COMPREHENSIVE TABLES GIVING PHYSICAL DATA AND THERMAL ENERGY ESTIMATES FOR YOUNG IGNEOUS SYSTEMS OF THE UNITED STATES

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INTRODUCTION

This report presents two tables. The first is a comprehensive table of 157 young igneous systems in the western United States, giving locations, physical data, and thermal energy estimates, where apropriate, for each system. The second table is a list of basaltic fields probably less than 10,000 years old in the western United States. These tables are updated and reformatted from Smith and Shaw's article "Igneous-related geothermal systems" in *Assessment of geothermal resources of the United States--1975* (USGS Circular 726, White and Williams, eds., 1975). This Open-File Report is a companion to Smith and Shaw's article "Igneous-related geothermal systems" in *Assessment of geothermal resources in the United States--1978* (USGS Circular 790, Muffler, ed., 1979). The article in Circular 790 contains an abridged table showing only those igneous systems for which thermal estimates were made. The article also gives an extensive discussion of hydrothermal cooling effects and an explanation of the model upon which the thermal energy estimates are based.

Thermal energy is calculated for those systems listed in table 1 that are thought to contribute significant thermal energy to the upper crust. As discussed by Smith and Shaw (1975), silicic volcanic systems are believed to be associated nearly always with high-level (<10 km) magma chambers. The thermal calculations in table 1 are made primarily for volcanic systems which show evidence from the presence of young silicic extrusions that a high-level magma chamber is being formed or has formed in the recent past.

Table 2 lists young basaltic lava fields that are probably less than 10,000 years old. The purpose of this listing is simply to call attention to these areas of very young basaltic eruptions where there may be very small thermal anomalies residual from the last magma injections in the upper crust. These areas and many older ones are shown by Luedke and Smith (1978a, 1978b, and in preparation) in a series of maps showing distribution, composition, and age of all late Cenozoic volcanic centers in the United States. Smith and Shaw (1975, p. 78) discussed young basic lava fields briefly and suggested that they should not be totally ignored for geothermal exploration. They do represent viable mantle sources for new magma and some fields may have small but significant thermal anomalies associated with hidden high-level silicic bodies. However, in general, exclusively basic volcanic systems rarely form thermal anomalies of economic interest because they rarely form high-level magma chambers that remain exclusively basic.

THERMAL ENERGY ESTIMATES

Three categories of thermal energy are given in table 1. ΔQ_{total} (column 10) is the thermal energy liberated if the entire magma chamber cools from an initial temperature of 850°C (the appropriate liquidus temperature for most silicic magmas) to a final temperature of 300°C (assumed ambient temperature) starting from a fixed time (in most cases, the age of the youngest silicic eruption). ΔQ_{now} (column 11) is the thermal enegy which remains in the system at the present time within and around the original magma chamber. This energy constitutes the identified accessible resource base for igneous-related geothermal systems as defined in USGS Circular 790 and is summarized in table 3 of Smith and Shaw (1979). ΔQ_{out} (column 12) is the thermal energy transferred from the magma chamber to the roof rocks between the assumed time of emplacement of the intrusive body and the present. Three assumptions were used when making these thermal calculations: 1) a single pulse of magma is instantaneously emplaced and cools conductively from that time, 2) for most systems, the time of emplacement is taken as the age of the youngest silicic extrusion, and 3) no additional thermal energy is contributed by magmatic preheating or resupply.

Calculations of heat contents are approximate. The number of significant figures retained is determined from requirements of internal consistency among columns 10, 11, and 12 for systems so old that much of their heat has been lost at the surface on the basis of the model. For example, the possibility of a slight residual heat content is indicated in Column 11 for OR19 (Wart Peak caldera, Oregon) and is roughly proportioned equally between roof rocks and igneous pluton. Thus, roughly 8 x 10^{18} J are residual so that about 4 x 10^{18} J are left, respectively in the pluton and in the roof rocks and 356 x 10^{18} J have been given up by the pluton to the roof rocks and losses at the surface; that is 352 x 10^{18} J have been totally lost from the system to the surface.

In very large, older systems like ID6 (Rexburg Caldera), calculations for columns 11 and 12 are very crude, particularly because of the limitations of closed-system models. In this case, the entries in columns 11 and 12 simply represent stabs at the orders of magnitudes of the possible heat balances. In such cases, the estimates are probably conservative.

ENTRY CHANGES

Table 1 of this report has been revised from table 7 of Smith and Shaw (1975; USGS Circular 726). The location number designations have been changed to correspond with the zip code abbreviations for each state (for example, Alaska location A-1 has been changed to AK-1), except Hawaii which has remained as H (not HI). Seven systems have been deleted: Double (A-81), Black (A-82), Odell Butte (O-9), Black Butte (O-10), Cougar Mountain (O-15), Tushar Mountains (U-4), and Topaz Mountain (U-5). Thirteen systems have been added: Ukinrek Maars (AK-89), Hayes Volcano (AK-90), Inyo-Mammoth Fissure System (CA-18), Templeton Domes (CA-19), East Butte (ID-5), Rexburg Caldera (ID-6), Bearwallow Buttes (OR-18), Wart Peak Caldera (OR-19), Frederick Butte (OR-20), Thomas Range (UT-4), Wildcat Hills (UT-7), Clear Fork Dacite (WA-6), and Mann Butte (WA-7). It should be noted that Idaho and Wyoming have been tabulated separately. Yellowstone Caldera is now WY-1. Island Park-Huckleberry Ridge System (IW-1 in 1975) has been changed to Island Park System (ID-1). In table 1, Island Park has two chamber area figures: 3900 Ac - the area of the original caldera system (2 m.y. old) and 2100 Ao - the area of the western part of the system which is not overlapped by the younger (0.6 m.y. old) Yellowstone Caldera (WY-1).

The thermal estimates in this report are given in joules (instead of in calories as in Circular 726). A number of systems have significantly different thermal energies because of recalculations made with new age and size data. These systems include: Adagdak (AK-14), Kendrick Peak (AZ-3), Bill Williams Mountain (AZ-4), Melvin-Three Creeks Buttes (OR-7), Cappy-Burn Butte Area (OR-8), Mineral Mountains (UT-1), and Cove Creek Domes (UT-2).

