic volcanic event is defined as being represented by the products of a batch of basaltic magma - a cogenetic assemblage of intrusive and extrusive features. An event occurs in the geologically brief time it takes for a batch of basaltic magma to ascend into the shallow crust, and to erupt and solidify. The duration of an event could be up to several decades, but numerical modeling of magmatic processes suggests a general time frame of several months to several years, depending on the scale of the eruption (Kuntz, 1992b). A single event produces an assemblage of cogenetic features, including dike-induced extensional structures, multiple vents along a common eruptive fissure, and numerous pahoehoe lava flows, together forming a lava field. Events of moderate to large volume (5 +/- 3 km^3 (1.2 +/- 0.7 mi^3)) on the ESRP typically produce monogenetic shield volcanoes surrounded by a lava field composed of many individual pahoehoe lava flows. Although evidence has been found for rare, multiple-shield eruptions on the northeastern INL (Kuntz, 2002), monogenetic eruptions, producing a single lava field or a shield volcano surrounded by a lava field, are the typical eruption style on the ESRP (Kuntz, 1992a; Hackett, 2002).

VOLCANIC RECURRENCE ESTIMATES

Table D-3, Estimated Volcanic Recurrence Intervals and Corresponding Annual Eruption Probabilities (in parentheses) for Volcanic Zones and Boreholes of the INL Area, is a compilation of recurrence estimates from the INL area, and such estimates are essential for probabilistic volcanic-hazard analysis. The recurrence data of Table D-3 span an order of magnitude. Surface geologic data from the axial volcanic zone near the southern boundary of the INL and the Arco volcanic rift zone of the southwestern INL yield estimated recurrence intervals of ~6×10^{-5}/year (Hackett, 2002). Subsurface data from boreholes of the southern INL near the axial volcanic zone yield similar estimated recurrence intervals of ~3×10^{-5}/year (Champion, 2002). In contrast, areas near the northwest margin of the ESRP and in the northern INL, far from the axial volcanic zone, have undergone older and less frequent volcanism, with estimated recurrence intervals of ~8×10^{-6}/year. Champion et al. (Champion, 2002) emphasize that volcanic recurrence intervals are variable in space and in time in the INL area, that periods of quiescence are commonly observed in the subsurface data, and that a hiatus of eruptions and lava-flow emplacement has existed across much of the INL during the past 200 ka. The post-200 ka hiatus is not evident within the axial volcanic zone, which has been the source of an estimated 45 volcanic events during the past 730 ka (Hackett, 2002), most of them younger than 400 ka, many of them younger than 200 ka, and four of them younger than 15 ka.

TEMPORAL AND SPATIAL MODELS OF BASALTIC VOLCANISM

Within the 4,800 km^2 (1,853 mi^2) area over which Quaternary basalt and surficial deposits have been mapped near the INL, limited geochronological data exist from surface and borehole volcanic materials. Kuntz et al. (Kuntz, 1994) provide a summary of such data from INL basalt lava flows obtained by potassium-argon (19 observations), paleomagnetic measurements (45) and radiocarbon dates (4). Similar data exist from borehole materials (Champion, 2002), as shown in Table D-3. These data are essential for describing the temporal framework of basaltic volcanism, for estimating recurrence intervals, and for subdividing the volcanic materials into lithostratigraphic units in geologic mapping. However, the limited geochronological data available from the INL area are insufficient to allow the construction of detailed temporal models that might involve waxing, waning or episodic volcanism. No clear evidence of waxing or waning rates of volcanism has been identified from the surface geology of the axial volcanic zone. Therefore, a homogeneous temporal model of basaltic volcanism is used for the axial volcanic zone. That is, a uniform rate of recurrence is assumed for the axial volcanic zone and for future eruptions within that zone.

The proposed site lies at the intersection of several volcanic zones as shown in Figure D-1, Volcanic Rift Zones, Volcanic Vents, and Dike-Induced Fissures and Faults: the Lava Ridge – Hells Half Acre volcanic rift zone (estimated recurrence interval of 40,000 years; 2.5×10^{-5} per year), the Circular Butte - Kettle Butte volcanic rift zone (estimated recurrence interval of 40,000 years; 2.5×10^{-5} per year) and the northeast-trending axial volcanic zone (estimated recurrence interval of 16,000 years; 6.2×10^{-5} per year) (Hackett, 2002). The axial volcanic zone has been the site of silicic and basaltic volcanism for at least the past 1.4 Ma. It is also the source of the most recent volcanism in the INL region, including the vents of four latest Pleistocene to Holocene basaltic lava fields: the 13.2-ka Cerro Grande lava field, the 5.2-ka Hells Half Acre lava field and several smaller lava fields (Kuntz, 1986; Kuntz, 1994). The proposed site is located within the axial volcanic zone near the broad topographic axis of the ESRP, and the recurrence estimate for the axial volcanic zone (6.2×10^{-5}/yr) is therefore adopted as a conservative estimate for this analysis.

