Proceedings 32nd Symposium
Engineering Geology and Geotechnical Engineering, 1997

MODEL MORPHOLOGIES OF SUBSURFACE QUATERNARY BASALTS AS EVIDENCE FOR A DECREASE IN THE MAGNITUDE OF BASALTIC MAGMATISM AT AND NEAR THE IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY, IDAHO

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ABSTRACT

Correlations of subsurface basalt flows based on selected properties of 26 cores and natural-gamma logs from 328 wells indicate that at least 121 Pleistocene flow groups are present at and near the Idaho National Engineering and Environmental Laboratory (INEEL). Each flow group, by definition, includes all basalt flows erupted from a single eruptive center during a brief period of time. However, many flow groups, identified at a facility scale (< 85 km^2), were correlated across the entire width of the INEEL, although their actual extents could not be verified by core data. These widespread flow groups are here designated supergroups to indicate that at the INEEL scale (~7500 km^2) they are likely the products of multiple eruptive centers. This conclusion is based on isopach maps of 14 selected subsurface supergroups that were generated using a simple Kriging method. The identification of individual eruptive centers was accomplished by comparing the isopach maps with topographic surface maps of the base of each supergroup to distinguish construction from ponding. This procedure resulted in the identification of multiple eruptive centers and flow groups within 11 of the 14 supergroups. In addition, the volume and areal extents were estimated for each supergroup and its respective flow groups.

Results of this study indicate that volumes and areal extents of individual Pleistocene flow groups underlying the INEEL commonly are several times greater than those of monogenetic Holocene lava fields on the eastern Snake River Plain (ESRP). These relations coupled with a substantial decrease in the accumulation rate of basalt about 200 ka lead to the conclusion that the magnitude of basaltic volcanism markedly decreased from the latest Pleistocene to Holocene at and near the INEEL and probably elsewhere on the ESRP. A decrease in the magnitude of volcanism is also indicated by a decrease in the spatial density of Holocene eruptive centers relative to that interpreted for Pleistocene eruptive centers in the subsurface.

INTRODUCTION

The eastern Snake River Plain (ESRP) is an 80-to-115 km-wide northeast-trending structural and topographic basin in southeastern Idaho extending approximately 300 km from Twin Falls to Ashton (Figure 1). As much as 1,000 m of Late Cenozoic basalt, eolian sand and loess, and alluvial and lacustrine sediments underlie much of the ESRP. Located on the northwest side of the ESRP is the Idaho National Engineering and Environmental Laboratory (INEEL) a nuclear research center (Figures 1 and 2) where disposal of radioactive and chemical wastes into subsurface volcanic rocks and sediments has occurred over the past four decades. The potential for migration of wastes has resulted in the need for a detailed understanding of the three dimensional stratigraphy of the subsurface at and near the INEEL. This area is underlain mainly by basalt and sediment of Pleistocene age, and basalt makes up about 85% of the deposits.