The coordinates of the igneous-related systems have been revised to best approximate the center of the caldera or the vent distribution. In some cases other physical criteria had to be used.

CIRCULAR 790 MAPS

The young igneous systems in table 1 are plotted on maps 1 and 2 of U. S. Geological Survey Circular 790. Those systems for which an estimate of the thermal energy still remaining in the ground (ΔQ_{now}; Column 11) can be made are shown on the maps by nested green triangles. For each system the number of triangles indicates the range of values in which the thermal estimate falls. Igneous systems in table 1 for which no estimates of thermal energy are made are symbolized on the maps by green snowflakes. The young basaltic fields of table 2 are also plotted on maps 1 and 2 of Circular 790, as brown shaded areas. The identifying numbers and letters in column 1 of tables 1 and 2 refer to the individual systems plotted on the maps. Longitude in column 3 is west unless otherwise noted (AK1 to AK7). Volcanic systems marked by asterisks in column 1 are known to have some associated hydrothermal activity (see Brook and others, 1979).

INPUT DATA

The input data from which all thermal estimates are made are shown in columns 4-9 of table 1. The physical basis of specific numbers is indicated by symbols which are explained below. The composition of the last eruption (for example, silicic or basic) and age data are listed in columns 4 and 5, respectively. Area of the magma chamber (column 6) is based on various surface manifestations of volcanism, geologic structure, or geophysics. The volume range of the chamber (column 7) is calculated by assuming the thickness of the magma chamber ranges from 2.5 to 10 km. This range is reduced to a single "best estimate" (column 8) to simplify the thermal calculations. Some volumes are derived by ten-fold extrapolation of ejecta volumes (Smith and Shaw, 1973, and unpublished). Column 9 indicates our best estimate (based on Smith and Shaw, 1979, fig. 3) as to the present thermal state of a magma chamber--that is, whether or not magma exists in the system now. Many entries are shown as greater or less than 650°C, which is the approximate minimum temperature of solidification of granitic melts. For those systems whose age and size data are incomplete, no thermal energy estimates are made.

EXPLANATION OF SYMBOLS IN TABLE 1

AGE = T

- Ty - Last eruption
- Tys - Youngest silicic eruption
- Tyb - Youngest basic eruption
- Ts - Age (silicic)
- Tc - Age caldera eruption
- Tg - Greatest known age (composition unspecified)
- Tgs - Greatest age (silicic)
- Tgb - Greatest age (basic)
- Tb - Age (basic)

AREA = A

Ac - From caldera
Av - From vent distribution
As - From shadow
Af - From fractures
Au - From uplift
Ag - From geophysical anomaly (unspecified)
  Agg - Gravity
  Agm - Magnetic
  Ags - Seismic
  Ago - Other, see remarks
Ao - Other, see remarks

VOLUME = V

Vc - From caldera
Vv - From vent distribution
Vs - From shadow
Vf - From fractures
Vu - From uplift
Vg - From geophysical anomaly
  Vgg - Gravity
  Vgm - Magnetic
  Vgs - Seismic
  Vgo - Other, see remarks
Vo - Other, see remarks
Vee - From extrapolation of silicic ejecta volume
Vb - Best estimate

METHODS OF CALCULATION OF THERMAL ENERGY

<u>COLUMN 10</u>: ΔQ_{total}, in units of 10^{18} joules

Assumptions:

Initial temperature = 850°C
Latent heat of crystallization = 272 J/g
Heat capacity = 1.3 J/g/°C
Mean density of magma = 2.5 g/cm^3

The above values are approximate averages for the composition and temperature ranges of table 1. From these values the heat liberated by crystallization and conductive cooling between 850°C and 650°C is (850°C - 650°C)(1.3 J/g/°C) + 271 J/g = 523 J/g. The total heat liberated in the same manner between 850°C and 300°C is 963 J/g.

One cubic kilometer of magma represents 2.5×10^{15}g. The total heat liberated (between 850°C and 300°C) per cubic kilometer is $(2.5 \times 10^{15}\ g/km^3)(963\ J/g) = 2.41 \times 10^{18}$ joules. This number multiplied by the volume V_b in column 8 gives the ΔQ_{total} of column 10.

COLUMN 11, ΔQ_{now}, in units of 10^{18} joules

The time required for a change of the original gradient at the Earth's surface to a steady-state gradient between the surface temperature and the magma chamber temperature is given approximately by relations discussed by Jaeger (1964). For the assumed depth of cover of 4 km and a thermal diffusivity of 0.007 cm^2/sec, this time is about 360,000 years. Where Ty (age of last eruption) is much younger than this time, the total heat remaining in the system now (column 11) is assumed to be about the same as the total value in column 10. Estimates of losses for older systems require detailed calculations of the disturbance of the geothermal gradient.

The value of thermal diffusivity used is an average estimate for crustal rocks. Roof rocks above large caldera systems such as Yellowstone, Wyoming (WY-1), Valles, New Mexico (NM-1) and Long Valley, California (CA-3) may have smaller values of conductive thermal diffusivity. Hydrothermal convection systems, however, can increase the effective value of thermal diffusivity by a significant amount, depending on average permeabilities of roof rocks.

COLUMN 12, ΔQ_{out}, in units of 10^{18} joules

The total amount of heat transfer per square centimeter from a magma chamber into roof rocks is given by Carslaw and Jaeger (1959, p. 61) and also is discussed by Shaw (1974). Using these relations the total heat transfer (Δ_Q out) in column 12 is given by:

$$\Delta Q_{out} = 216At^{\frac{1}{2}}$$

where A is contact area (from column 6 converted to square centimeters) and t is the time in seconds since Ty. Calculations in column 12 are approximately valid only if the time of solidification is greater than Ty in column 5. The time of solidification is approximated by lines 3 and 4 in figure 3 of Smith and Shaw (1979).