MAGNITUDE OF BASALTIC VOLCANISM

The most important volcanic hazard in the INL area is the inundation or burning of facilities by a basalt lava flow (Volcanism Working Group, 1990; Hackett, 2002). To estimate lava-flow magnitude, two parameters are used: the lengths and the areas of basalt lava flows in the INL region. Hackett et al. (Hackett, 2002) report statistics for INL basaltic lava-flow lengths and areas, as measured from the INL geologic map of Kuntz, et al. (Kuntz, 1994), with supplementary measurements taken from La Pointe (La Pointe, 1977). Many of the measured lava flows issued from vents within the axial volcanic zone; therefore, the measured lava-flow lengths and areas are considered to be representative of future lava flows from the axial volcanic zone that might affect the proposed site.

The median length of 46 measured INL lava flows is 10 km (6 mi), the mean length is 12.4 km (7.7 mi), the range is 0.1 – 31 km (0.06 – 19 mi) and the standard deviation is 7.9 km (4.9 mi). The median area of 43 measured lava flows is 70 km^2 (27 mi^2), the mean area is 97 km^2 (37 mi^2), the range is 0.5 – 400 km^2 (0.2 – 154 mi^2), and the standard deviation is 94 km^2 (36 mi^2). The median and mean lava-flow areas are similar, and the mean value of 97 km^2 (37 mi^2) is used in this analysis to represent the average area of a future basaltic lava flow that might affect the site. It is notable that the complete range of INL lava-flow areas and nearly the complete range of lava-flow lengths is represented by the Holocene basalt flows of the axial volcanic zone, indicating that the most recent volcanism of the axial volcanic zone has been similar in magnitude to older volcanism of the past 730 ka.

PROBABILISTIC VOLCANIC HAZARD ANALYSIS FOR THE PROPOSED SITE

The parameters needed to estimate the probability of lava inundation are the recurrence intervals of the appropriate volcanic source zones, the topographic setting of the proposed site within the volcanic source zones, the statistics of the lengths and areas of basalt lava flows from the region of interest during the recent geologic past, and the distance between the proposed site and the potential vents of future lava flows. Two approaches are taken, both giving similar results, and no mitigation is assumed in either approach.

Analysis 1

The results are shown in a volcanism event tree for lava flow inundation of the proposed site in Figure D-2, Volcanism Event Tree for Lava-Flow Inundation of the Proposed Site. The event tree is a modeling tool used to depict the chains of events that may result in some outcome of interest, in this case the potential inundation of a facility by lava flows. The event-tree modeling process begins with an initial condition that may lead to several end states, depending on the results of subsequent events. In this analysis, events are processes or conditions that are relevant to the outcome of interest. Event-tree branches are decision points, with upward branches representing the achievement of a desired outcome. Downward branches represent the absence of a desired condition. Each binary branch represents the universe of possible processes or conditions; therefore, the probabilities of all the possible processes or conditions must sum to one. Probabilities are assigned to each branch, and the probability of each event in the sequence is the product of the branch probabilities.

"Eruption" is the initial condition, and the 6.2×10^{-5} recurrence value is the annual probability of volcanism at a random location within the axial volcanic zone (Hackett, 2002), given homogeneous spatial and temporal models of volcanism. The second event, "lava flows away from the site," concerns vent location and topography near the proposed site, given an eruption within the axial volcanic zone. The proposed site lies within a shallow topographic basin, near the topographic crest of the axial volcanic zone as shown in Figure D-3, Geologic and

Physiographic Features Near the Proposed Site. The area of this basin, within which lava is likely to flow toward the site, is about 230 km^2 (89 mi^2). The basin is larger than the median (70 km^2 (27 mi^2)) and mean (97 km^2 (37 mi^2)) areas of INL lava flows measured by Hackett et al (Hackett, 2002), and larger than the proposed site area (25 km^2 (9.7 mi^2)). The probability of a future eruption within the basin can be estimated by dividing the 230-km^2 (89-mi^2) area of the basin by the 1,500-km^2 (579-mi^2) area of the axial volcanic zone, giving 0.15 as the fraction of future eruptions estimated to occur within the basin. Note that the 9.3×10^{-6} value reported for the second event serves as an upper bound for the site inundation probability. This is because the largest lava fields on the eastern Snake River Plain, erupted from the axial volcanic zone, would likely inundate the entire 230-km^2 (89-mi^2) topographic basin. This implies a zero probability of lava stopping short of the site (addressed in event 3, next step) and is therefore an upper bound. Examples of large lava fields near the proposed site are Hells Half Acre (400 km^2 (154 mi^2) (Kuntz, 1992)) and Kettle Butte (>320 km^2 (>124 mi^2) (Kuntz, 1979)).