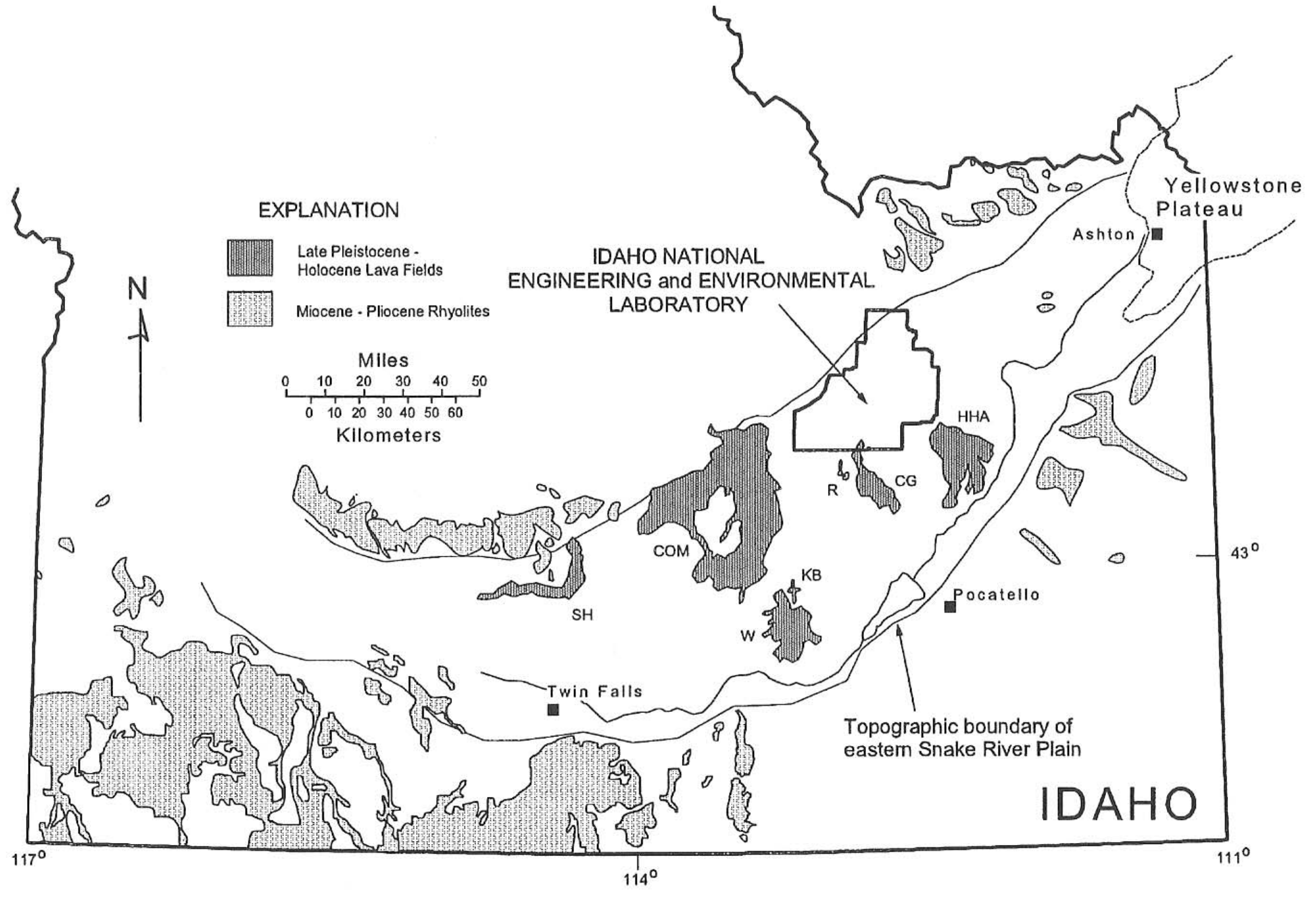
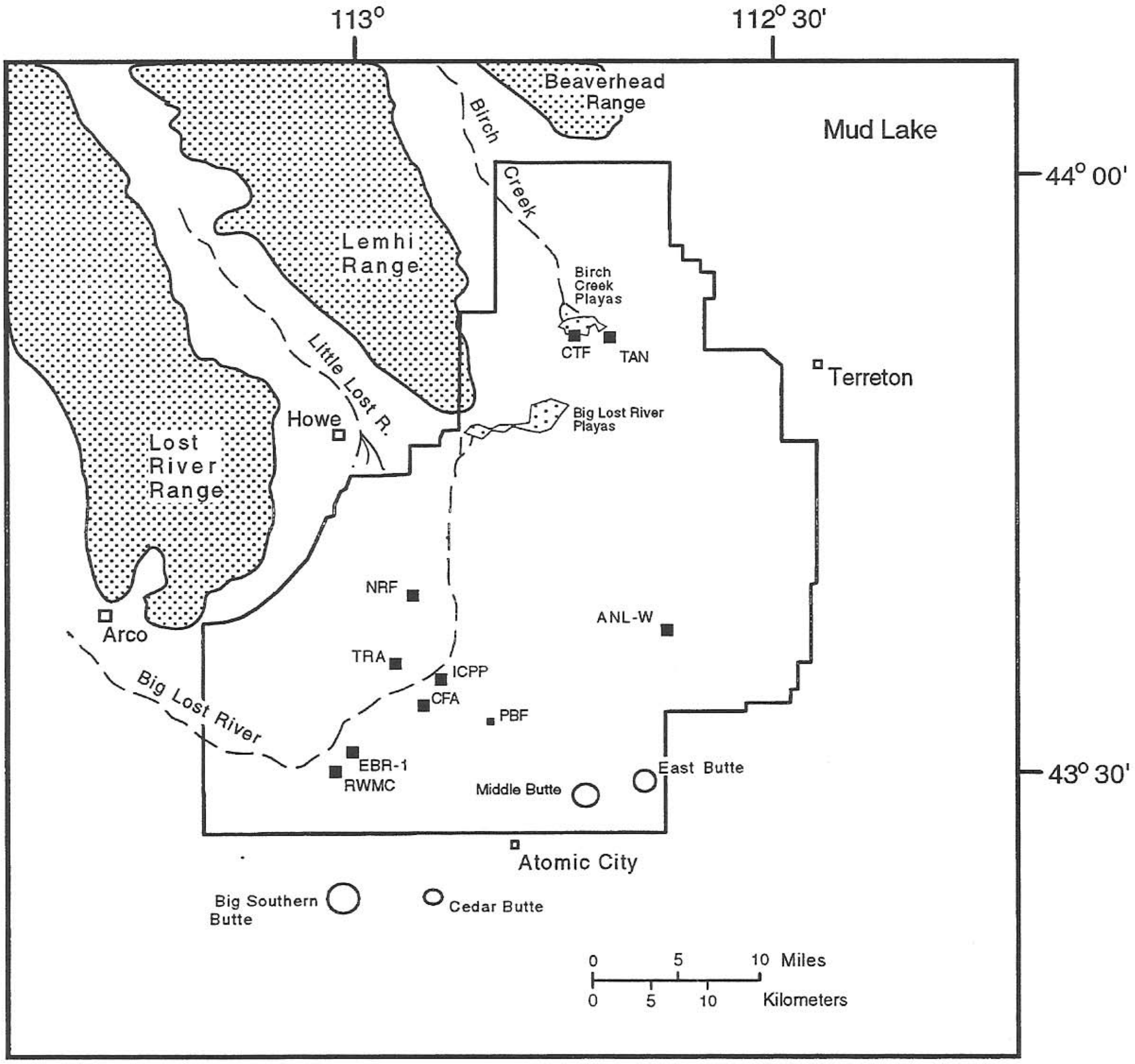


Figure 1. Map of southern Idaho and the eastern Snake River Plain showing locations of the Idaho National Engineering and Environmental Laboratory (INEEL) and latest Pleistocene-Holocene lava fields. Abbreviations for lava fields are: SH = Shoshone, COM = Craters of the Moon, W = Wapi, KB = Kings Bowl, R = North and South Robbers, CG = Cerro Grande, and HHA = Hells Half Acre.



ANL-W	Argonne National Laboratory-West
CFA	Central Facilities Area
CTF	Contained Test Facility
EBR-1	Experimental Breeder Reactor No.1
ICPP	Idaho Chemical Processing Plant
NRF	Naval Reactors Facility
PBF	Power Burst Facility
RWMC	Radioactive Waste Management Complex
TAN	Test Area North
TRA	Test Reactors Area

Figure 2. Map of the Idaho National Engineering and Environmental Laboratory with locations of facilities and major topographic features.

Holocene basalts on the ESRP, which are useful as models for understanding the characteristics of basalts in the subsurface, occur as low shields, cinder cones, and minor fissure eruptions. Maximum volumes of the surficial monogenetic Holocene lava fields do not exceed 6 km^3 (e.g. Hells Half Acre and Wapi field, Figure 1), and areal extents of these fields are no greater than 400 km^2 (Kuntz et al., 1992). Lava flows in Holocene fields on the ESRP typically extend less than 20 km from source vents (e.g. Wapi and Cerro Grande lava fields, Figure 1). However, channelized basaltic lava in the Shoshone lava field extends approximately 60 km from the source at Black Butte Crater (Figure 1). Kuntz et al. (1992) suggest that Shoshone and other extensive ESRP lava fields were tube-fed in distal regions, which may explain their great travel lengths.