If Ty is much greater than 360,000 years and the time for solidification, the calculation of heat content is ambiguous because of the increasing importance of hydrothermal losses. On the basis of conduction models, however, the total time for decay of igneous-related thermal anomalies may be very long. As an example, the time required for the central temperature in a magma chamber of horizontal slab-like geometry to decay from the initial magma temperature to nearly ambient temperature is about 2 m.y. for a magma chamber 5 km thick and about 10 m.y. for a chamber 10 km thick. Even a liberal allowance for hydrothermal losses means that the igneous-related thermal anomalies for the largest systems of table 1 probably are preserved for times of the order 10 m.y. or longer.

Queries in columns 10-12 mean that even though data exist, we are not confident that they pertain even approximately to the assumptions of the calculations. Blank spaces in the table mean that more geological and geochronological study is needed before we are willing to make estimates.

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Table 1.--*Magnitudes and heat contents of identified volcanic systems*--Continued

1 No.	2 Name of area	3 Latitude, longitude (deg min)	4 Composition last eruption	5 Age data (yr)	6 Chamber area (km^2)	7 Chamber volume range (km^3)	8 Chamber volume Vb (km^3)	9 Solidification state (°C)	10 ΔQ total (10^{18} J)	11 ΔQ now (10^{18} J)	12 ΔQ out (10^{18} J)	13 Remarks	14 References
							U T A H						
UT1	Mineral Mts.	38 26 112 48	Rhyolite	5×10^5 Tys 8×10^5 Tgs	66 Av	165-660 Vv	300	<650	724	710	59		2UT, 4UT
UT2	Cove Creek Domes	38 45 112 44	Basalt	2.3×10^6 Ts	94 Av	235-940 Vv	400	<650	960	84	920	Need geophysical data. May be low-grade system.	2UT, 4UT
UT3	White Mtn. Rhyolite	38 55 112 30	Basalt	$<10^4$ Tyb 4×10^5 Tys	No data Small							Need geophysical data.	2UT, 4UT
UT4	Thomas Range	39 42 113 07	Rhyolite	6×10^6 Tys	>100? Av	>250-1,000 Vv	>500?	<650	>1,210	42	1,190	Need more data. Possible low-grade system.	1UT, 4UT
UT6	Smelter Knoll	39 26 112 50	Rhyolite	3.4×10^6 Ts	No data			<650				Need more data.	1UT, 4UT
UT7	Wildcat Hills	41 51 113 01	Rhyolite	3.1×10^6 Ts	Small			<650				Need more data.	3UT
						W A S H I N G T O N							
WA1	Mt. Baker	48 47 121 49	Andesite	Active								>10 km depth	3WA
WA2	Glacier Peak	48 07 121 07	Rhyodacite	1.2×10^4 Tys $<7 \times 10^5$ Tg	5 ± 5 Ao	12.5-50 Vo	12.5 ± 12.5	>650?	35?	35?	17?	Volume by analogy to Mount St. Helens and other cascade volcanoes.	3WA
WA3	Mt. Ranier	46 51 121 45	Andesite	Active								>10 km depth	3WA
WA4	Mt. St. Helens	46 12 122 11	Andesite	Active 1.19×10^2 Tyb 1.75×10^2 Tys	5 Av	12.5-50 Vv	>12.5	>850	>35	>35			3WA
WA5	Mt. Adams	46 12 121 29	Andesite?	Active?								Need more data. >10 km depth?	3WA
WA6	Clear Fork Dacite	46 37 121 30	Dacite	$>2 \times 10^4$ Ts $\sim 3 \times 10^4$ Ts $<4 \times 10^4$ Ts								Need more data.	3WA
WA7	Mann Butte	45 56 121 39	Rhyolite	$(11-80) \times 10^4$ Ts								Need more data.	1WA
							W Y O M I N G						
WY1	Yellowstone Caldera system	44 31 110 35	Rhyolite	6.9×10^4 Tys 6×10^5 Tc	2,500 Ac	6,250-25,000 Vc	15,000	>650	36,100	36,100	7,950	Yellowstone caldera treated as independent from older system.	1WY, 6WY

Table 1.--*Magnitudes and heat contents of identified volcanic systems*--Continued

1 No.	2 Name of area	3 Latitude, longitude (deg min)	4 Composition last eruption	5 Age data (yr)	6 Chamber area (km^2)	7 Chamber volume range (km^3)	8 Chamber volume Vb (km^3)	9 Solidification state (^{o}C)	10 ΔQ total (10^{18} J)	11 ΔQ now (10^{18} J)	12 ΔQ out (10^{18} J)	13 Remarks	14 References
						O R E G O N							
OR2 *	Newberry	43 43 121 15	Rhyolite	1.3×10^3 Tys $>6.6 \times 10^3$ Tc	32 Ac	80-320 Vc	100	>650	240	240	13		2OR, 4OR
OR3	South Sister	44 06 121 46	Rhyolite	$<2 \times 10^3$ Tys	30 Av 40 As	75-300 Vv	100	>650	240	240	21		4OR
OR4 *	Mt. Hood	45 22 121 42	Andesite	Active								>10 km depth?	4OR, 7OR
OR5	Mt. McLoughlin	42 47 122 19	Andesite	Active?								>10 km depth	4OR
OR6 *	Mt. Jefferson Domes (Breitenbush?)	44 41 121 49	Silicic	No data Pleist.								Need age data.	4OR, 6OR
OR7	Melvin-Three Creeks Buttes	44 10 121 36	Rhyolite	4×10^5? Tys	10 Av	25-100 Vv	40	<650	96	76	58	Need better age data. Three domes.	1OR, 2OR, 4OR
OR8	Cappy-Burn Butte Area	43 19 121 56	Silicic	2.5×10^6? Ts	8 Av	20-80 Vv	40	<650	96	26	83	Need more data.	2OR
OR11	Rustler Peak	42 37 122 21	Dacite?	No data Pleist.								Need age data.	4OR
OR12	China Hat and East Butte	43 40 121 01	Rhyolite	7.8×10^5 Tys 8.4×10^5 Tys		85 Vee	85	<650	205			These two domes may be close enough in time & space to be part of a single thermal anomaly.	3OR, 4OR
OR13	Quartz Mountain	43 38 120 53	Rhyolite	1.1×10^6 Tys		36 Vee	36	<650	88				3OR, 4OR
OR14	Glass Buttes	43 33 120 04	Rhyolite	$\leq 4.9 \times 10^6$ Ts		330 Vee	330	<650	800	<40?	750?	Needs investigation as low temperature system.	3OR, 4OR
OR16	Cougar Peak Area	42 18±30 120 38±20	Rhyolite?	$7.1\text{-}7.7 \times 10^6$ Ts				<650				Needs more detailed investigation including gravity data. May be underlain by pluton. See CA11-same age.	3OR, 4OR
OR17 *	Harney-Malheur	43 15? 119 08?	Rhyolite?	$\leq 6.6 \times 10^6$ Ts 9×10^6 Ts		2,500 Vee	2,500	<650	6020	?		Needs more detailed investigation especially more accurate location of chamber area. Probably is large low grade system.	4OR, 5OR
OR18	Bearwallow Buttes	44 05 121 33	Silicic	$<10^6$?	8 Av	20-80 Vv	30	<650	71	41	51	Need age data-four domes.	2OR, 4OR
OR19	Wart Peak Caldera	43 19 121 23	Rhyolite	4.5×10^6? Tc Ts	40 Ac	100-400 Vc	150	<650	360	8	356		2OR
OR20	Frederick Butte	43 37 120 28	Rhyolite	3.9×10^6 Ts	32 Av Ac?	80-320 Vv Vc?	125	<650	300	4	300		3OR