The third event, "lava stops short of the site," addresses the probability of lava reaching the site, given an eruption within the topographic basin. The entire site lies within 12 km (7.5 mi) of the topographic rim of the basin, and most of the proposed site is within 8 km (5 mi) of this boundary. The median length of INL lava flows is 10 km (6 mi). It is therefore estimated that 70 percent of future lava flows erupted from a vent within the topographic basin will reach the site. Thus, the estimated annual frequency of lava inundation at the proposed site is 6.5×10^{-6}.

Analysis 2

The second analysis does not account for topography, and calculates the probability of lava inundation for a random location within the axial volcanic zone. This is accomplished by dividing the estimated magnitude (area) of a future lava flow into the area of its source zone, the axial volcanic zone. As in the first analysis, the initial condition is the 6.2×10^{-5} annual recurrence interval for the axial volcanic zone (Hackett, 2002); this is the annual probability of volcanism at a random location within the axial volcanic zone, given homogeneous spatial and temporal models of volcanism. The mean INL lava flow of the past 400 ka covers 97 km^2 (37 mi^2) (Hackett, 2002), and this is taken to represent the average area of a lava flow in the future. Dividing 97 km^2 (37 mi^2) by the 1,500 km^2 (579 mi^2) area of the source zone gives 0.06, meaning that a random location within the axial volcanic zone, including the proposed site, is estimated to have a 6 percent chance of being inundated by an average-sized lava flow in the future. The estimated mean annual probability of inundation of the proposed site is therefore

$(0.06)(6.2 \times 10^{-5}) = 3.7 \times 10^{-6}$.

An upper bound for the probability distribution of future lava inundation can be estimated by using the 400 km^2 (154 mi^2) area of the largest lava field on the ESRP, the Hells Half Acre lava field. This yields an estimated upper bound or highest inundation probability of about 10^{-5} per year, assuming the largest credible event. A lower bound for the probability of future inundation can be estimated by using the 3 km^2 (1.2 mi^2) area of the South Robbers lava field, one of the smallest and most recent lava fields in the axial volcanic zone. This yields an estimated lower bound for the smallest credible event of about 10^{-7} per year. The preferred, mean value for the annual probability of future lava inundation is 3.7×10^{-6}.

SUMMARY OF SITE-SPECIFIC RESULTS

Combining the similar results of the two analyses given above, the estimated mean annual probability (preferred value) of lava inundation at the proposed site is 5×10^{-6}. The estimated upper and lower bounds of the annual probability distribution span two orders of magnitude, from 10^{-5} to 10^{-7}, respectively.

COMPARISON WITH OTHER RESULTS

Hackett et al. (Hackett, 2002) calculate the annual probability of lava inundation at the Central Facilities Area (CFA), a cluster of facilities on the southwestern INL about 12 km (7.5 mi) from vents in the volcanic zones to the west and south, and within a topographic basin about 100 m (328 ft) lower than the surrounding volcanic highlands. The estimated annual probability of lava inundation for the CFA is 5×10^{-6}, without attempted mitigation. This result is identical to the results calculated here for the proposed site. Unlike the proposed site, the CFA is not situated within a volcanic source zone. The agreement of results is understandable because the CFA is nearby and downslope from two volcanic source zones with high recurrence intervals, including the axial volcanic zone.

The New Production Reactor (NPR) site was a proposed facility in the south-central INL, about 10 km (6 mi) from the nearest vents of the axial volcanic zone to the south. The Volcanism Working Group (Volcanism Working Group, 1990) considered basalt lava-flow inundation to be the most significant volcanic hazard at the NPR site. The annual probability of future lava inundation at the NPR site was qualitatively estimated by the Volcanism Working Group to be "less than 10^{-5}."

The results of two probabilistic analyses of lava-flow inundation for the proposed site yield an estimate of 5×10^{-6} per year. This agrees with the results of two other probabilistic volcanic-hazard analyses for sites on the southern INL, suggesting that 5×10^{-6} per year is a robust probability estimate for future lava-flow inundation across the proposed EREF site and adjacent areas within about 10 km (6 mi) of the axial volcanic zone.