The movement of water and waste through the vadose zone and the Snake River Plain aquifer, which underlies the ESRP, is controlled, in part, by the spatial arrangement, physical characteristics, and volumes of volcanic layers and sedimentary interbeds, especially those of basalt. On the basis of natural-gamma log correlations from 328 wells and 26 cores at and near the INEEL, Anderson and Bartholomay (1995) and Anderson et al. (1996) identified at least 121 basalt flow groups, 102 sedimentary interbeds, 6 andesite flow groups, and 1 rhyolite dome in the subsurface. Paleomagnetism and radiometric methods were used to constrain the ages and distribution of these stratigraphic units (Anderson et al., 1997). Geologic ages of volcanic units in the vadose zone and the Snake River Plain aquifer generally range from approximately 100 ka to 1.8 Ma. Geologic ages of surficial volcanic units at and near the INEEL range from 5.2 thousand (ka) to 1.4 million (Ma) years before present (Kuntz et al., 1994).

This report describes the three dimensional geometries of 14 selected basalt flow groups identified by Anderson et al. (1996) to evaluate the morphologies of subsurface Quaternary basalts at and near the INEEL. A basalt flow group consists of a single flow or multiple flows emplaced during a single eruptive event and from a single source area (Kuntz et al., 1980). For example, the basalt of Wapi and Hells Half Acre lava fields each represent one basalt flow group (Figure 1). However, present studies now recognize that many of the flow groups described in the subsurface by Anderson et al. (1996) are the products of multiple eruptive centers that are spatially isolated from one another. Correlations made at individual INEEL facilities for areas less than 85 km^2 (Figure 2) (Anderson and Lewis, 1989; Anderson 1991; Anderson and Bowers, 1995) utilized the definition of a flow group as described by Kuntz et al. (1980); however, these correlations may not be valid on an INEEL scale. To provide a more precise definition of basalt underlying the area, basalt flow groups at the INEEL scale herein are referred to as basalt supergroups after Welhan et al. (this volume). This term indicates that, at the INEEL scale, many of the widespread basalt flow groups of Anderson et al. (1996) may each actually represent the combination of several basalt flow groups of similar age and stratigraphic position from different eruptive centers.

CALCULATION OF BASALT VOLUMES AND AREAL EXTENTS

Isopach maps of 14 selected basalt supergroups were generated by a computer mapping program (Keckler, 1995) using the stratigraphic database of Anderson et al. (1996). The data set is a compilation of stratigraphic intervals in all INEEL wells based on paleomagnetic data, petrographic characterizations, interpretations of natural-gamma logs, radiometric ages, and drilling log information (Anderson and Bartholomay, 1995; Anderson et al., 1996). Basalt supergroups include, and retain the same stratigraphic names as, basalt flow groups B though I described by Anderson et al. (1996). Basalt supergroups increase in relative age from B to I

(Table 1). Each basalt supergroup was selected primarily on the basis of the number of INEEL wells that yielded information on its presence or absence throughout the area. Stratigraphic interpretations suggest that, except for supergroups H and I, all basalt supergroups selected for this study were penetrated in at least 90 wells.

Data used in this assessment include X-Y coordinates of each well and elevations of the tops and bottoms of basalt supergroups from which flow thicknesses were calculated. Some minor adjustments to the original data set were necessary to allow conformity between original and new data sets and the mapping program. These adjustments include: 1) the utilization of a triangulation method to extrapolate the base of each supergroup in partially penetrating wells; 2) the combination of basalt flow groups D(1), D(2), D(3), and D(4) to produce one basalt supergroup D; and I(1) and I(2) to produce one basalt supergroup I; and 3) ignoring the presence of a minor sedimentary interbed (< 3 m) in supergroup I that occurs in three out of 72 wells containing I basalts. In order to define the boundaries of each basalt supergroup, it was necessary to identify, and include into the data set, those wells that penetrate the stratigraphic section where a selected supergroup is not present. In this case, the elevation of the top of the next older supergroup was used for the elevation of the top and base of the missing basalt supergroup in the data set. This technique yielded a unit thickness of zero and identified the topographic surface present at the time the missing unit was erupted elsewhere in the area.

A simple Kriging method was selected to generate the grid from which the isopach maps were created. Each map was generated using a grid spacing of 49x50 points for a map area of 85x95 km. Each grid point value, the interpolated thickness of a supergroup was determined using a quadrant search with a minimum of 6 data points per quadrant. Thus, the value determination for each grid point required the data from six wells in each quadrant. The search ellipse radius for each grid point was approximately half the map width. If six wells were not found in each quadrant within the search ellipse radius for a particular grid point that point was blanked. A linear variogram model was utilized to set interpolation weights for each grid node. Drift or nugget effects were not applied to the grid. Areas of the map occupied by the mountains in the Basin and Range province northwest of the INEEL (Figure 2) were systematically given zero values so the computer program would avoid these areas for extrapolating thicknesses. However, in the case of basalt supergroup B, the area occupied by Big Southern Butte (Figure 2) was not removed; thus the volume and areal extent of basalt supergroup B are slightly overestimated.

The final modification of the Kriging method was to limit the thickness of isopach maps of the selected supergroups to values greater than 5 m, the approximate thickness of a single lava flow lobe. This was done to avoid mathematical construction of lava fields extending into regions of the map not supported by stratigraphic data. Essentially, Kriging of any supergroup having a cutoff value less than 5 m produced an unreasonable isopach map that extended beyond the region supported by well data, often as much as 30 km beyond the 5 m contour. Holocene flows that are less than a few meters in thickness are typically minor lobes of a larger flow and do not add significantly to flow volumes. However, in a kriged map construction, these lobes greatly influence the isopach map as well as any calculations made from it. By definition, areas calculated are minimum values based on the 5 m cutoff; computed volumes were corrected to include the 5 m thickness below the cutoff. Accumulation rates for volume and thickness were calculated using estimated mean ages from linear regressions determined from a composite stratigraphic section underlying the INEEL (Anderson et al., 1997).