Table 1.--*Magnitudes and heat contents of identified volcanic systems*--Continued

1 No.	2 Name of area	3 Latitude, longitude (deg min)	4 Composition last eruption	5 Age data (yr)	6 Chamber area (km^2)	7 Chamber volume range (km^3)	8 Chamber volume Vb (km^3)	9 Solidification state (°C)	10 ΔQ total (10^{18} J)	11 ΔQ now (10^{18} J)	12 ΔQ out (10^{18} J)	13 Remarks	14 References
						H A W A I I							
H 3	Hualalai	19 42 155 50	Olivine Basalt	1.74×10^2 Tyb								Potentially active. >5 km depth.	1HI
H 4	Mauna Kea	19 49 155 28	Hawaiite	Post-glacial Tyb								Potentially active? No historic eruptions. >5 km depth.	1HI
H 5	Haleakala	20 43 156 15	Mafic Olivine Basalt	2.25×10^2? Tyb								Potentially active. >5 km depth.	1HI
						I D A H O							
ID1	Island Park system	44 17 111 24	Basic	2×10^5 Tyb 1.2×10^6 Tys 1.2×10^6 Tc 2.0×10^6 Tc	3900 Ac 2100 Ao	5,250-21,000 Vc	16,200	≤650	39,000	16,850	27,600	Compound system with Yellowstone caldera (WY-1). Ao and 16,200 km^2 (area and volume of western part of Island Park system, not overlapped by Yellowstone Caldera) are used to calculate thermal energies.	2ID, 6ID
ID3	Blackfoot Domes	42 49 111 36	Silicic?	4×10^4 Ts 8×10^4 Ts	25 Av	60-240 Vv	100	<650	240	240	59		1ID, 3ID, 6ID
ID4	Big Southern Butte	43 24 113 01	Rhyolite	3×10^5 Ts	No data	100 Vee	100	<650	240	<240		Some evidence that ID4 & ID5 could be part of single system. If so, huge thermal anomaly is possible.	1ID, 6ID
ID5	East Butte	43 30 112 40	Rhyolite	6×10^5 Ts	No data	2 Vee	2	<650				See remarks ID4	1ID
ID6	Rexburg Caldera	43 49 111 47	Rhyolite	4.2×10^6 Ts	1800 Ac	4,500-18,000 Vc	9,000	<650	21,660	8,400	16,800		4ID, 5ID
						N E V A D A							
NV1	Steamboat Springs	39 22 119 48	Rhyolite	1.2×10^6 Tys	18 Av	45-180 Vv	90	<650	220	?	?	Fault-controlled system possibly related to chamber much larger than indicated.	2NV, 3NV
NV2	Silver Peak	37 45 117 52	Basic	4.8×10^6 Tyb 6.1×10^6 Tys	40 Ac	100-400 Vc	200	<650	480	?		Recent basalt cinder cone on lower flanks.	1NV, 2NV
						N E W M E X I C O							
NM1	Valles Caldera	35 52 106 34	Rhyolite	$\sim 10^5$ Tys 1.1×10^6 Tc 1.4×10^6 Tc	400 Ac	1,000-4,000 Vc	3,500	>650	8,425	8,425	~1,700	>20 rhyolitic eruptions <1.1 x 10^6 yrs. Vee subject to revision. Probably close to solidus temperature.	1NM, 3NM, 4NM
NM2	Mt. Taylor	35 14 107 35	Basalt?	2.73×10^6 Tys								Need more data.	2NM, 4NM
NM3	No. Agua Domes	36 45 105 57	Rhyolite	3.8×10^6 Ts									2NM, 4NM
						O R E G O N							
OR1	Crater Lake	42 56 122 07	Silicic?	>7×10^2? Ty 6.6×10^3 Tc	50 Ac	125-500 Vc	>320	>650	>770	>770	17		4OR