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TABLES

TABLE D-1 Characteristics of Volcanism in the INL Area

(Page 1 of 1)

	CALDERA FORMATION	RIFT-ZONE VOLCANISM	AXIAL-ZONE VOLCANISM	AREAS BETWEEN VOLCANIC ZONES
GEOLOGIC AGE	6.5 to 4.3 million yrs in site area, now covered by younger basaltic lava. [2.1 to 0.6 million yrs on Yellowstone Plateau]	Surficial INL basalts: 1.2 to 0.05 million yrs; most are 0.7 to 0.1 million yrs. Inception of major basaltic volcanism was ca. 4 million yrs ago.	Basalt: >1 million yrs (Middle Butte), to 5,400 yrs (Hells Half Acre). Rhyolite: >1 million yrs (near East Butte) to 300,000 yrs (Big Southern Butte)	As per rift zones
QUATERNARY ERUPTION FREQUENCY	zero in Site area; Quaternary calderas closest to INL occur on Yellowstone Plateau	low; one eruption per 35,000 to 125,000 yrs	low: one basaltic eruption per 35,000 yrs one rhyolitic intrusion or dome every 200,000 yrs or longer	very low; by definition less frequent than within rift zones; one eruption per 125,000 yrs or longer
STRATIGRAPHY	calderas filled with up to several km (several mi) of welded, silicic ash-flow tuffs, lava flows and volcaniclastic sediment [Heise Volcanics]	piles of 1 to 30m (3.3 to 99 feet) thick basalt lava flows &minor interbedded sediment; total lava thickness up to 1 km (0.6 mile) in INL area [Snake River Group]	basaltic lava flows and dispersed small tephra cones; isolated rhyolite domes and intrusions [Snake River Group]	fine clastic sediment of fluvial, lacustrine and eolian origin; fewer lava flows than near VRZs [Snake River Group]
TECTONICS AND PHYSICAL CONFIGURATION	collapse: broad, oval depressions, 10s to 100 km (10s to 62 miles) wide and 1 to 2 km (0.6 to 1.2 mi) deep, ringed by inward-dipping fractures	extensional: NW- trending belts of open fissures, monoclines small normal faults and basaltic vents	extensional, but magma-induced fissures or, faults are rare; a diffuse, NE-trending, volcanic highland along the ESRP axis	subsidence: broad, low topographic basins between extensional and constructional volcanic highlands; seldom disturbed by magma intrusion
VOLCANIC STYLE AND PRODUCTS	highly explosive; voluminous pumice and fine ash blankets entire regions	mild &effusive; erupt mainly lava flows from fissures, low shield volcanoes and small tephra cones	as per rift zones, but also local rhyolite domes & intrusions (Big Southern, Middle, East Buttes) with local explosive phenomena	as per volcanic rift zones (VRZs) and axial volcanic zone

Source: Hackett, 2002.

Note: Refer to Figure D-1 for Map Description of Volcanic Zones and Related Features

TABLE D-2 Hazards Associated with Basaltic Volcanism on the Eastern Snake River Plain

(Page 1 of 1)

Phenomenon	Relative Frequency	Size or Area of Influence	Comments
Lava flow	Common	0.1 km^2 to 400 km^2 (0.04 mi^2 to 154 mi^2) in area; up to 32 km (20 mi) in length based on sizes of ESRP lava flows of the past 400 Ka	Significant hazard; typical basaltic phenomenon; lava from fissures or shield volcanoes may inundate large areas downslope of vents
Ground deformation: fissuring, faulting, and uplift	Common; associated with virtually all shallow magma intrusion and eruption	Fissuring could affect areas to 1 x 10 km (0.62 x 6.2 mi); minor tilting and broad uplift in areas to 2 x 20 km (1.2 x 12.4 mi)	Significant hazard; due to shallow dike intrusion; "dry" intrusion may occur without lava flows; affects smaller areas than for lava inundation
Volcanic earthquakes	Common; associated with magma intrusion before and during eruption	Maximum M = 5.5 and most events M < 3; ground vibration may affect facilities within 25 km (16 mi)	Low to moderate hazard; swarms of shallow earthquakes (< 4 km (< 2.5 mi) focal depth) occur as dikes propagate underground
Gas release (toxic and corrosive vapors)	Common; associated with fissuring and lava eruption	Restricted to near-vent areas; may affect several square-km (square-mi) area downwind	Low hazard; local plume of corrosive vapor, downwind from eruptive vent or fissure; cooled vapor may collect in local topographic depressions
Tephra fall (volcanic ash and bombs)	Common	Restricted to near-vent areas; may affect several square-km (square-mi) area downwind	Low hazard; basaltic eruptions are inherently nonexplosive and may form small tephra cones but little fine ash to be carried downwind
Base surge (ground-hugging blast of steam and tephra)	Rare	Effects limited to radius of several km from vent; < 10 km^2 (< 4 mi^2) area	Low hazard; steam explosions due to interaction between ascending magma and shallow ground water; water table too deep under most of INEEL (> 200 m (> 656 ft))
Tephra flow (ground-hugging flow of hot, pyroclastic material)	Extremely rare	Near vent; may affect area < 1 km^2 (< 0.4 mi^2)	Very low hazard; as per tephra fall but affecting even smaller areas

