JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 87, NO. C2, PAGES 1231–1238, FEBRUARY 20, 1982

The Volcanic Explosivity Index (VEI): An Estimate of Explosive Magnitude for Historical Volcanism

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Knowledge of the frequencies of highly explosive, moderately explosive, and nonexplosive eruptions would be useful in a variety of volcano studies. Historical records are generally incomplete, however, and contain very little quantitative data from which explosive magnitude can be estimated. Only the largest eruptions have a complete record back to the early 19th Century; other important explosive events went unrecorded prior to about 1960. Only a handful of the very biggest eruptions are represented in the geologic record, so it will be impossible to augment historical records post facto. A composite estimate of the magnitude of past explosive eruptions, termed the Volcanic Explosivity Index (VEI), is proposed as a semiquantitative compromise between poor data and the need in various disciplines to evaluate the record of past volcanism. The VEI has been assigned to over 8000 historic and prehistoric eruptions, and a complete list is available in a companion document.

INTRODUCTION

In compilations of historic volcanism there is a need for an estimate of the scale or 'magnitude' of each eruption. Earthquakes are routinely reported with a Richter magnitude, plus intensity estimates at different locations, but no analogous reporting system has been instituted for volcanic eruptions. This presents a predicament for studies that require some quantitative or semiquantitative basis for comparing explosive eruptions. The problem has been particularly acute in attempts to evaluate the role of historical volcanism on past climatic, particularly temperature, variation [e.g., *Humphreys,* 1940; *Wexler,* 1951, 1952; *Lamb,* 1970, 1977; *Mitchell,* 1970; *Bray,* 1974; *Schneider and Mass,* 1975; *Baldwin et al.,* 1976; *Newell,* 1976; *Bryson and Goodman,* 1980; *Hirschboeck,* 1980; *Robock,* 1981]. The problem also arises in studies of freqency of various kinds of volcanic events, for use both in understanding fundamental controls of volcanism and in quantifying volcanic hazards. To be useful, studies of historic volcanism need: (1) up-to-date, readily manageable historical information about eruptions, including dates and the nature of activity, and (2) a basis for comparing the scale or magnitude of each type of activity. We describe here a simple scheme for estimating explosive magnitude, with notes on its use and limitations.

2. PREVIOUS WORK

Compilations of Volcanological Information

Information about historic eruptions is scattered widely throughout the historical and geological literature. The *Catalogue of Active Volcanoes and Solfatara Areas of the World* (*IAVCEI,* Rome, Italy, 1950–1975) is an exceptionally valuable compilation of such information in a text and table format. Reports of G. Hantke (Ubersicht über die vulkanische Tätigkeit, in the *Bulletin Volcanologique,* volumes *11, 14, 16, 20,* and *24,* 1941–1962), the Volcanological Society of Japan (*Bulletin of Volcanic Eruptions,* volumes *1–14,* 1961–1978), Smithsonian Center for Short-Lived Phenomena (*Reports of Volcanic Eruptions on Event Cards,* 1968–1975), and the Smithsonian Scientific Event Alert Network (*SEAN Monthly Report,* 1975–1981) provide valuable supplements to the Catalogue also in a text and table format. The most recent addition to these sources, and one which includes information from the sources mentioned above plus a comprehensive study of other literature, is another Smithsonian project, *Volcanoes of the World,* a regional directory, gazetteer, and chronology of volcanism in the last 10,000 years [*Simkin et al.,* 1981]. This last source contains a more complete chronology than any previous compilation and is also in a flexible, computer-based format which allows for easy data retrieval.

Compilations of Volcanic Eruption Records for the Purpose of Comparison With Climate Records

Lamb [1970, 1977] used atmospheric opacity, temperature records, and volcanological information to estimate the amount of dust introduced in to the upper atmosphere by each of approximately 250 eruptions. When determined from atmospheric opacity, his ratio of dust veil index/maximum extent (dvi/E_{max}) is a realistically direct measure of the dust injection. Unfortunately, *dvi* can only be evaluated in this way for the relatively small number of eruptions identifiable in atmospheric records. Early eruptions, small eruptions, and eruptions closely spaced in time cannot easily be assigned dvi/E_{max} values, nor can the effects of nonvolcanic phenomena (e.g., dust storms) be easily filtered out. Of Lamb's 250 *dvi* estimates (excluding cumulative estimates for periods of several years), 5% are based on a change in radiation, 5% on temperature records, 12% on quantitative estmates of tephra volumes, 30% on *Sapper*'s [1927] semi-quantitative estimates of tephra volumes, and 48% on non-quantitative descriptions of eruptions. *Cronin* [1971] referred to an unpublished survey of explosive volcanism in the last two centuries, and *Hirschboeck* [1980] and *Bryson and Goodman* [1980] referred to another unpublished list in which they used volcanologic information to characterize approximately 5000 eruptions as small, moderate, or great. This last list avoided the circular reasoning and limited, indeed often incorrect, eruption information of some previ-

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Paper number 1C1367.
0148-0227/82/001C-1367$01.00

TABLE 1. Criteria for Estimation of the Volcanic Explosivity Index (VEI)