Table 1.—*Magnitudes and heat contents of identified volcanic systems*—Continued

1 No.	2 Name of area	3 Latitude, longitude (deg min)	4 Composition last eruption	5 Age data (yr)	6 Chamber area (km^2)	7 Chamber volume range (km^3)	8 Chamber volume Vb (km^3)	9 Solidification state (°C)	10 ΔQ total (10^{18} J)	11 ΔQ now (10^{18} J)	12 ΔQ out (10^{18} J)	13 Remarks	14 References
						C A L I F O R N I A							
CA7	Medicine Lake	41 35 121 37	Rhyolite	$\leq 10^3$ Tys	64 Ac 74 Av	160-640 Vc 185-740 Vv	300	>650	724	724	29	Should be studied in greater detail	17CA
CA8	Shasta	41 24 122 12	Andesite	$<2 \times 10^2$ Tyb (5-9.5) x 10^3? Tys	50 Aogo	125-500 Vogo	300	>650	724	724	42	By analogy to Crater Lake and large gravity low.	5CA, 17CA
CA9	Sutter Buttes	39 13 121 49	Basic?	1.4×10^6 Tys 1.5×10^6 Tyb 2.4×10^6 Tgs	40 Av	100-400 Vv	100	<650	240	<42	210?	Ring of silicic vents	17CA, 18CA
CA10 *	Morgan Mtn Domes	40 23 121 32	Dacite?	No data Pleist.?								Needs investigation, age data.	17CA
CA11 *	Warner Mtns (Boyd Creek-Sugar Hill Domes)-(Surprise Valley)	41 43 120 17	Rhyolite	7.1×10^6 Tys 7.7×10^6 Ts								Needs investigation. May be part of large subjacent pluton. See Cougar Peak, Oregon (same age).	13CA, 17CA
CA12	Bridgeport-Bodie Volcanic complex Calif.-Nevada	38 14±10 119 05±10	Basic	2.5×10^5 Tyb 1.1×10^7 Tg 2.5×10^6 Tys								Needs investigation. May be large low grade system.	15CA, 17CA
CA13 *	Lava Mountains	35 26 117 31	Silicic	No data Pleist.? Plio.		120 Vee	>120	<650	>290			Needs investigation as low grade resource. Volume probably greater by 5-10 times.	16CA, 17CA
CA14	Big Pine	37 03 118 19	Rhyolite	9.8×10^5 Tys 6×10^4 Tyb	42 As	105-420 Vs	100	<650	240	<85	125?	Highly speculative (Vs).	4CA, 17CA
CA15	Olancha Domes	36 20 117 51	Rhyolite?	No data								Need age data.	1CA, 17CA
CA16	Jackson Buttes	38 16 120 44	Dacite?	No data Plio?								Need age data.	17CA
CA17 *	Paoha Island Mono Lake	38 01 119 02	Silicic	85 yrs? Data not definitive								Needs more data. Active fumaroles; considered as separate system from Mono Domes.	2CA, 17CA
CA18	Inyo-Mammoth fissure system	37 46 119 01	Silicic?	7.25×10^2 Tys $\geq 5 \times 10^2$ Ty								May be thermal source and root for Long Valley system.	2CA
CA19	Templeton Domes	36 17 118 12	Silicic	1.9×10^5 Tys 2.4×10^6 Tgs	50 Av	125-500 Vv	250	<650	603	603	318		1CA
						H A W A I I							
H 1 *	Kilauea	19 26 155 18	Basalt	Active Tyb	12.5 Au	37.5-50 Vugs	40	>850	96	96		Chamber probably a plexus of sills and dikes with <5% of hot rock volume molten at any one time.	1HI, 2HI
H 2	Mauna Loa	19 29 155 35	Olivine Basalt	Active Tyb								>5 km depth	1HI

Table 1.--*Magnitudes and heat contents of identified volcanic systems*--Continued

No. (1)	Name of area (2)	Latitude, longitude (deg min) (3)	Composition last eruption (4)	Age data (yr) (5)	Chamber area (km²) (6)	Chamber volume range (km³) (7)	Chamber volume Vb (km³) (8)	Solidification state (°C) (9)	ΔQ total (10^{18} J) (10)	ΔQ now (10^{18} J) (11)	ΔQ out (10^{18} J) (12)	Remarks (13)	References (14)
						A L A S K A							
AK88	Edgecumbe	57 01 135 46	Basic? Silicic	Active? $<9 \times 10^3$ 9×10^3 Ts	74 Av	185-740 Vv	250	>650	602	602	250	Silicic in focus. Basic on flanks.	1AK
AK89	Ukinrek Maars	57 50 156 29	Basic	Active								Two new volcano vents 1977. >10 km depth?	9AK
AK90	Hayes volcano	61 37 152 27	Silicic	$<3.7 \times 10^3$								Probably potentially active vent area, probably ice capped.	9AK
						A R I Z O N A							
AZ1	San Francisco Mountains	35 20 111 40	Basalt Rhyolite	9×10^2 Tyb 2×10^5 Tys 2.7×10^6 Tgs	250 As	625-2500 Vs	1250	>650	3010	3010	1320	Shadow area and volumes so derived highly speculative. Migrating system.	1AZ, 2AZ
AZ2	Kendrick Peak	35 24 111 52	Silicic	1.5×10^6 Tys 1.9×10^6 Ts $<1.9 \times 10^6$ Tyb	50 Av	125-500 Vv	250	>650	603	150	519	Tys on Slate Mountain	1AZ, 2AZ
AZ3	Sitgreaves Peak	35 21 112 00	Rhyolite	1.9×10^6 Tys 2.8×10^6 Tgs $>1.9 \times 10^6$ Tyb	50 Av	125-500 Vv	200	>650	481	46	456		1AZ, 2AZ
AZ4	Bill Williams Mountain	35 12 112 12	Silicic	3.5×10^6 Tys 4.1×10^6 Tgs	20 Av	50-200 Vv	100	>650	240	4	240		1AZ, 2AZ
						C A L I F O R N I A							
CA1 •	Lassen Peak	40 29 121 30	Rhyodacite	61 yrs Tys	80 Av	200-800 Vv	400	>650	960	960	8		17CA
CA2 •	Clear Lake	38 55 122 45	Basic?	$<10^4$ Tyb 2×10^6 Tgs 9×10^4 Tys 2×10^6 Tgb	256 Av	640-2560 Vv	1500	>650	3610	3610	2050	Chamber volume estimated here is virtually unchanged by new geophysical data (1400 Vgg).	6CA, 5CA, 10CA, 17CA
CA3 •	Long Valley	37 42 118 52	Rhyolite	10^5 Tys 7×10^5 Tc 9×10^5 Tgs	480 Ac	1200-4800 Vc	2400	>650	5780	5780	1800	Considered here as a system independent from Mono-Inyo Domes, but may be influenced by heat from Inyo fissure system.	3CA, 11CA, 17CA
CA4 •	Salton Sea	33 12 115 37	Rhyolite	1.6×10^4? $<5.5 \times 10^4$ Tys	50 Av	125-500 Vv	200	>650	480	480	75	More and better age data needed	8CA, 7CA, 17CA
CA5 •	Coso Mts.	36 02 117 49	Basalt	3×10^4 Tyb 4×10^4 Tys 9×10^5 Tgs	110 Av	275-1100 Vv	650	>650	1570	1570	270	Circular 726 estimate still considered valid. Data from new studies lead to both more liberal and more conservative estimates of chamber.	1CA, 7CA, 12CA, 17CA
CA6	Mono Domes	37 53 119 00	Rhyolite	$<10^3$? Tys $<7 \times 10^4$ Tgs	130 Avf	325-1300 Vvf	650	>650	1570	1570	50	Mono-Inyo valley systems complicated by Inyo Dome chain which intersects both and is best evidence for viable deep heat source.	2CA, 17CA