Source: Hackett, 2002; Table 2 (note minor revisions to table)

TABLE D-3 Estimated Volcanic Recurrence Intervals and Corresponding Annual Eruption Probabilities (in parentheses) for Volcanic Zones and Boreholes of the INL Area

(Page 1 of 2)

Volcanic Zone or Borehole	Data Sources	Time Interval of Volcanism	Number of Vents, Fissures or Flow Groups	Comments	Estimated Recurrence Interval
Great Rift (25 km SW of INL)	Kuntz, 1986; Kuntz, 1988	2.1 - 15 ka (radiocarbon dating)	>100 vents 8 Holocene eruptive periods (each lasting a few decades or centuries, and each including multiple cones and flows	No impact on INL; most recently and frequently active of all ESRP rift zones; gives minimum recurrence for entire ESRP; most probable area of future ESRP volcanism	2 ka (5 x 10^{-4}/yr)
Axial Volcanic Zone (southern INL)	Kuntz, 1986; Kuntz, 1994; Hackett, 2002	5 – 730 ka (K-Ar, radiocarbon, paleomagnetic data)	73 vents and fissure sets; 4 Holocene lava fields, 3 shared by volc rift zones. 45 cogenetic vent & fissure groups	Could affect much of southern INL; most recently and frequently active of all volc zones that could impact INL	16 ka (6.2 x 10^{-5}/yr)
Arco Volcanic Rift Zone (southwestern INL)	Kuntz, 1994; Hackett, 2002	10 – 600 ka (radiocarbon, K-Ar, thermoluminescence, paleomagnetic data)	83 vents and fissure sets; 2 Holocene lava fields. 35 cogenetic vent & fissure groups	Volcanism could affect southwestern INL	17 ka (5.9 x 10^{-5}/yr
Lava Ridge-Hells Half Acre and Circu-lar Butte/Kettle Butte Volc Rift Zones (N & eastern INL)	Kuntz, 1986; Kuntz, 1994; Hackett, 2002	5 ka – 1.2 Ma (K-Ar, radiocarbon, paleomagnetic data)	48 vents & fissure sets; 1 Holocene lava field (Hells Half Acre) 30 cogenetic vent & fissure groups	Could affect N & eastern INL; extremely long eruptive history; includes oldest & youngest basalts of INL area	40 ka (2.5 x 10^{-5}/yr)
Howe-East Butte Volcanic Rift Zone (central INL)	Kuntz, 1992b; Golder, 1992; Hackett, 2002	230 – 730 ka (K-Ar dating; paleomagnetic data)	7 vents and fissure sets; no Holocene features. 5 cogenetic vent & fissure groups	Old, poorly exposed and sediment-covered; identified in part by subsurface geophysical anomalies	100 ka (1.0 x 10^{-5}/yr)
Borehole NPR Test/WO-2 (south-central INL)	Champion, 2002	230 – 640 ka (K-Ar, paleomagnetic data)	9 lava-flow groups (each group contains multiple lava flows, erupted over a short time)	Dates from subsurface lava flows give recurrence estimates consistent with surficial geology of area	51 ka (2.0 x 10^{-5}/yr)