RESULTS AND DISCUSSION

The isopach maps of supergroups B though I (figure 3), and the calculation of physical parameters derived from them (Table 1), are analyzed in this study to determine: 1) if the basalt supergroups are the composite of multiple flow groups erupted from spatially separate and identifiable centers; 2) if these flow groups are concordant with monogenetic Holocene lava fields in terms of volume and areal extent; and 3) if the magnitude of volcanism for the monogenetic Holocene lava fields of the ESRP is similar to that interpreted from the subsurface.

Table 1. Volumes, areas, thicknesses, and ages of selected supergroups (S.G.) and flow groups (F.G.).

Super-Group	S.G. Vol. (km^3)	Avg. F.G. Vol. (km^3)	S.G. Area (km^2)	Avg. F.G. Area (km^2)	Avg. Thickness (m)	Holocene Model Area (km^2)+	Mean* Age (ka)	Eruptive Centers
B	40	13	3,000	1,000	13.3	1,110	(221)	3
C	8.3	2.8	980	320	8.5	230	(268)	3
D	64	16	3,000	750	21.3	1,330	(302)	4
DE2	43	21.5	3,400	1,700	12.7	1,790	350	2
DE3	43.5	43.5	3,300	3,300	13.2	3,630	(362)	1
DE5	51	17	4,200	1,400	12.1	1,420	441	3
DE6	6.6	2.2	800	270	8.3	190	(473)	3
DE7	8.8	4.4	1,000	500	8.8	370	(479)	2
DE8	68	22.7	4,800	1,600	14.2	1,890	491	3
E	72	24.2	4,500	1,500	16.1	2,020	515	3
F	33	33	3,600	3,600	9.2	2,750	567	1
G	50.5	50.5	4,500	4,500	11.2	4,210	(598)	1
H	54	27	3,800	1,900	14.2	2,250	619	2
I	145	72.5	6,000	3,000	24.2	6,040	626	2

+ Areal extents of flow groups calculated assuming their average thicknesses are equivalent to those of Holocene lava fields.

* Anderson et al., 1997; parentheses indicate estimated ages.

The presence of multiple eruptive centers, based on isolated regions of greatest thickness, was identified in 11 of the 14 selected basalt supergroups. Inspection of isopach maps in conjunction with basal surface maps for individual supergroups indicates that nearly all of the thick sequences of basalt are located outside of topographic depressions and are volcanic constructs. The implications of this observation are that: 1) ponding has not been a major aspect of basaltic volcanism in the past at and near the INEEL; and 2) thick sequences of basalt typically indicate the location of eruptive centers. Although this observation does provide a tool for identifying relatively large eruptive centers and the flow groups that have issued from them, the probability of not identifying smaller eruptive centers and flow groups (e.g. lava fields the size of North and South Robbers lava fields) is likely quite high. This is due, in large part, to the fact that two thirds of the wells at and near the INEEL are located within two kilometers of the facilities (Figure 2); small eruptive centers can be identified only where a sufficient number of wells exist.