Table 1.--*Magnitudes and heat contents of identified volcanic systems*--Continued

1	2	3	4	5	6	7	8	9	10	11	12	13	14
No.	Name of area	Latitude, longitude (deg min)	Composition last eruption	Age data (yr)	Chamber area (km^2)	Chamber volume range (km^3)	Chamber volume Vb (km^3)	Solidification state (^oC)	ΔQ total (10^{18} J)	ΔQ now (10^{18} J)	ΔQ out (10^{18} J)	Remarks	References
						A L A		S K A					
AK69	Katmai	58 16 154 59	Basic	Active	8.1 Ac	20-80 Vc	>20	>850	50	50			
AK70	Snowy	58 20 154 44	No data	No data								No data	
AK71	Denison	58 25 154 27	No data	No data								No data	
AK72	Steller	58 26 154 24	No data	No data								No data	
AK73	Kukak	58 28 154 21	No data	Active?								No data	
AK74	Devils Desk	58 29 154 18	No data	No data								No data	
AK75	Kaguyak	58 37 154 05	Silicic	$<10^4$?	4.1 Ac	10-40 Vc	>15	>650	38	38	13	Need age data	9AK
AK76	Fourpeaked	58 46 153 41	No data	$<10^4$?								No data	
AK77	Douglas	58 52 153 33	No data	Active?								No data	
AK78	Augustine	59 22 153 25	Silicic-Basic Ty	Active								Need geophysical data?	9AK
AK79	Iliamna	60 02 153 05	Basic	Active								>10 km depth	
AK80	Redoubt	60 29 152 45	Basic	Active								>10 km depth	
AK83	Spurr	61 18 152 15	Basic	Active								Caldera? Need more data.	9AK
AK84	Drum	62 07 144 38	Silicic	2.4×10^5 Tys 2.4×10^5 Ts 8×10^5 Tg	140 Av	350-1400 Vv	400	650	960	~840	>420	A more liberal volume and thermal estimate is given by Miller and others, see reference.	10AK, 11AK
AK85	Sanford	62 13 144 07	No data	$<3.2 \times 10^5$ Tb								Need data on parasitic vents high on flanks of Sanford (inaccessible?)	11AK
AK86	Wrangell	62 00 144 01	Basic?	Active $>1.7 \times 10^3$ Tc	15 Ac	37.5-150 Vc	50	>850	120	120			11AK
AK87	White River	61 27 141 28	Silicic	1.5×10^3		80 Vee	80	>650	190	190			11AK

Table 1.--*Magnitudes and heat contents of identified volcanic systems*--Continued

1 No.	2 Name of area	3 Latitude, longitude (deg min)	4 Composition last eruption	5 Age data (yr)	6 Chamber area (km^2)	7 Chamber volume range (km^3)	8 Chamber volume Vb (km^3)	9 Solidification state (^oC)	10 ΔQ total (10^{18} J)	11 ΔQ now (10^{18} J)	12 ΔQ out (10^{18} J)	13 Remarks	14 References
						A L A S K A							
AK52	Bague	55 22 161 59	Basic	Active								in Emmons caldera	9AK
AK53	Double Crater	55 23 161 57	Basic	Active?								in Emmons caldera	9AK
AK54	Pavlof	55 25 161 54	Basic	Active								>10 km depth	9AK
AK55	Pavlof Sister	55 27 161 52	Basic	Active								>10 km depth	9AK
AK56	Dana	55 37 161 13	Silicic	No data $<10^4$?	1.6 Ac	4-16 Vc	>5		13			Need age data	9AK
AK57	Kupreanof	56 01 159 48	No data Basic?	Active								Need more data. Probably two volcanoes	9AK
AK58	Veniaminof	56 10 159 23	Basic	Active 3.7×10^3 Tc	50.4 Ac	125-500 Vc	200	>850	481	481			9AK
AK59	Black (Purple)	56 34 158 48	Silicic	$<10^4$?	6.9 Ac	17.5-70 Vc	>20	>650	50	50		Need age data	9AK
AK60	Aniakchak	56 53 158 09	Silicic	Active 3.6×10^3 Tc	55.6 Ac	140-560 Vc	225	>650	540	540			9AK
AK61	Chiginigak	57 08 157 00	Basic? Silicic?	Active								Need more data	9AK
AK62	Kialagvik	57 12 156 42	Silicic	No Data								Need age data	9AK
AK63	Peulik (Ugashik caldera)	57 45 156 21	Basic? Silicic	Active? $>1.7 \times 10^5$ Tc	10.5 Ac	25-100 Vc	>30	>650	71	71		Silicic in focus of both caldera and Mt. Peulik; perhaps young basic eruption on north flank of Peulik. Need age data.	9AK
AK64	Martin	58 09 155 23	Basic?	Active								>10 km depth?	
AK65	Mageik	58 12 155 15	?	Active								Silicic domes? Need more data.	
AK66	Novarupta	58 16 155 10	Silicic	Active	8.1 Ac	20-80 Vc	50	>650	120	120			
AK67	Mt. Griggs (Knife Peak)	58 21 155 07	Basic?	Active								>10 km depth?	
AK68	Trident	58 14 155 07	Basic	Active								>10 km depth?	