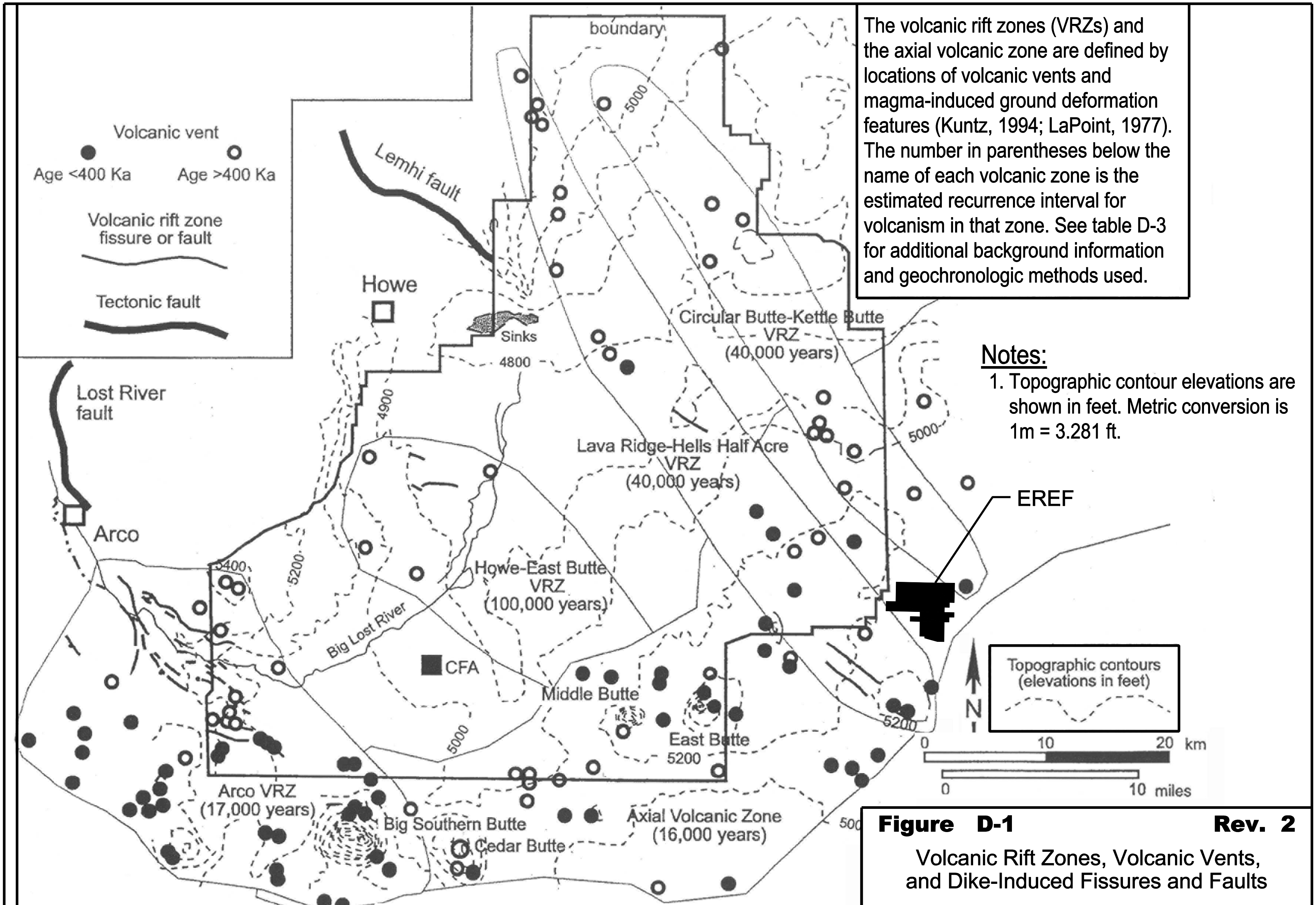
TABLE D-3 Estimated Volcanic Recurrence Intervals and Corresponding Annual Eruption Probabilities (in parentheses) for Volcanic Zones and Boreholes of the INL Area

(Page 2 of 2)

Volcanic Zone or Borehole	Data Sources	Time Interval of Volcanism	Number of Vents, Fissures or Flow Groups	Comments	Estimated Recurrence Interval
Borehole RWMC BG-77-1 (southwestern INL)	Kuntz, 1978; Champion et al., 2002	100 – 565 ka (K-Ar and thermoluminescence dating; paleomagnetic data)	11 lava-flow groups (each group contains multiple lava flows, erupted over a short time)	Dates from subsurface lava flows give longer recurrence interval than nearby Arco and axial volcanic zones	43 ka (2.3×10^{-5}/yr)
Sixteen Boreholes of the South-Central INL	Champion et al, 2002	ca. 200 – 700 ka (K-Ar, Argon isotopic and paleomagnetic data)	Variable; uses age dates of independent lava flows together with interpolations from linear age-depth relationships observed in boreholes	Smooth contour pattern of recurrence intervals in a 200-km^2 area of south-central INL parallels the axial volcanic zone. Mean recurrence intervals are shorter near axial volc zone (~40 ka) and longer near NW margin of ESRP (~116 ka).	40 ka – 116 ka (2.5×10^{-5}/yr to 8.6×10^{-6}/yr) Range of mean recurrence for individual boreholes
Two boreholes of Test Area North (northern INL)	Champion et al., 2002	1 Ma – 2.5 Ma (K-Ar, Argon isotopic and paleomagnetic data)	Variable; uses age dates of independent lava flows together with interpolations from linear age-depth relationships observed in boreholes	Long recurrence and low lava accumulation rates reflect locations near margin of ESRP and far from volcanic zones. Dated lava flows record earlier volcanism than most other boreholes and surface lava flows.	130 ka (7.7×10^{-6}/yr) Average of two mean values from two boreholes

