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U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
U.S. DEPARTMENT OF ENERGY

Exh. AES000050

Table 1. *Paleomagnetic-age and paleomagnetic data for samples of basalt, rhyolite, and andesite from surface flows and domes in and near the Idaho National Engineering Laboratory, Idaho*

[n.d., not data; N, normal polarity; R, reversal polarity]

Field No.	Vent or name	$^{40}K/^{40}Ar$ (weight percent)	$^{40}Ar_{rad}$ (moles g 10^{-10} ^{40}K)	$^{40}Ar_{rad}/^{40}Ar_{tot}$ (percent)	Calculated age (ka) Sample	Paleomagnetic Pole	Magnetic polarity
84Lu-15	Tabor Butte	0.634±0.032	2.897 ±0.015	2.22	1120±90	180±52	R
84Lu-14	Table Legs Butte	0.838±0.033	3.793	1.24	2974±95	3071±65	R
84Lu-06	Mid Butte	0.476±0.021	2.198 ±0.010	2.22	2944±98	3005±53	N
			2.198 ±0.010	2.22	2944±98	3015±55	
78QH22	Big Southern Butte (aphanitic flank—western dome)	5.195±0.019	22.02	31.3	2944±15	2944±15	n.d
78QH21	Big Southern Butte (aphanitic—eastern dome)	4.741±0.035	21.24 ±0.09	30.9 ±2.7	3111±15 ±0.5	3094±10	n.d
84Lu-1	Radio Butte	0.720±0.090	3.269	1.48	2916±75	2916±75	N
84Lu-18	Radio Relay Butte	0.780±0.010	3.697 ±0.018	1.87 ±0.06	3500±22 ±0.5	3501±40	N
78QH24	Cinder Butte (glassy andesite, midbrown-gray)	3.626±0.018	22.12 ±0.09	6.0 ±0.7	4031±20 ±0.5	4086±19	N
84Lu-17	Vent SHES Rim	3.738±0.032	4.075 ±0.017	2.32 ±0.04	4314±22 ±0.5	4314±28	N
84Lu-20	Crater Butte	0.318±0.007	4.251 ±0.018	3.08 ±0.07	8761±112 ±0.5	8410±52	N
84Lu-24	Skate Butte	0.304±0.004	4.870 ±0.017	1.77 ±0.04	9761±100 ±0.5	9761±58	N
n.d.	East Butte (data from Jarosevich and others, 1978)	n.d.	n.d.	n.d.	6800±80	6800±80	n.d.
84Lu-30	Unnamed flow, Arco-Big Southern Butte volcanic complex	0.439±0.002	3.884	2.64	6600±50 ±0.5	6600±62	N
84Lu-26	AEC Butte	0.455±0.004	4.599 ±0.021	2.82 ±0.76	6977±66 ±0.5	6950±87	N
84Lu-6	Cinder Butte	0.046±0.003	0.073	2.20	7394±128	7394±128	N
84Lu-23	Richard Butte	0.436±0.001	5.778 ±0.048	7.12 ±0.05	8977±65 ±0.5	8973±53	R
			5.778 ±0.048	7.03 ±0.07	8744±67 ±0.5		
84Lu-22	Lava Ridge area	0.516±0.003	6.893	3.42	9984±104	9984±104	R
84Lu-10	Regarding Island flow, Nicolas Butte, Midnight Point lava (also at base of Inferno)	0.977±0.004	8.812	4.05	14041±28 ±0.5	14044±128	n.d.
84Lu-2	Circular Butte	0.878±0.030	11.97	9.81	1,319±56	1,310±50	R
78KS27	Unnamed cyclite dome, southern	0.839±0.011	105.9 ±0.4	77.7 ±0.6	1,350±43 ±0.5	1,400±20	n.d.

[1]Mean and calculated standard deviation of five measurements.
[2]λ_e=581a $^{-1}$, $^{40}K/^{39}K$ = 1.2 ±0.002 x 10^{-4} mol $^{-1}$, $^{40}K/K$=.00 x 10^{-6} mol/mol. Errors are estimates of the standard deviation of analytical precision.
[3]Weighted mean of the sample ages, where weighting is by the inverse of the variance, and weighted standard deviation.