Table 1.--*Magnitudes and heat contents of identified volcanic systems*--Continued

1 No.	2 Name of area	3 Latitude, longitude (deg min)	4 Composition last eruption	5 Age data (yr)	6 Chamber area (km^2)	7 Chamber volume range (km^3)	8 Chamber volume Vb (km^3)	9 Solidification state (°C)	10 ΔQ total (10^{18} J)	11 ΔQ now (10^{18} J)	12 ΔQ out (10^{18} J)	13 Remarks	14 References
						ALASKA							
AK35	Tulik	53 23 168 03	Basic	No data								>10 km depth	2AK
AK36	Bogoslof	53 56 168 02	Basic	Active								>10 km depth	2AK
AK37	Makushin	53 54 166 56	Silicic?	Active	3.6 Ac	9-36 Vc	>10	>850	25	25			5AK, 9AK
AK38	Table Top	53 58 166 40	Basic	No data								>10 km depth	5AK, 9AK
AK39	Akutan	54 08 166 00	Basic?	Active	3.5 Ac	9-36 Vc	>10	>850	25	25			3AK, 9AK
AK40	Mt. Gilbert (Akun)	54 15 165 39	Basic?	No data								>10 km depth?	3AK, 9AK
AK41	Pogromni	54 34 164 42	Basic	Active?								>10 km depth. Satellitic to Westdahl. Doubtfully active.	4AK, 9AK
AK42	Westdahl	54 31 164 39	No data Basic?	Active								Need more data. >10 km?	4AK, 9AK
AK43	Fisher	54 40 164 21	Basic	Active? $<2 \times 10^3$ Ty $<10^4$ Tc	122.6 Ac	300-1200 Vc	600	>850	1440	1440			4AK, 9AK
AK44	Shishaldin	54 45 163 58	Basic	Active								>10 km depth	4AK, 9AK
AK45	Isanotski	54 45 163 44	Basic?	Active								>10 km depth?	4AK, 9AK
AK46	Roundtop	54 48 163 36	No data	Active? $<2 \times 10^3$?									4AK, 9AK
AK47	Amak	55 25 163 09	Basic?	$<10^4$?								>10 km depth?	4AK, 8AK
AK48	Frosty	55 04 162 49	Silicic? Basic?	No data								Need data on composition and age	9AK, 15AK
AK49	Walrus (Morzhovoi)	55 01 162 50	Basic	No data $>10^4$?								>10 km depth	9AK, 15AK
AK50	Dutton	55 11 162 16	Basic	No data								>10 km depth	9AK
AK51	Emmons	55 20 162 04	Basic	Active	117.3 Ac	300-1200 Vc	600	>650	1440	1440		in Emmons caldera	6AK, 9AK

Table 1.--*Magnitudes and heat contents of identified volcanic systems*--Continued

1 No.	2 Name of area	3 Latitude, longitude (deg min)	4 Composition last eruption	5 Age data (yr)	6 Chamber area (km^2)	7 Chamber volume range (km^3)	8 Chamber volume Vb (km^3)	9 Solidification state (^oC)	10 ΔQ total (10^{18} J)	11 ΔQ now (10^{18} J)	12 ΔQ out (10^{18} J)	13 Remarks	14 References
						A L A	S K A						
AK18	Sergief	52 19 174 23	No data	No data								Need data on composition and age	4AK
AK19	Korovin	52 23 174 09	Basic	Active								>10 km depth	4AK
AK20	Kliuchef	52 20 174 09	No data	No data	28.6 Ac	70-280 Vc	>100		240			Need data on composition and age. A18 to A21 may be one system	4AK
AK21	Sarichef	52 19 174 01	Basic?	Active?								>10 km depth	4AK
AK22	Seguam	52 19 172 29	No data	Active	20 Ac	100-400 Vc	200	>850	480	480		Appears to be a double caldera. Not reported. Needs investigation.	
AK23	Amukta	52 30 171 15	Basic?	Active								>10 km depth? Need data.	
AK24	Chagulak	52 34 171 08	Basic?	$<10^4$?								>10 km depth? Need data.	
AK25	Yunaska	52 38 170 42	No data Basic?	Active	12.1 Ac	30-120 Vc	40	>850	96	96		Probably two volcanoes. Need data.	
AK26	Herbert	52 45 170 07	Basic?	$<10^4$?								>10 km depth? Need data	
AK27	Carlisle	52 54 170 03	Basic?	Active								>10 km depth? Need data.	
AK28	Cleveland	52 49 169 57	Basic?	Active								>10 km depth? Need data.	
AK29	Uliaga	53 04 169 46	Basic?	$<10^4$?								>10 km depth? Need data.	
AK30	Tana	52 50 169 46	Basic?	No data								>10 km depth? Need data.	
AK31	Kagamil	52 59 169 43	Basic?	Active								>10 km depth? Need data	
AK32	Vsevidof	53 08 168 41	Silicic	Active								Need more data. Probable high level chamber.	2AK
AK33	Recheschnoi	53 09 168 33	Basic? Silicic?	$<10^4$								Need more data. Probable high level chamber.	2AK
AK34	Okmok	53 25 168 08	Basic	Active 8×10^3 Tc	62.9 Ac	155-620 Vc	250	>850	603	603			2AK