[Modified from Hackett, 2002; Table 3]

FIGURES



The volcanic rift zones (VRZs) and the axial volcanic zone are defined by locations of volcanic vents and magma-induced ground deformation features (Kuntz, 1994; LaPoint, 1977). The number in parentheses below the name of each volcanic zone is the estimated recurrence interval for volcanism in that zone. See table D-3 for additional background information and geochronologic methods used.

Notes:

1. Topographic contour elevations are shown in feet. Metric conversion is 1m = 3.281 ft.

Source: Hackett, 2002.

Figure D-1 **Rev. 2**

Volcanic Rift Zones, Volcanic Vents, and Dike-Induced Fissures and Faults

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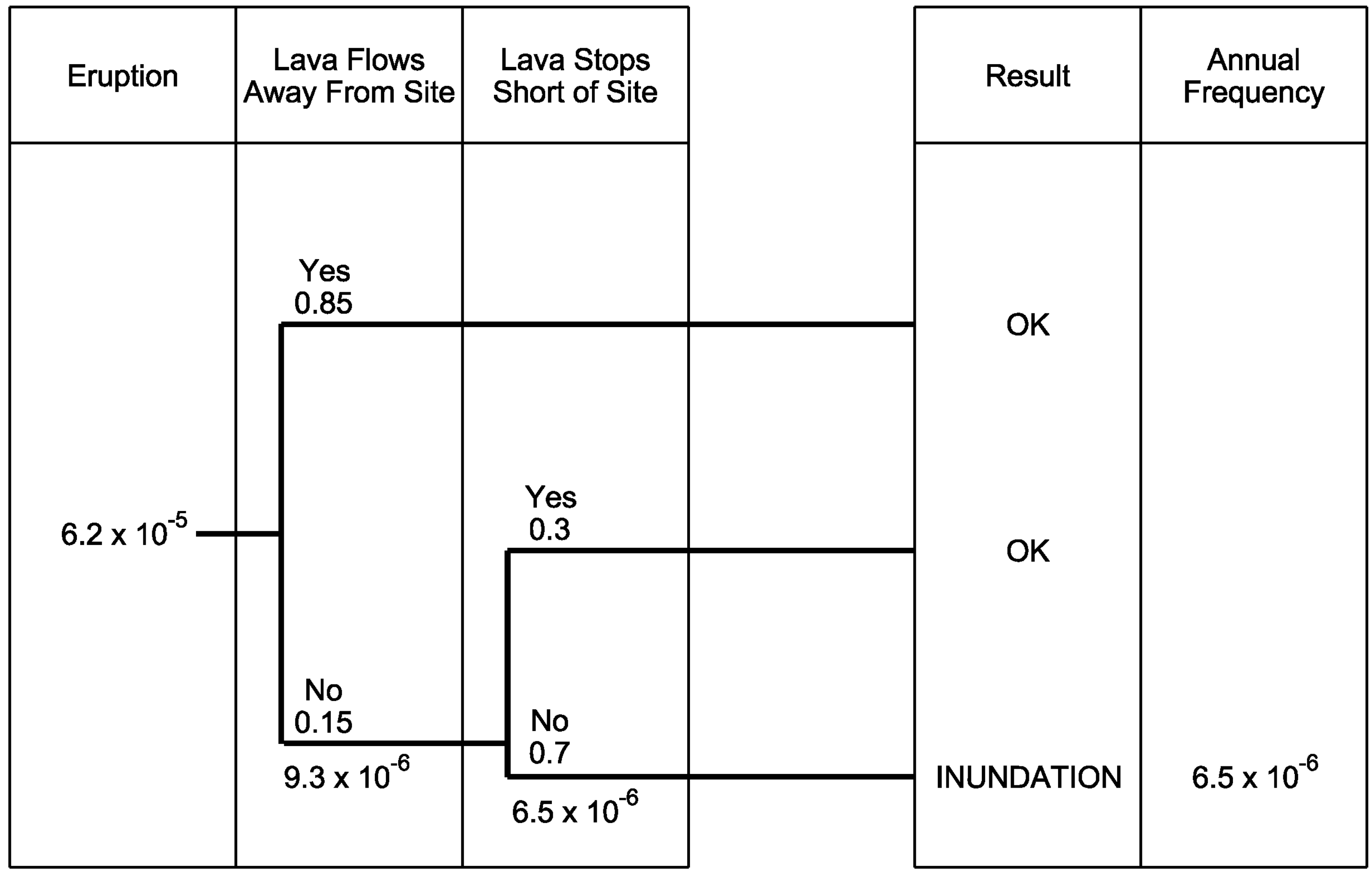