Table 2. *Radiocarbon-ages for Holocene-lava flows and rhyolite domes in and near the Idaho National Engineering Laboratory, Idaho*

[See Rodin and others (1984) for details of radiocarbon-dating studies]

Lava field	Radiocarbon age (yr B.P.)
Craters of the Moon:	
Blue Dragon flow	2,130±95
Kings Bowl lava flow	3,000±100
Inferno flow	10,270±150
Hells Half Acre	5,300±150
North Robinson	11,000±300
Cerro Grande	15,000±200
Quaking Aspen Butte	>40,000

CONVERSION FACTORS

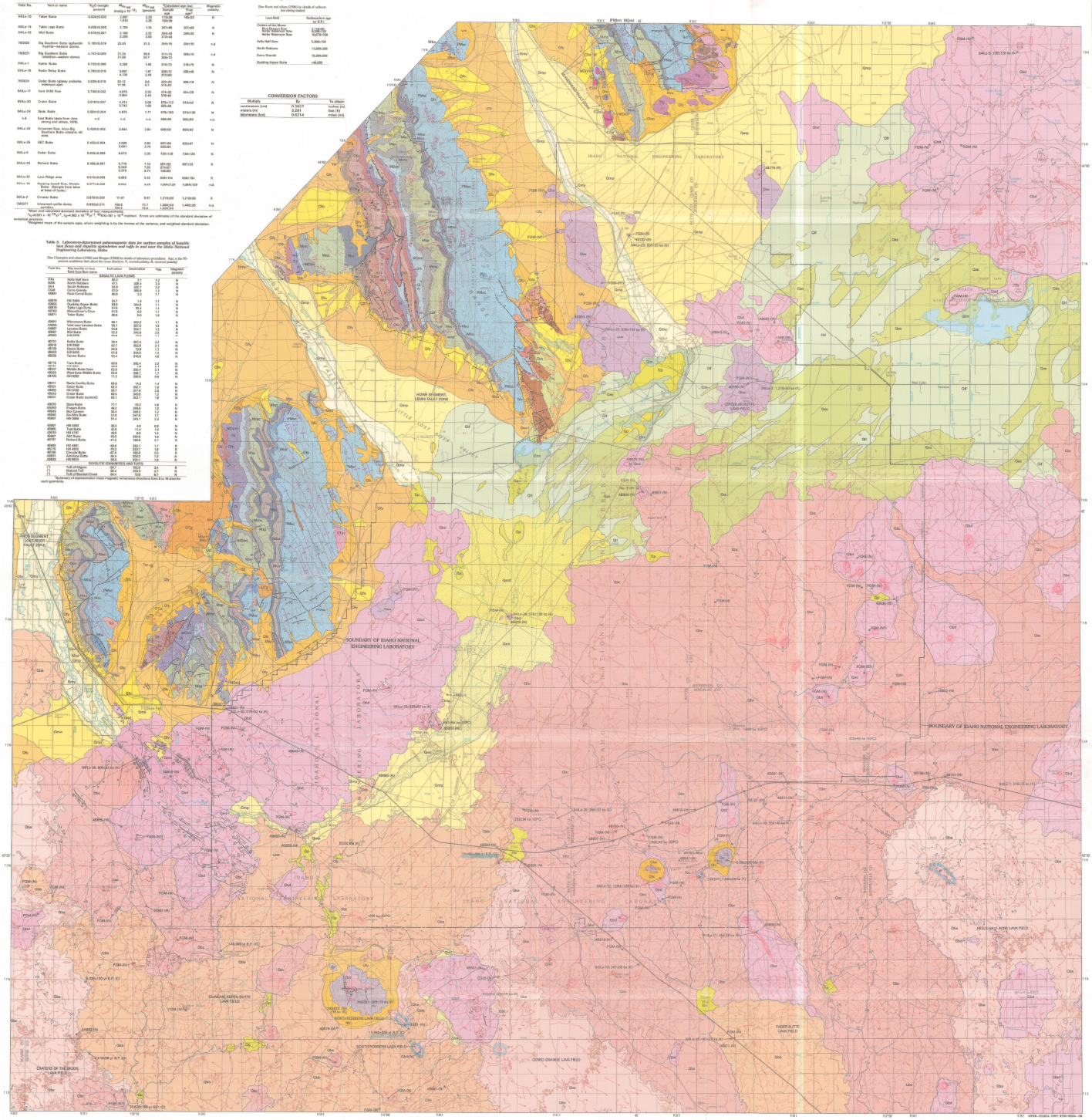
Multiply	By	To obtain
centimeters (cm)	0.3937	inches (in)
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	miles (mi)

Table 3. *Laboratory-determined paleomagnetic data for surface samples of basaltic lava flows and rhyolitic spatterdikes and tuffs in and near the Idaho National Engineering Laboratory, Idaho*

[See Champion and others (1988) and Morgan (1988) for details of laboratory procedures. Age is the 95-percent confidence limit about the mean direction; N, normal polarity; R, reversal polarity]