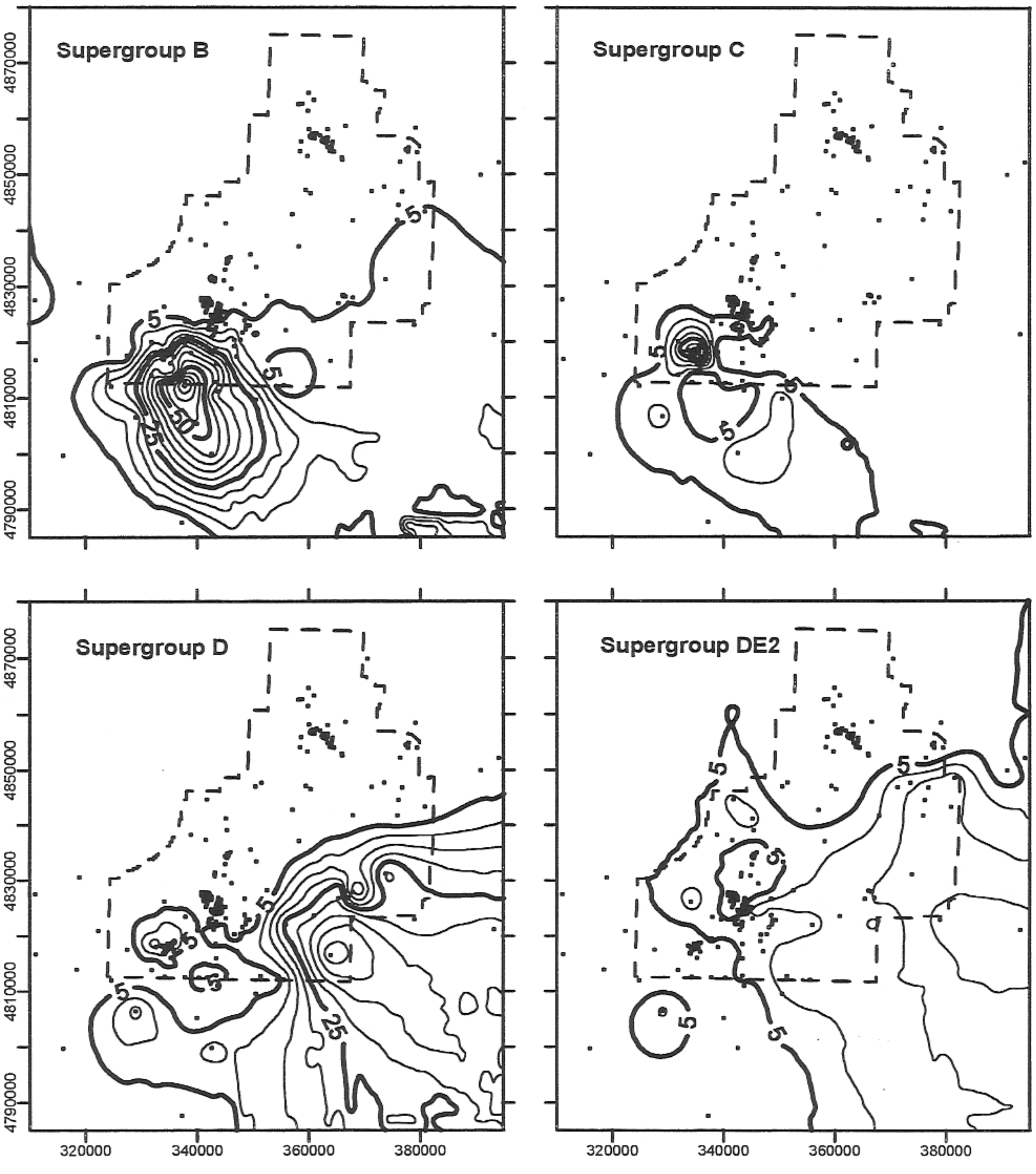


Figure 3. Isopach maps of supergroups B, C, D, and DE2. Contour interval is 5 m. Dots represent well locations. UTM coordinate system.

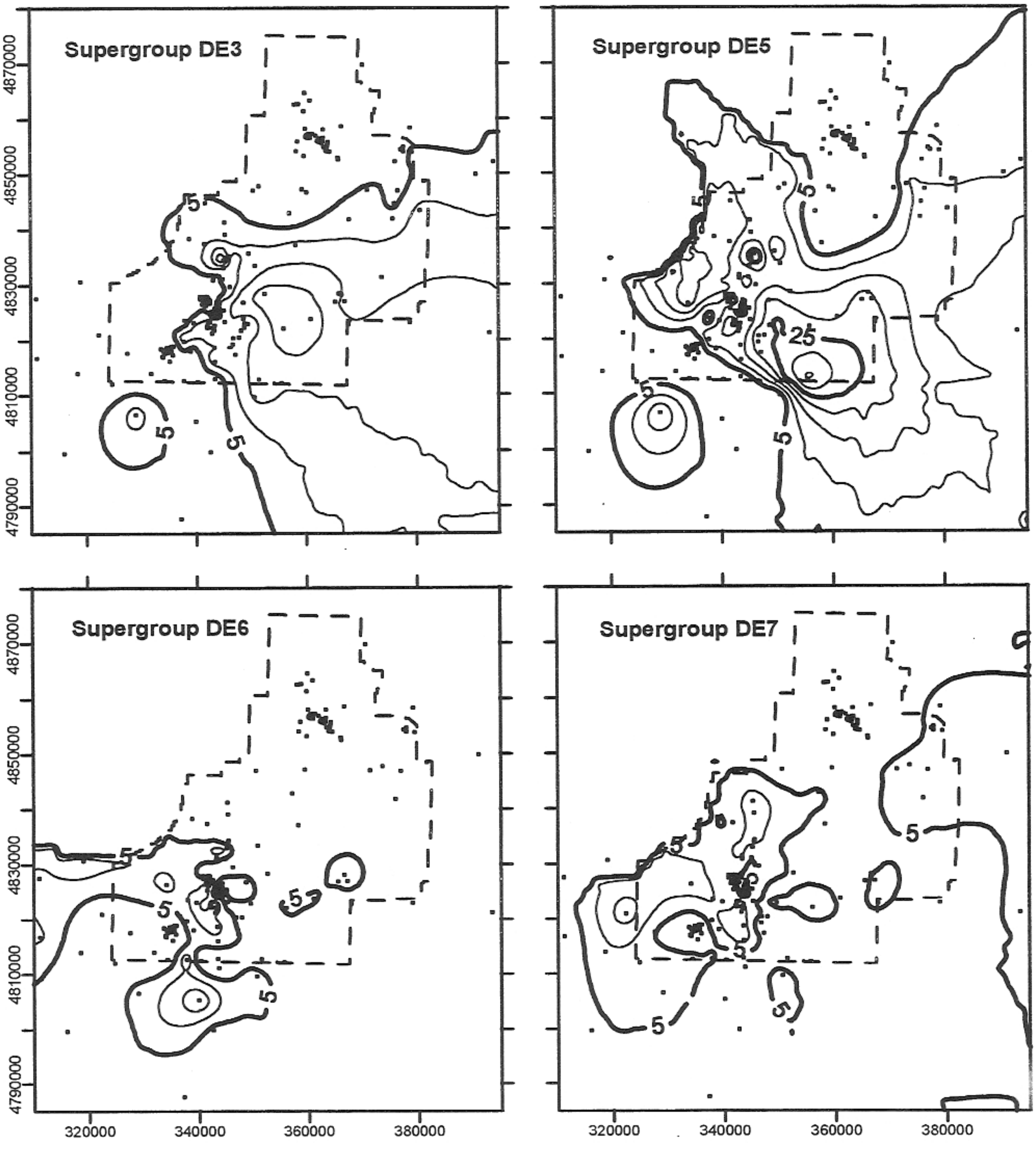


Figure 3 continued. Isopach maps of supergroups DE3, DE5, DE6, and DE7. Contour interval is 5 m. Dots represent well locations. UTM coordinate system.