Table 1.--*Magnitudes and heat contents of identified volcanic systems*

1 No.	2 Name of area	3 Latitude, longitude (deg min)	4 Composition last eruption	5 Age data (yr)	6 Chamber area (km^2)	7 Chamber volume range (km^3)	8 Chamber volume Vb (km^3)	9 Solidification state (^oC)	10 ΔQ total (10^{18} J)	11 ΔQ now (10^{18} J)	12 ΔQ out (10^{18} J)	13 Remarks	14 References
						A L A	S K A						
AK1	Buldir	52 21 175 55 E	Basic	$<10^4$?								>10 km depth	4AK
AK2	Kiska	52 06 177 36 E	Basic	Active								>10 km depth	
AK3	Segula	52 01 178 08 E	Basic Silicic?	$<10^4$?								Need data on composition and age	
AK4	Davidof	51 58 178 20 E	No data	$<10^4$?	5 Ac	12.5-50 Vc	12.5	>650?	29	29		Need data on composition and age	
AK5	Little Sitkin	51 57 178 32 E	Basic	Active	17.3 Ac	45-180 Vc	75	>850	180	180			14AK
AK6	Semisopochnoi (Cerberus)	51 56 179 36 E	Basic	Active	42.4 Ac	106-424 Vc	150	>850	360	360			4AK
AK7	Sugarloaf	51 53 179 38 E	Basic	$<10^4$?								>10 km depth	4AK
AK8	Gareloi	51 48 178 48	Basic	Active								>10 km depth	4AK
AK9	Tanaga	51 53 178 09	Basic?	Active	85.9 Ac	215-860 Vc	400	>850	960	960		Need more data	4AK
AK10	Takawangha	51 52 178 00	Basic?	$<10^4$?	8.9 Ac	22.5-90 Vc	>22.5	>650	54	54		Need data on composition and age	4AK
AK11	Bobrof	51 54 177 26	Basic?	$<10^4$?								>10 km depth	4AK
AK12	Kanaga	51 56 177 09	Basic?	Active	23.0 Ac	57.5-230 Vc	75	>850	180	180			4AK
AK13	Moffet	51 56 176 44	Basic	0.14 Tyb								>10 km depth?	4AK, 9AK
AK14	Adagdak	51 59 176 35	Basic? Silicic?	3.4×10^5 Tys 1.4×10^5 Tyb		25 Vee	25	<650	59	50	9	Probable low temperature hydrothermal system	4AK, 9AK
AK15	Great Sitkin	52 04 176 08	Basic	Active	1.8 Ac	4.5-18 Vc	>5	>850	>13	>13			4AK
AK16	Kasatochi	52 11 175 30	Basic?	Active?								>10 km depth?	4AK
AK17	Koniuji	52 13 175 08	Basic?	Active?								>10 km depth?	4AK

Table 2.--*Basic volcanic fields probably less than 10,000 years old*

		Longitude	Latitude
ALASKA			
AK1	Devil Mountain Field	66°18'	164°31'
AK2	Imuruk Lake field	65°29'	163°17'
AK3	St. Lawrence Island	63°37'	170°17'
AK4	St. Michaels field	63°36'	162°37'
AK5	Ingrichuak Hill area	62°11'	164°06'
AK6	Ingakslugwat Hills area	61°22'	163°58'
AK7	Nunivak Island (?)	60°01'	166°20'
AK8	Pribilof (St. Paul) Islands(?)	57°10'	170°23'
ARIZONA			
AZ1	Unikaret flow	36°22'	113°09'
AZ2	Sunset Crater flow	35°22'	111°30'
CALIFORNIA			
CA1	Copco Lake area	41°59'	122°20'
CA2	Goosenest area	41°43'	122°13'
	Mt. Lassen - Mt. Shasta area		
CA3a	Callahan flows	41°41'	121°36'
CA3b	Burnt Lava flows	41°31'	121°32'
CA3c	Paint Pot Crater flow	41°33'	121°42'
CA3d	Six Shooter Butte flows	41°31'	121°37'
CA3e	Fall River Mills flow	40°57'	121°22'
CA3f	Hat Creek flow	40°39'	121°26'
CA3g	Cinder Cone flow "1851"	40°33'	121°19'
CA4	Ubehebe Craters area	37°01'	117°27'
CA5	Cima Lava field	35°11'	115°49'
CA6	Pisgah field	34°45'	116°23'
CA7	Amboy field	34°33'	115°47'
COLORADO			
CO1	Dotsero	39°40'	107°02'

Table 2.--*Basic volcanic fields probably less than 10,000 years old*--continued

		Longitude	Latitude
HAWAII			
Hawaii Island			
H 1	Hualalei	19°42'	155°52'
H 2	Mauna Kea	19°50'	155°29'
H 3	Mauna Loa	19°29'	155°36'
H 4	Kilauea	19°25'	155°17'
Maui Island			
H 5	Haleakala	20°43'	156°13'
IDAHO			
ID1	Craters of the Moon area	43°25'	113°32'
ID2	North Robbers flow	43°23'	112°59'
ID3	Cerro Grande	43°22'	112°53'
ID4	Hells Half Acre	43°30'	112°27'
ID5	Wapi	42°53'	113°13'
ID6	Kings Bowl	42°57'	113°13'
NEVADA			
NV1	Lunar Crater lava field	38°29'	115°59'
NEW MEXICO			
NM1	Capulin flow	36°47'	103°58'
NM2	McCartys flow	34°49'	108°00'
NM3	Carrizozo flow	33°47'	105°56'

Table 2.--*Basic volcanic fields probably less than 10,000 years old*--continued

		Longitude	Latitude
OREGON			
OR1	North Cinder Peak flow	44°36'	121°47'
OR2	Nash Crater flow	44°25'	121°57'
OR3	Sand Mountain flow	44°23'	121°56'
OR4	Belknap lava field	44°17'	121°51'
OR5	North Sister lava field	44°12'	121°47'
OR6	Le Conte Crater flow	44°03'	121°48'
OR7	Cayuse Crater flow	44°04'	121°42'
OR8	Bachelor Butte lava field	43°59'	121°41'
OR9	Lava Butte flow	43°55'	121°21'
OR10	Newberry Crater area (lower flanks)	43°50'	121°17'
OR11	Wuksi Butte area	43°46'	121°45'
OR12	Pine Butte area	43°40'	121°51'
OR13	Black Rock Butte area	43°29'	121°48'
OR14	Devils Garden area	43°30'	120°54'
OR15	Squaw Ridge field	43°28'	120°45'
OR16	Four Craters lava field	43°22'	120°40'
OR17	Brown Mountain area	42°22'	122°17'
OR18	Diamond Craters area	43°06'	118°45'
OR19	Jordan Craters field	43°02'	117°25'
OR20	Jackies Butte field	42°36'	117°35'
UTAH			
UT1	Ice Springs field	38°58'	112°30'
UT5	Cove Fort flow	38°34'	112°39'
UT2	Markagunt field	37°34'	112°43'
UT4	Santa Clara flow	37°15'	113°38'
UT3	Crater Hill Flow	37°13'	113°06'
WASHINGTON			
WA1	Red Mountain-Big Lava Bed	45°55'	121°45'