Field No.	Site locality or lava field (see lava flow name)	Inclination	Declination	Age	Magnetic polarity
	BASALTIC LAVA FLOWS				
1761	Hells Half Acre	41.1	332.1	1.2	N
0206	North Robinson	41.7	330.0	2.0	N
0241	Saddle Robinson	53.0	332.1	3.2	N
0242	Robinson Bench	50.0	332.0	1.7	N
43801	Flood-Carrol Butte	50.0	332.0	1.7	N
43870	Hill 5984	54.7	1.4	1.7	N
43802	Quaking Aspen Butte	53.0	341.0	1.7	N
43839	Table Legs Butte	51.0	20.4	1.4	N
43840	Unnamed flow, Vera	51.0	9.0	1.6	N
43871	Tabor Butte	56.0	5.0	1.6	N
43881	Minnemans Butte	56.1	343.2	1.1	N
43880	Vent near Lemolo Butte	55.1	337.0	1.0	N
43882	Middle Butte	55.0	354.1	1.3	N
43887	Mid Butte	54.8	354.0	1.0	N
43883	Hill 5946	55.1	11.4	1.1	N
43721	Radio Butte	50.4	337.0	2.3	N
43722	Radio Relay	49.0	337.0	1.7	N
43728	Cinder Butte	55.5	13.0	1.7	N
43723	Hill 5810	51.0	343.0	1.3	N
43725	Tarzan Butte	53.4	2.0	4.8	N
43715	Twin Butte	53.0	345.4	2.3	N
43716	Cerro Grande	52.0	3.0	2.1	N
43717	Middle Butte Cone	52.0	355.0	2.1	N
43835	West lava Middle Butte	53.0	350.1	1.7	N
43836	Hill 5850	51.7	350.0	0.9	N
43811	Radio Facility Butte	65.0	14.0	1.4	N
43812	Radio Butte	63.0	14.0	1.4	N
43850	Hill 5942	55.7	357.0	2.0	N
43843	Cinder Butte	65.5	343.0	1.2	N
43844	Cinder Butte (summit)	66.0	345.1	1.8	N
43870	Stone Butte	71.1	33.2	4.6	N
43869	Hill 5920	70.0	348.0	1.0	N
43842	Skin Canyon	69.4	348.2	1.2	N
43841	Hell's Half Acre	57.0	347.0	1.7	N
43847	Hot Springs	56.4	347.0	1.3	N
43867	Hill 5920	35.3	1.4	0.8	N
43865	Toad Butte	35.8	1.4	0.8	N
43866	Hill 5920	36.0	4.0	1.4	N
43867	Hot Springs	35.5	1.0	1.0	N
43797	Richard Butte	47.2	350.8	3.1	N
43893	Hill 4951	55.6	333.1	1.7	R
43775	Hill 4925	55.3	333.7	1.0	R
43874	Quaking Aspen Butte	55.0	333.0	1.0	R
43873	Antelope Butte	56.4	333.2	1.1	R
43863	Hill 5833	56.0	331.1	1.0	R
	RHYOLITIC CINDERS AND TUFFS				
1[1]	Tuff of Edgar	50.0	332.0	3.4	R
2[1]	Wallace Tuff	56.4	343.3	4.1	N
3[1]	Tuff of Kettle Creek	50.0	332.0	3.0	R

[1]Summary of representative mean magnetic remanence directions from 6 to 16 samples for each ignimbrite.



Base modified from U.S. Geological Survey
Arco, 1983; Blackfoot, 1983; Birch Peak, 1983
Circular Butte, 1983; Craters of the Moon, 1978; Dubois, 1983
Projection, zone 12, Universal Transverse Mercator

APPROXIMATE MEAN DECLINATION, 1984

Geology mapped 1975–1983; radiometric and paleomagnetic studies conducted 1978–1987
Cartography by Kenneth L. Pierce and Lynn Glover
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Cartography by Isaac Williams
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GEOLOGIC MAP OF THE IDAHO NATIONAL ENGINEERING LABORATORY AND ADJOINING AREAS, EASTERN IDAHO

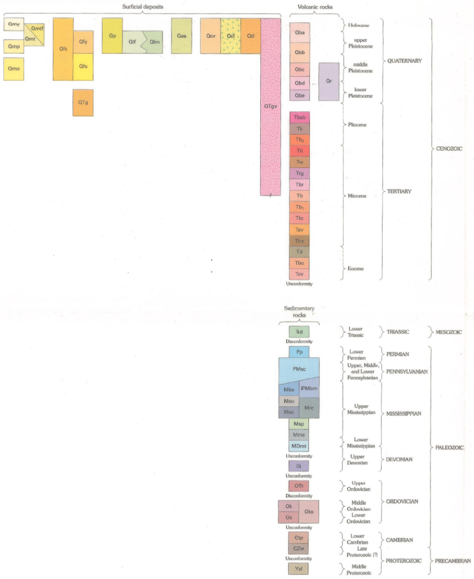
By
Mel A. Kuntz, Betty Skipp, Marvin A. Lanphere, William E. Scott, Kenneth L. Pierce, G. Brent Dalrymple, Duane E. Champion,[1]
Glenn F. Embree,[2] William R. Page,[1] Lisa A. Morgan,[1] Richard P. Smith,[3] William R. Hackett,[4] and David W. Rodgers[4]