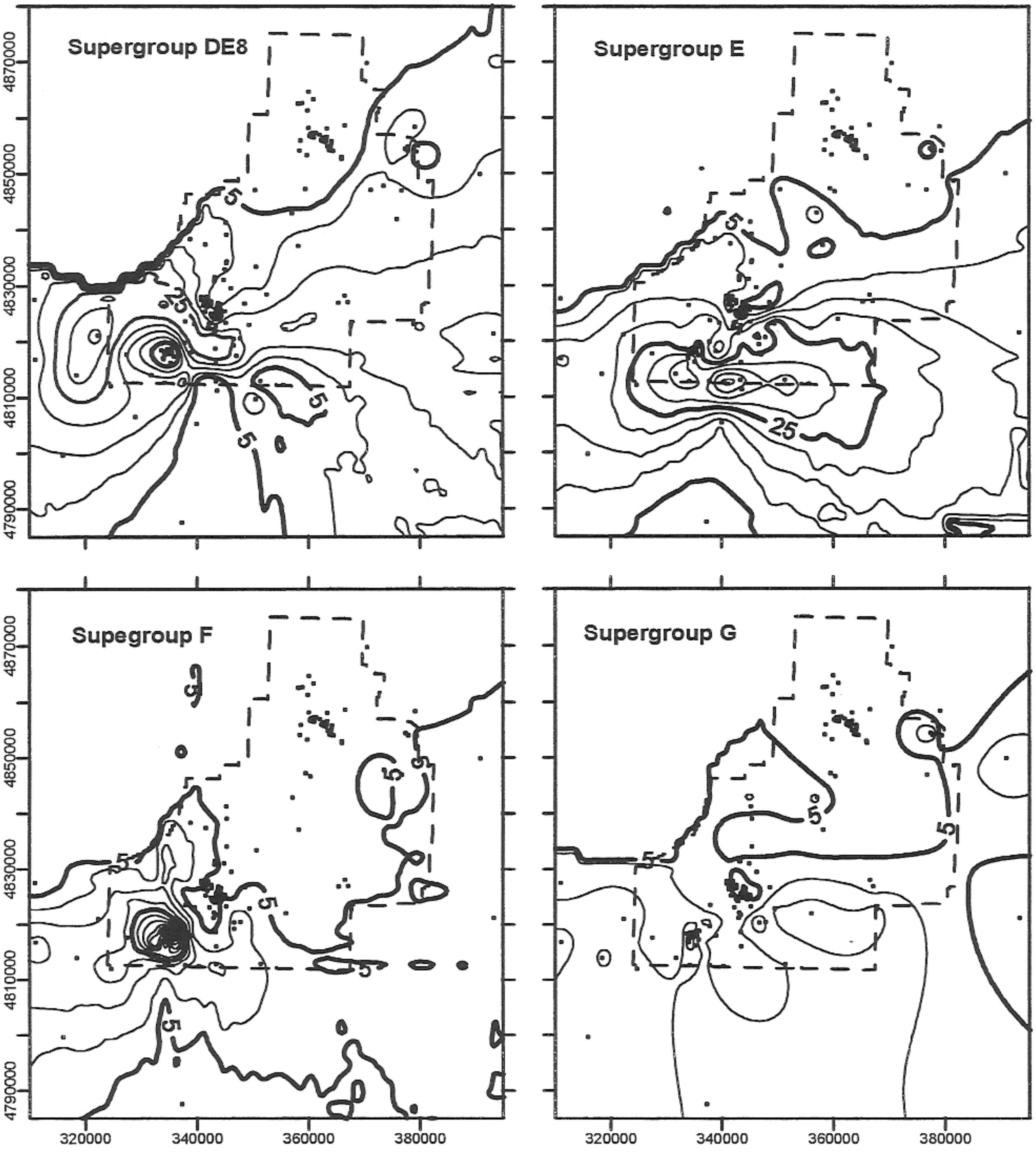


Figure 3 continued. Isopach maps of supergroups DE8, E, F, and G. Contour interval is 5 m. Dots represent well locations. UTM Coordinate system.

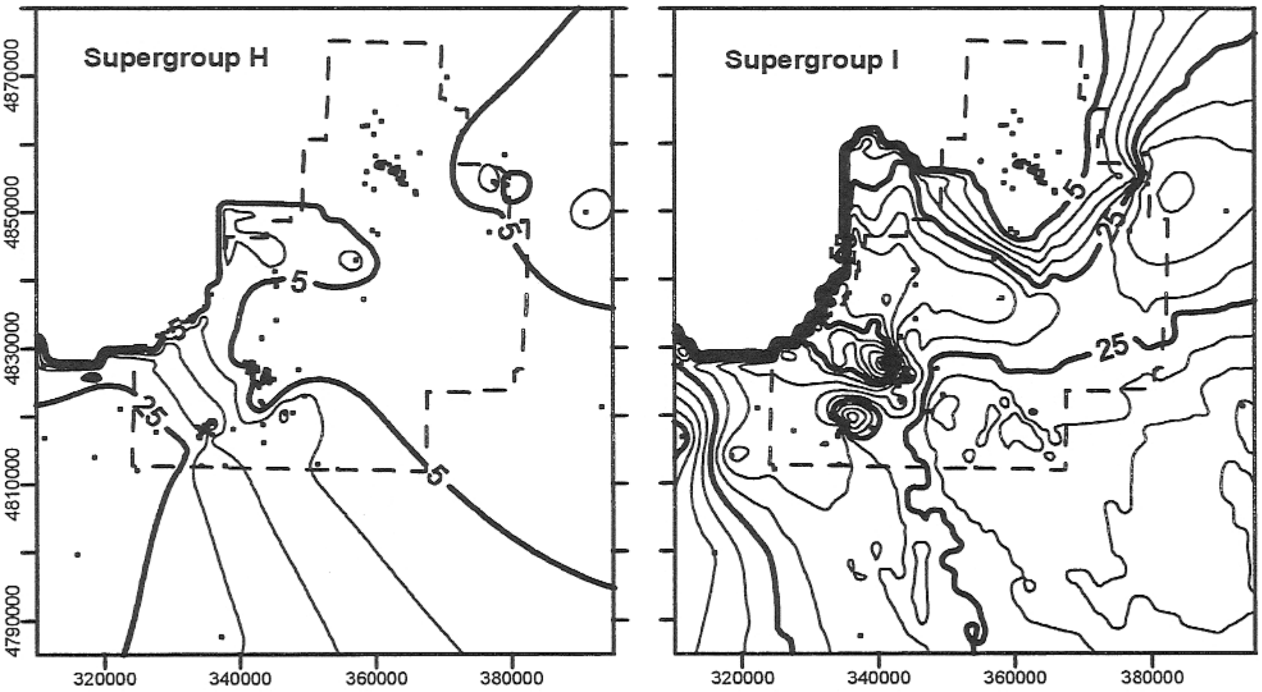


Figure 3 continued. Isopach maps of supergroups H and I. Contour interval is 5 m. Dots represent well locations. UTM Coordinate system.