Source: Original Figure by W. R. Hackett

FIGURE D-2 **Rev. 2**

Volcanism Event Tree for Lava-Flow Inundation of the Proposed Site

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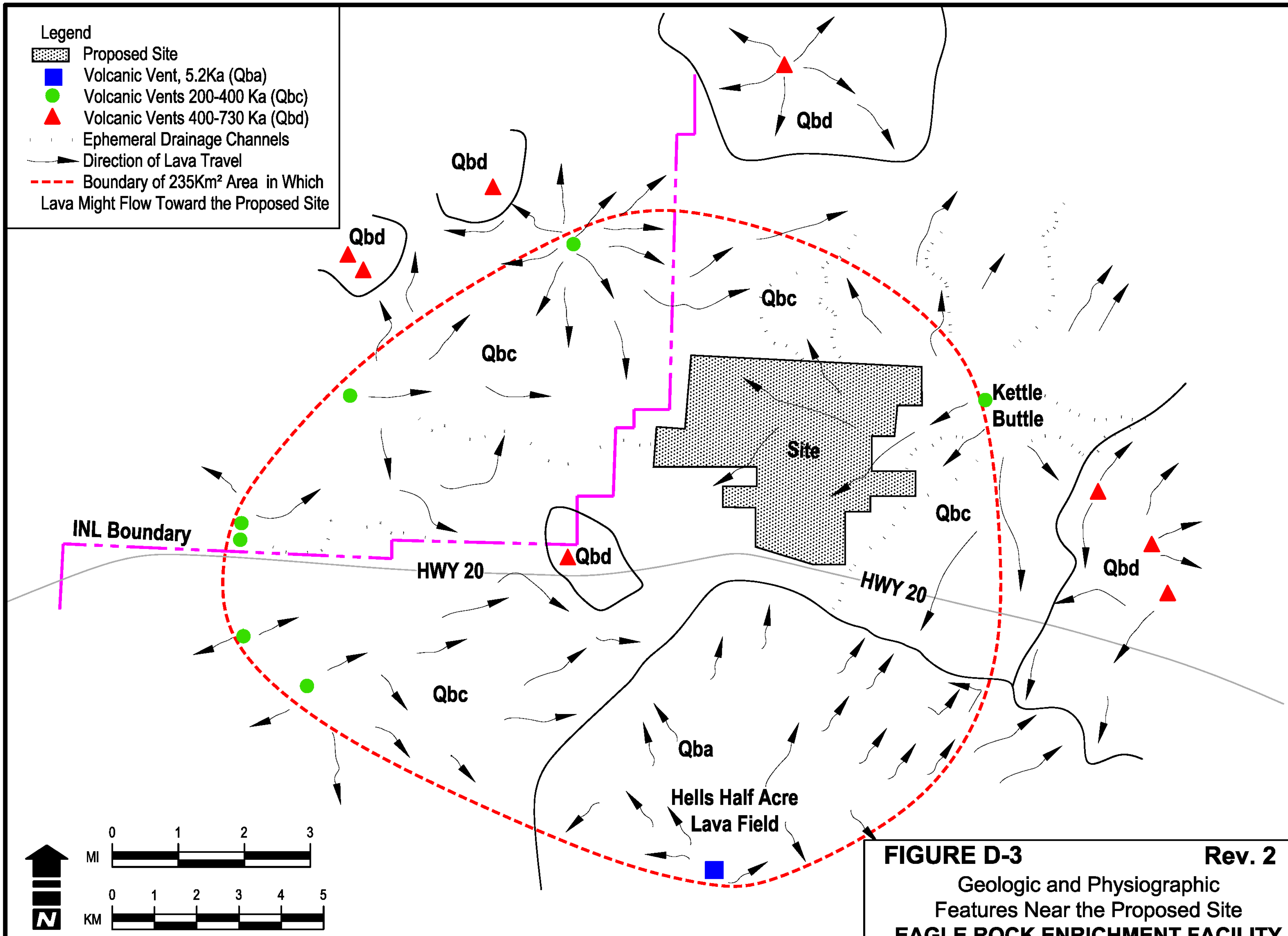

Source: Original drawing by W.R Hackett, based on Map from Kuntz, 1994.

FIGURE D-3 **Rev. 2**

Geologic and Physiographic Features Near the Proposed Site

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