1994

[1]U.S. Geological Survey
[2]Department of Geology, Ricks College, Rexburg, Idaho
[3]CH2M Hill Inc., Idaho Falls, Idaho
[4]Department of Geology, Idaho State University, Pocatello, Idaho

[redacted]

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

INTRODUCTION

The Idaho National Engineering Laboratory (INEL), formerly the National Reactor Testing Station, was established in 1949 by the Atomic Energy Commission, the predecessor of the Department of Energy, as an area where various types of nuclear reactors and supporting facilities and equipment could be built, tested, and operated with maximum safety. More than 50 reactors and critical facilities have been built to date and many of them are still operable. Also located at the INEL are the Idaho Chemical Processing Plant (ICPP) for processing spent fuel from government-owned reactors, and the Radioactive Waste Management Complex (RWMC) for the burial and storage of various forms of solid radioactive waste.

The INEL is situated on a remote 2,315-km^2 tract on the northwest margin of the central part of the eastern Snake River Plain (index map). The Snake River Plain is a broad, flat lava plain, 50–100 km wide and 600 km long, that forms an arcuate trough across southern Idaho. The plain extends from Payette on the west for about 300 km southeast to Twin Falls and then for about 300 km northeast to Ashton. Exposed in the eastern Snake River Plain are Pleistocene and Holocene basaltic lava flows and interbedded, thin, discontinuous, surficial deposits of loess, eolian sand, alluvial-fan sediments, and flood-plain alluvium. Rhyolitic volcanism produced large calderas in Neogene time, and remnants of rhyolitic ignimbrite and flows erupted from those calderas are exposed in the mountains along the margins of the plain. The eastern Snake River Plain is bounded on the north by mountains that were uplifted along normal faults in Tertiary and Quaternary time during Basin and Range tectonism and that are composed of folded Precambrian, Paleozoic, and Mesozoic rocks (fig. 1).

THE MAP

This map is a revision of a previous map (Kuntz and others, 1984) that depicts the geology of the INEL and contiguous parts of the eastern Snake River Plain. The geology and structure of the southernmost parts of the Lost River Range, Lemhi Range, and Beaverhead Mountains along the northwestern and northern borders of the INEL are also shown (fig. 1). This map includes new results of both in-the-field geologic investigations of the rocks, surficial deposits, and structures of the lava plain and bordering mountain ranges, and laboratory studies of the age and paleomagnetic character of the volcanic rocks. The map incorporates field and laboratory studies performed by geologists of the U.S. Geological Survey (USGS), various academic institutions, and private companies. This map forms the core of the geologic data base upon which studies of the volcanology and geologic hazards at the INEL may be based. Studies of the subsurface geology of the INEL by the USGS form a separate but related body of data that are not included on this map.

A scale of 1:100,000 was chosen for this map to show details both of the bedrock geology of the mountains bordering the INEL and of the structures of the vent areas and flow features of the basaltic lava fields.

RADIOMETRIC AND PALEOMAGNETIC DATA

Potassium-argon (K-Ar) ages have been determined for 15 surface basaltic lava flows, 1 andesite dome (76G024), and 4 rhyolite domes (76G022, 76G021, 76KS77, East Butte) within the map area (table 1). Ages were assigned to several surface flows by geologic and paleomagnetic correlation of these flows with dated subsurface flows sampled from cores (see Champion and others, 1988; Kuntz and Dalrymple, 1979). Details of the analytical procedures for K-Ar measurements of samples obtained from both the surface and cores are given in Champion and others (1988). For all samples, the calculated ages for individual measurements and the weighted mean flow ages have large uncertainties both because of low percentages of radiogenic ^{40}Ar, typically 1–3 percent of total Ar as a result of low K_2O contents (0.44–0.94 weight percent), and because of the youth of the flows. The new K-Ar ages of basaltic lava flows on this map supersede those of an earlier version of this map (Kuntz and others, 1984).

Six radiocarbon ages ranging from 2,110±90 yr B.P. to >40,000 yr B.P. were determined for Holocene–latest Pleistocene lava fields within the map area (table 2). An additional radiocarbon age for the Hells Half Acre lava field, 5,200±150 yr B.P., was determined for a sample obtained from a site about 5 km southeast of the southeast corner of this map (table 2). Details of the sampling, sample preparation, and analytical procedures for the radiocarbon studies are given in Kuntz and others (1986).