The physical parameters of the largest individual flow groups can only be estimated at this time. Volumes and areal extents of the flow groups are estimated by dividing the values of each supergroup by the number of eruptive centers identified within it (Table 1). The results of this procedure reveal that the average volumes of all but four of the interpreted flow groups, those within supergroups DE3, G and I, are less than three times the largest monogenetic Holocene lava fields. Eight flow groups , those within supergroups C, DE6, and DE7, have average volumes that are similar to that of Shoshone lava field (Table 1, Figure 1). Only two of the supergroups, C and DE6, contain flow groups that have areal extents that are within the range of the monogenetic Holocene lava fields. These excessive areas are likely the result of the liberal griding parameters used. This result suggests that the calculated volumes are also excessive. However, when the griding parameters were changed to 75% more conservative by decreasing the search ellipse radius from 80 km to 20 km, the corresponding volumes were only 10% less for most supergroups and flow groups. This result suggests that the volumes determined for the supergroups and flow groups are reasonable.

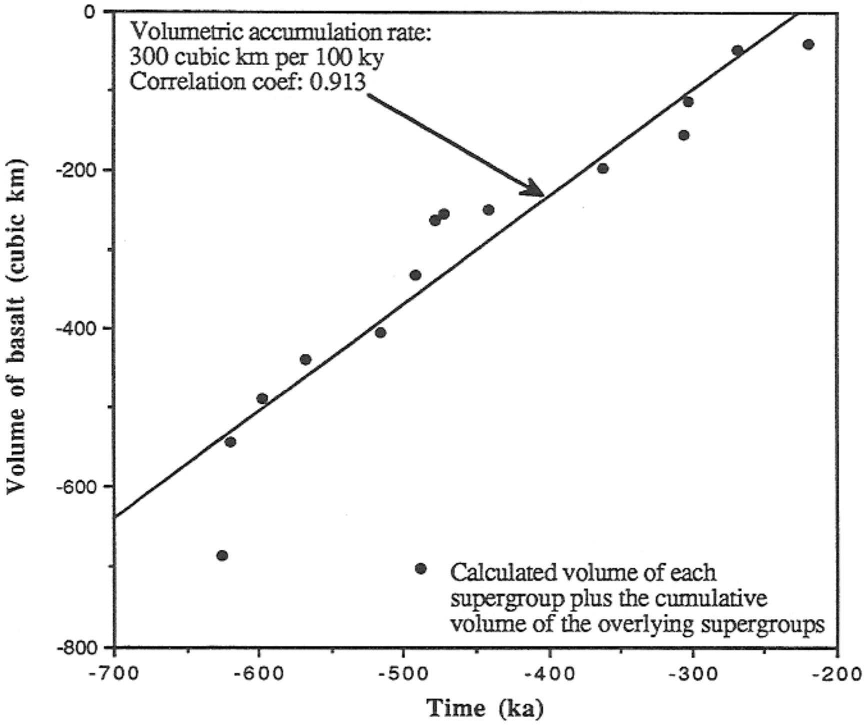
The average thickness of basalt supergroups B through I is about 14 m, based on calculated data from all wells. This value is consistent with the average of 12 m for the monogenetic Holocene lava fields of the ESRP (Kuntz et al., 1992). Using the volumes of the supergroups and the average thickness of the Holocene lava fields, the areal extents of individual flow groups present in Table 1 may be evaluated for reasonableness. This is accomplished by dividing the volume of each supergroup by the product of the average thickness of the Holocene lava fields (12 m) and the number of flow groups for each supergroup. The results of this procedure indicate that most of the flow groups have areal extents several times greater than any of the monogenetic Holocene lava fields (Table 1).

The physical parameters of the individual basalt flow groups (Table 1) suggest a decrease in magnitude of basaltic volcanism on the ESRP from middle Pleistocene to latest Pleistocene and Holocene. Although some Pleistocene flow groups are characterized by volumes and areal extents consistent with the monogenetic Holocene lava fields, most are larger than their younger counterparts. This difference between Pleistocene and Holocene basalts may, in part, be due to the inability to completely resolve the number of individual flow groups in the subsurface. However, this difference is also supported by other data that indicate a marked decrease in the magnitude of basaltic volcanism from late Pleistocene through the Holocene at and near the INEEL.

Figure 4 shows plots of average volumetric and thickness accumulation rates for the basalt supergroups B through I. These data indicate average accumulation rates of 300 km^3 per 100 ky and 75 m per 100 ky respectively from about 700 to 200 ka. Following the deposition of basalt supergroup B at about 200 ka, only part of the latest Pleistocene Quaking Aspen Butte lava field and a small lobe of the Holocene Cerro Grande lava field (Figure 1) accumulated on the INEEL during the past 100 ky. Extending past average accumulation rates (Figure 4) to the present suggests that the INEEL is in a basalt deficit of 600 km^3 and 150 km^3 respectively.