The magnetic polarity of many lava flows in the map area was determined by a portable, field-type, fluxgate magnetometer. Basaltic lava flows of the eastern Snake River Plain having normal magnetic polarity are believed to have been erupted in the Brunhes Normal-polarity Chron (younger than 730 ka) and flows of reversed magnetic polarity are believed to have been erupted in the Matuyama Reversed-polarity Chron (730–2,480 ka).

Laboratory determinations of magnetic polarity and inclination-declination directions of the paleomagnetic field (table 3) were determined for basaltic lava flows from surface sample sites within the map area, mainly at or very near sites of samples collected for K-Ar analyses. Details of the laboratory procedures for the paleomagnetic studies of the basalt are given by Champion and others (1988). Laboratory determinations of the magnetic polarity and inclination-declination directions for the tuff of Kilgore, Walcott Tuff, and tuff of Blacktail Creek were made from samples obtained at surface sites within the map area and from sampling sites along the margins of the eastern Snake River Plain beyond the margins of this map. Details of the laboratory procedures for the paleomagnetic studies of the rhyolitic ignimbrites (tuffs) are given by Morgan (1988). The confidence limits on paleomagnetic-field directions for basalt flows and rhyolitic ignimbrites are in general small, but they vary as a function of age, topography, and lightning-strike effects.

AGES OF LAVA FLOWS

The data in tables 1 and 2 represent a significant addition to the limited body of radiometric data that was available for the preliminary version of this map (Kuntz and others, 1984); consequently, many changes occur in the age designations for basaltic lava fields in and near the INEL on this map. In general, the new radiometric ages turn out to be older than those given in 1984. It should be noted, however, that estimated ages of most lava flows shown on this map are based chiefly on nonquantitative geomorphic and stratigraphic criteria, as discussed below. Future radiometric investigations may also result in changes in the ages of specific lava fields shown on this map.

The youngest lava fields in the map area show little or no eolian sand and loess cover and are largely unweathered. Progressively older lava fields are covered by progressively greater thicknesses of these sediments and are more deeply weathered. In the absence of radiometric data, the latter two factors, in addition to stratigraphic age relations among contiguous fields, have been used subjectively to assign lava fields to age units. Users of this map should be aware that there are discrepancies in ages of the same lava field as determined by radiometric and by stratigraphic-geomorphic methods. Where stratigraphic-geomorphic criteria and radiometric data conflict, age designations have been assigned based on the radiometric data, but field- and aerial-photograph-determined stratigraphic relations between flows (shown as Y (younger) and O (older) across a contact on the map) have been retained.

SURFICIAL DEPOSITS

Unconsolidated sediments of alluvial, lacustrine, eolian, and colluvial origin cover large parts of all rock units except the largely barren Holocene–latest Pleistocene lava flows (unit Qba). Under Pleistocene glacial climates, streams originating in the mountain ranges north of the INEL had greater sustained flows than at present, and deposited alluvial fans below the mouths of canyons and deposited wide gravel plains along the axis of the major basins north of the plain (Pierce and Scott, 1982; Scott, 1982). In addition, at least one large flood, probably related to failure of a natural dam, coursed down Big Lost River during late Pleistocene time (Rathburn, 1989). As is the case now, the topographically high area along the axis of the eastern Snake River Plain, which was formed by numerous eruptions of lava from numerous basalt volcanoes along the axis, caused streams draining the mountain ranges north of the INEL to flow northeast along the plain margin. Increased streamflow during glacial ages filled the basin in the northeastern part of the map area to form a large, shallow lake, Lake Terreton. Formation of the lake was probably aided by the Pleistocene glacial climate when runoff was enhanced and evaporation diminished. Also during glacial times, strong winds blowing across seasonally active alluvial surfaces deflated silt to form widespread loess, and sand to form local dunes (Pierce and Scott, 1982).

FAULTS THAT BOUND MOUNTAIN RANGES NORTH OF THE SNAKE RIVER PLAIN

Late Cenozoic movement on the fault zones that bound the Lost River Range, Lemhi Range, and Beaverhead Mountains has produced the basin-and-range topography of the area north of the eastern Snake River Plain (Baldwin, 1951; Skipp and Hait, 1977; Reynolds, 1979; Ruppel, 1982; Scott and others, 1985; Pierce and Morgan, 1992). Total throw on these normal faults is at least several kilometers and may locally exceed 6 km (Skipp and Hait, 1977). Each of the range-front fault zones that bound the west sides of the Lost River and Lemhi Ranges and the Beaverhead Mountains are about 100 km long, but are divided into a series of 15- to 30-km-long fault segments by various geometric and structural elements (Scott and others, 1985; Crone and others, 1987; Pierce and Morgan, 1992). The southern segments of each fault zone extend into the northwestern part of the map area (fig. 1).

The rupture associated with a large earthquake is thought commonly to be limited to a single segment of a fault, although minor movement might propagate into adjacent segments. For example, the faulting that accompanied the 1983 Borah Peak earthquake (Ms 7.3) occurred mainly along the Thousand Springs segment, one of the central segments of the Lost River fault zone, but minor offset also occurred along part of the next segment to the north (Crone and others, 1987).

During the past 15,000 years, the central segments of the range-front fault zones of the Lost River and Lemhi Ranges and the Beaverhead Mountains have experienced one or more surface displacements, whereas the distal segments have been inactive (Scott and others, 1985). The southern segments of the Lost River and Lemhi fault zones, the Arco and Howe segments of this map, offset well-preserved older fan alluvium (unit Qfo; Malde, 1971, 1985). On the basis of uranium-series dating and morphology of scarps along the Arco segment, Pierce (1985) estimated the age of surface unit Qfo, which has been vertically offset as much as 19 m by multiple faulting events, to be about 160 ka and the last movement on the fault to be about 30 ka. The Howe segment of the Lemhi fault zone appears to have had a similar history (Malde, 1985). Deposits of younger fan alluvium (unit Qfy) that are estimated to be about 15 ka are not offset along either of these faults. The southern segment of the Beaverhead fault zone does not displace middle Pleistocene or younger units.

SELECTED REFERENCES AND SOURCES OF MAP DATA

[Numbered references are sources of map data (fig. 1)]

Armstrong, R.L., Leeman, W.P., and Malde, H.E., 1975, K-Ar dating, Quaternary and Neogene volcanic rocks of the Snake River Plain, Idaho: American Journal of Science, v. 275, p. 225–251.

Baldwin, E.W., 1951, Faulting in the Lost River area of Idaho: American Journal of Science, v. 249, p. 884–902.

1. Beutner, E.C., 1968, Structure and tectonics of the southern Lemhi Range, Idaho: University Park, Pa., The Pennsylvania State University Ph. D. thesis, 106 p.

Champion, D.E, Lanphere, M.A., and Kuntz, M.A., 1988, Evidence for a new geomagnetic reversal for lava flows in Idaho—Discussion of short polarity reversals in the Brunhes and late Matuyama polarity chrons: Journal of Geophysical Research, v. 93, p. 11,667–11,680.

Chase, G.H., 1972, Potassium-argon ages from whole-rock analyses of igneous rocks in the area of the National Reactor Testing Station, Idaho, *in* Geological Survey Research 1972, Chapter D: U.S. Geological Survey Professional Paper 800–D, p. D123–D126.

Crone, A.J., Machette, M.N., Bonilla, M.G., Lienkaemper, J.J., Pierce, K.L., Scott, W.E., and Bucknam, R.C., 1987, Surface faulting accompanying the Borah Peak earthquake segmentation of the Lost River fault, central Idaho: Bulletin of the Seismological Society of America, v. 77, p. 739–770.

Derstler, Kraig, and McCandless, D.O., 1981, Cambrian trilobites and trace fossils from the southern Lemhi Range, Idaho—Their stratigraphic and paleotectonic significance: Geological Society of America Abstracts with Programs, v. 13, no. 4, p. 194.

2. Embree, G.F., Hait, M.H., Jr., Skipp, Betty, Hoggan, R.D., Williams, E.J., Prostka, H.J., McBroome, L.A., and Doherty, D.J., unpublished field mapping, northwest margin of eastern Snake River Plain, scale 1:250,000.

3. Garmezy, Lawrence, 1981, Geology and tectonic evolution of the southern Beaverhead Range, east-central Idaho: University Park, Pa., The Pennsylvania State University M.S. thesis, 155 p.

Groves, J.R., 1984, Foraminifers and biostratigraphy of the Arco Hills, Bluebird Mountain, and Lower Snaky Canyon Formations (Mid-Carboniferous) of east-central Idaho: Journal of Foraminiferal Research, v. 14, no. 4, p. 282–302.

Huh, O.K., 1967, The Mississippian System across the Wasatch line, east-central Idaho, extreme southwestern Montana, *in* Centennial basin of southwest Montana: Montana Geological Society Guidebook, 18th Annual Field Conference, p. 31–62.

Karlo, J.F., 1977, The geology and Bouguer gravity of the Hells Half Acre area and their relation to volcano-tectonic processes within the Snake River Plain rift zone, Idaho: Buffalo, N.Y., State University of New York at Buffalo Ph. D. thesis, 152 p.