Additional evidence for a decrease in basaltic volcanism during the late Pleistocene to Holocene is a change in the density of eruptive centers and cumulative volumes of each center. The major Holocene volcanic fields of the ESRP and, hence, their eruptive centers (i.e. Shoshone, Wapi , and Hells Half Acre lava fields, Figure 1) are separated from each other by distances of approximately 50 to 100 km. The interpreted locations of the eruptive centers within many of the Pleistocene supergroups used in this study, such as D, DE5, and E, are separated by average

Plot of volumetric accumulation rate



Plot of thickness accumulation rate

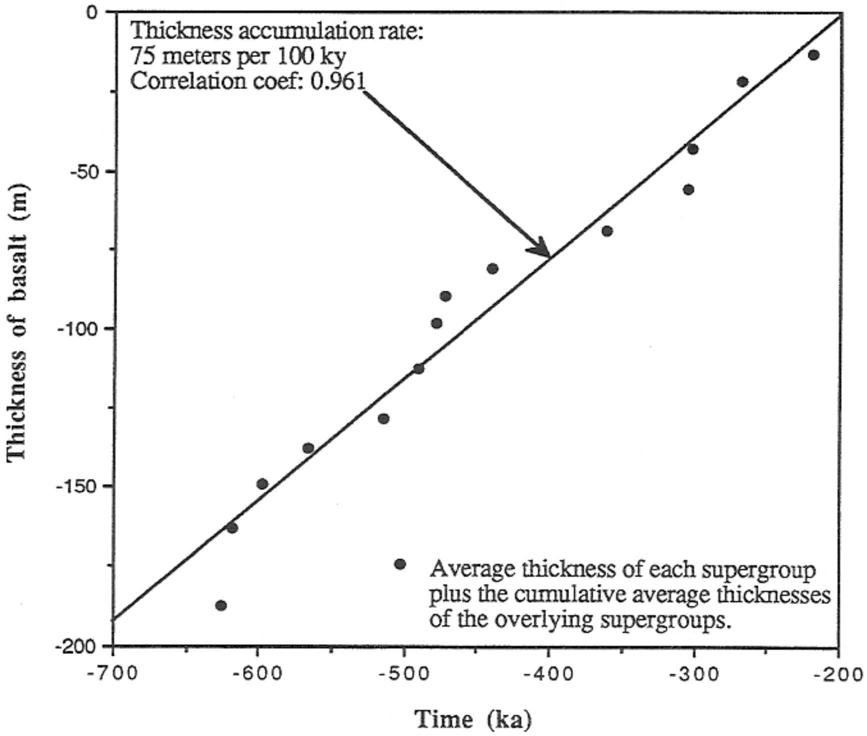


Figure 4. Volumetric and thickness accumulation rate plots.

distances of 20 to 30 km. In addition, the total volume of basalt erupted on the ESRP from 15 to 2 ka (~24 km^3, Kuntz et al., 1992) was only about half that of basalt supergroup DE2 (43 km^3), which accumulated at and near the INEEL from about 360 to 350 ka.

CONCLUSIONS

Pleistocene basalt supergroups B through I and many of their respective flow groups underlying the INEEL have volumes and areal extents that are greater to much greater than those of the monogenetic Holocene lava fields on the ESRP. Provided the data and the calculations made herein are reasonable, the magnitude of volcanism at and near the INEEL, and probably elsewhere on the ESRP, has decreased since the late-middle Pleistocene. This change is marked by a dramatic decrease in the accumulation rate of basaltic lava since about 200 ka and is indicated by a relative decrease in the size of individual flow groups in terms of volumes and areas. This change is also supported by a decrease in the spatial density of eruptive centers of the monogenetic Holocene lava fields relative to what is inferred from the subsurface.

ACKNOWLEDGMENTS

Technical assistance, support and insight was provided by Duane Champion, USGS, Geologic Division, Tim Funderberg, Dave Rodgers, Idaho State University, Department of Geology, and John Welhan, Idaho Geological Survey. Mel A. Kuntz, USGS, Geologic Division, Paul K. Link, Idaho State University, Department of Geology, and Richard P. Smith, Idaho National Engineering and Environmental Laboratory, reviewed the report and provided many helpful suggestions concerning its content and organization.

REFERENCE LIST

Anderson, S.R., 1991, Stratigraphy of the unsaturated zone and uppermost part of the Snake River Plain aquifer at the Idaho Chemical Processing Plant and Test Reactors Area, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 91-4010, 71 p.

Anderson, S.R., and Bartholomay, R.C., 1995, Use of natural-gamma logs and cores for determining stratigraphic relations of basalt and sediment at the Radioactive Waste Management Complex, Idaho National Engineering Laboratory, Idaho: Journal of the Idaho Academy of Science, v. 31, no. 1, p. 1-10.

Anderson, S.R., and Bowers, B., 1995, Stratigraphy of the unsaturated zone and uppermost part of the Snake River Plain aquifer at Test Area North, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 95-4130, 47 p.

Anderson, S.R., and Lewis, B.D., 1989, Stratigraphy of the unsaturated zone at the Radioactive Waste Management Complex, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 89-4065, 54 p.

Anderson, S.R., Ackerman, D.J., Liszewski, M.J., and Feiburger, R.M., 1996, Stratigraphic data for wells at and near the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 96-248, 27 p.

Anderson, S.R., Liszewski, M.J., and Cecil, L.D., 1997, Geologic ages and accumulation rates of basalt-flow groups and sedimentary interbeds in selected wells at the Idaho National

Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 97-4010, in press.

Keckler, D., 1995, Surfer for Windows: contouring and 3D surface mapping, version 6: Golden Software, Inc., Golden Colorado.

Kuntz, M. A., Dalrymple, G. B., Champion, D. E., and Doherty, D. J., 1980, Petrography, age, and paleomagnetism of volcanic rocks at the Radioactive Waste Management Complex , Idaho National Engineering Laboratory, Idaho, with an evaluation of potential volcanic hazards: U.S. Geological Survey Open-File Report 80-388, 63p.

Kuntz, M. A., Covington, H. R., and Schorr, L. J., 1992, An overview of basaltic volcanism of the eastern Snake River Plain, Idaho: *in* Link, P. K., Kuntz, M. A., and Platt, L. P., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 227-267.

Kuntz, M. A. and twelve others, 1994, Geologic map of the Idaho National Engineering Laboratory and adjoining areas, eastern Idaho: U.S. Geological Survey Miscellaneous Invest. Series Map I-2330.

Welhan, J., Funderberg, T., Smith, R.P., and Wylie, A., 1997, Stochastic modeling of hydraulic conductivity in the Snake River Plain Aquifer: Geologic constraints and conceptual approach; this volume.