Kellogg, K.S., Pierce, K.L., Mehnert, H.H., Hackett, W.R., Rodgers, D.W., and Hladky, F.R., 1989, New ages on biotite-bearing tuffs of the eastern Snake River Plain, Idaho—Stratigraphic and mantle-plume implications: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 101.

4. Kuntz, M.A., 1978a, Geologic map of the Arco–Big Southern Butte area, Butte, Blaine, Bingham Counties, Idaho: U.S. Geological Survey Open-File Report 78–302, 1 pl., scale 1:48,000.

———1978b, Geology of the Arco–Big Southern Butte area, eastern Snake River Plain, and potential volcanic hazards to the Radioactive Waste Management Complex and other waste storage and reactor facilities at the Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Open-File Report 78–691, 70 p.

5. ———unpublished field mapping, eastern Snake River Plain, scale 1:24,000.

Kuntz, M.A., and Dalrymple, G.B., 1979, Geology, geochronology and potential volcanic hazards in the Lava Ridge–Hells Half Acre area, eastern Snake River Plain, Idaho: U.S. Geological Survey Open-File Report 79–1657, 72 p.

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 volcanic hazards: U.S. Geological Survey Open-File Report 80–388, 63 p.

6. Kuntz, M.A., Scott, W.E., Skipp, Betty, Hait, M.H., Jr., Embree, G.F., Hoggan, R.D., and Williams, E.J., 1979, Geologic map of the Lava Ridge–Hells Half Acre area, eastern Snake River Plain, Idaho: U.S. Geological Survey Open-File Report 79–669, 1 pl., scale 1:48,000.

Kuntz, M.A., Skipp, Betty, Scott, W.E., and Page, W.R., 1984, Preliminary geologic map of the Idaho National Engineering Laboratory and adjoining areas: U.S. Geological Survey Open-File Report 84–281, scale 1:100,000.

Kuntz, M.A., Spiker, E.C., Rubin, Meyer, Champion, D.E., and Lefebvre, R.H., 1986, Radiocarbon studies of latest Pleistocene and Holocene lava flows of the Snake River Plain, Idaho—Data, lessons, interpretations: Quaternary Research, v. 25, p. 163–176.

LaPoint, P.J.I., 1977, Preliminary photogeologic map of the eastern Snake River Plain, Idaho: U.S. Geological Survey Miscellaneous Field Studies Map MF–850, scale 1:250,000.

Malde, H.E., 1971, Geologic investigations of faulting near the National Reactor Testing Station, Idaho, with a section on microearthquake studies by A.M. Pitt and J.P. Eaton: U.S. Geological Survey Open-File Report, 167 p.

———1985, Quaternary faulting near Arco and Howe, Idaho: Bulletin of the Seismological Society of America, v. 77, p. 847–867.

7. McBroome, L.A., 1981, Stratigraphy and origin of Neogene ash-flow tuffs on the north-central margin of the eastern Snake River Plain, Idaho: Boulder, Colo., University of Colorado M.S. thesis, 74 p.

8. McCandless, D.A., 1982, A reevaluation of Cambrian through Middle Ordovician stratigraphy of the southern Lemhi Range: University Park, Pa., The Pennsylvania State University M.S. thesis, 157 p.

McIntyre, D.H., Ekren, E.B., and Hardyman, R.F., 1982, Stratigraphic and structural framework of the Challis Volcanics in the eastern half of the Challis 1° × 2° quadrangle, Idaho, *in* Bonnichsen, Bill, and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 3–22.

Morgan, L.A., 1988, Explosive rhyolitic volcanism on the eastern Snake River Plain: Manoa, Hawaii, University of Hawaii Ph. D. dissertation, 191 p.

Morgan, L.A., Doherty, D.J., and Leeman, W.P., 1984, Ignimbrites of the eastern Snake River Plain—Evidence for major caldera-forming eruptions: Journal of Geophysical Research, v. 89, p. 8665–8678.

Pierce, K.L., 1985, Quaternary history of faulting on the Arco segment of the Lost River fault, central Idaho, *in* Stein, R.S., and Bucknam, R.C., eds., Proceedings of Workshop XXVIII on the Borah Peak, Idaho, Earthquake: U.S. Geological Survey Open-File Report 85–290, p. 195–206.

Pierce, K.L., and Morgan, L.A., 1992, The track of the Yellowstone hotspot—Volcanism, faulting and uplift, *in* Link, P.K., Kuntz, M.A., and Platt, L.W., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 1–53.

Pierce, K.L., and Scott, W.E., 1982, Pleistocene episodes of alluvial-gravel deposition, southeastern Idaho, *in* Bonnichsen, Bill, and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 685–702.

9. ———unpublished field mapping, southern end of Arco segment of Lost River fault zone, scale 1:24,000.

Rathburn, S.L., 1989, Pleistocene glacial outburst flooding along the Big Lost River, eastern Snake River Plain, Idaho: Geological Society of America Abstracts with Programs, v. 21, no. 5, p. 132.

Reynolds, M.W., 1979, Character and extent of basin-range faulting, western Montana and eastern central Idaho, *in* Newman, C.W., and Goode, H.D., eds., 1979 Basin and Range Symposium: Rocky Mountain Association of Geologists and Utah Geological Association, p. 185–193.

Ross, C.P., 1961, Geology of the southern part of the Lemhi Range, Idaho: U.S. Geological Survey Bulletin 1081–F, p. 189–260.

Ruppel, E.T., 1982, Cenozoic block uplifts in east-central Idaho and southwest Montana: U.S. Geological Survey Professional Paper 1224, 24 p.

Ruppel, E.T., and Lopez, D.A., 1988, Regional geology and mineral deposits in and near the central part of the Lemhi Range, Lemhi County, Idaho: U.S. Geological Survey Professional Paper 1480. 122 p.

Ruppel, E.T., Ross, R.J., Jr., and Schleicher, D.L., 1975, Precambrian Z and Lower Ordovician rocks in east-central Idaho: U.S. Geological Survey Professional Paper 889–B, p. 25–34.

10. Scott, W.E., 1982, Surficial geologic map of the eastern Snake River Plain and adjacent areas, 111° to 115° W., Idaho and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I–1372, 2 pl., scale 1:250,000.

Scott, W.E., Pierce, K.L., and Hait, M.H., Jr., 1985, Quaternary tectonic setting of the 1983 Borah Peak earthquake, central Idaho: Bulletin of the Seismological Society of America, v. 75, p. 1053–1066.

Skipp, Betty, Baesemann, J.F., and Brenckle, P.L., 1985, A reference area for the Mississippian-Pennsylvanian (Mid-Carboniferous) boundary in east-central Idaho: Madrid, Spain, Compte Rendu X International Carboniferous Congress, v. 4, p. 403–428.

11. Skipp, Betty, Embree, G.F., Hait, M.H., Jr., Hoggan, R.D., Janecke, S.V., and Williams, E.J., unpublished field mapping, southern Lost River Range, scale 1:24,000.

12. Skipp, Betty, and Hait, M.H., Jr., 1977, Allochthons along the northeast margin of the Snake River Plain, Idaho, *in* Heisey, E.L., and others, eds., Rocky Mountain thrust belt; geology and resources: Wyoming Geological Association Guidebook, No. 29, p. 499–515.

13. Skipp, Betty, Hoggan, R.D., Schleicher, D.L., and Douglass, R.C., 1979, Upper Paleozoic carbonate bank in east-central Idaho—Snaky Canyon, Bluebird Mountain, and Arco Hills Formations, and their paleotectonic significance: U.S. Geological Survey Bulletin 1486, 78 p.

Skipp, Betty, and Link, P.K., 1992, Middle and Late Proterozoic rocks in the southern Beaverhead Mountains, Idaho and Montana—Implications for Late Proterozoic tectonics, a preliminary report, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 141–154.

14. Smith, R.P., Hackett, W.R., and Rodgers, D.W., unpublished field mapping, Arco–Big Southern Butte volcanic rift zone, scale 1:10,000.

Spear, D.B., 1979, The geology and volcanic history of the Big Southern Butte–East Butte area, eastern Snake River Plain, Idaho: Buffalo, N.Y., State University of New York at Buffalo Ph. D thesis, 136 p.

Stearns, H.T., Bryan, L.L., and Crandall, L., 1939, Geology and water resources of the Mud Lake region, Idaho: U.S. Geological Survey Water Supply Paper 818, 125 p.

Wilson, A.B., Janecke, S.U., Skipp, Betty, Kleinkopf, M.D., McCafferty, A.E., Barton, H.N., and Miller, M.S., 1990, Mineral resources of the Borah Peak Wilderness Study Area, Custer County, Idaho: U.S. Geological Survey Bulletin 1718–E, p. E1–E15.

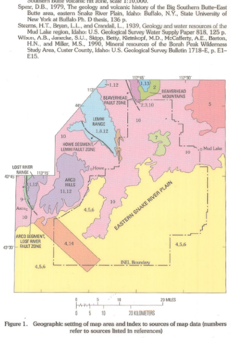


Figure 1. Geographic setting of map area and index to sources of map data (numbers refer to sources listed in references)

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