Criteria — VEI:	0	1	2	3	4	5	6	7	8
DESCRIPTION	non-explosive	small	moderate	mod-large	large	very large---	---	---	---
VOLUME OF EJECTA (M^3)	$<10^4$	10^4-10^6	10^6-10^7	10^7-10^8	10^8-10^9	10^9-10^{10}	10^{10}-10^{11}	10^{11}-10^{12}	$>10^{12}$
(TSUYA CLASSIFICATION)+	(I)	(II-III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX) ---	---
COLUMN HEIGHT (KM)*	<0.1	0.1-1	1-5	3-15	10-25	>25---	---	---	---
QUALITATIVE DESCRIPTION	---"gentle, effusive"--	---	-----"explosive"-------	---	-----"cataclysmic, paroxysmal, colossal"---	---	---	---	---
				"severe, violent, terrific"---	---	---	---	---	---
CLASSIFICATION		----------"Strombolian"-	---	---	-------"Plinian"---	---	---	---	---
	-------"Hawaiian"------	---	-------------"Vulcanian"-------------	---	---	--------"Ultraplinian"---	---	---	---
DURATION (hours)	------------------------<1--------------	---	---	---	------------>12---	---	---	---	---
of continuous blast			------------------1-6----------------	---	---				
				---------------------6-12----------------	---	---			
CAVW MAX EXPLOSIVITY**	--lava flows-	---------------explosion or nuée ardente---	---	---	---	---	---	---	---
		------phreatic---------	---	....	....	....			
	-----dome or mudflow---	---							
TROPOSPHERIC INJECTION	negligible	minor	moderate	substantial---	---	---	---	---	---
STRATOSPHERIC INJECTION	none	none	none	possible	definite	significant---	---	---	---

+If all eruptive products were pyroclastic ejecta
*For VEI's 0-2, uses km above crater; for VEI's 3-8, uses km above sea level.
**The most explosive activity indicated for the eruption in the Catalogue of Active Volcanoes

Criteria are listed in decreasing order of reliability.

ous work, but unfortunately includes in its category of 'great eruptions' both great eruptions with potential climatic impact and many small eruptions with no likely climatic impact.

Estimating the 'Explosive Magnitude' of an Eruption

Previous attempts at quantifying the scale of eruptions have centered on estimating the thermal and kinetic energy involved in the eruption, as estimated from volumes of lava and pyroclastic debris, column heights, and ballistic trajectories of individual fragments [e.g., *Sapper,* 1927; *Escher,* 1933; *Tsuya,* 1955; *Hedervari,* 1963; *Yokoyama,* 1956, 1957]. The most widely adopted scale is that of *Tsuya* [1955], but it can only be applied when the volume of ejecta is known and even then includes both pyroclastic ejecta and lava flows. *Gorshkov* [1960] proposed a different and novel approach using barograph records from meteorological stations to measure the atmosphere shock wave resulting from volcanic explosions, but this method has proven to be limited in application and difficult in interpretation.

Walker [1980] has proposed five complementary parameters for estimating the scale of explosive eruptions, namely, (1) magnitude (determined from the volume of ejecta), (2) intensity (volume of ejecta per unit time, as determined from the column height and calculated muzzle velocities), (3) dispersive power (determined by column height), (4) violence (release rate of kinetic energy, analogous to intensity but for instantaneous rather than sustained eruptions), and (5) destructive potential (the extent of devastation, actual or potential, caused by an eruption). For the estimate of magnitude, Walker proposes to use the scale of *Tsuya* [1955]; for the other parameters, no scales have yet been proposed.

TABLE 2. Numbers of Reported Eruptions by VEI Category, Per Decade, From 1500 to the Present

	VEI								
Decade	0	1	2	3	4	5	6	7	8
1500	0	10	12	1	0	1	0	0	0
1510	0	10	14	4	1	0	0	0	0
1520	1	10	26	5	1	0	0	0	0
1530	10	12	23	8	1	0	0	0	0
1540	11	11	7	6	0	0	0	0	0
1550	10	12	7	7	0	0	0	0	0
1560	10	21	9	11	1	0	0	0	0
1570	2	22	7	7	1	0	0	0	0
1580	1	21	18	13	1	0	0	0	0
1590	0	20	20	10	3	0	0	0	0
1600	0	23	16	7	1	0	0	0	0
1610	0	27	11	8	0	0	0	0	0
1620	0	26	4	5	0	0	0	0	0
1630	1	25	11	8	2	0	0	0	0
1640	0	28	23	14	2	1	0	0	0
1650	2	26	18	14	0	0	0	0	0
1660	0	20	21	15	2	2	0	0	0
1670	2	20	47	12	2	0	0	0	0
1680	1	22	35	15	2	0	0	0	0
1690	0	20	32	20	2	0	0	0	0
1700	5	20	29	5	1	1	0	0	0
1710	1	24	26	9	1	0	0	0	0
1720	5	23	42	7	2	0	0	0	0
1730	4	21	42	13	0	1	0	0	0
1740	1	20	47	2	2	0	0	0	0
1750	3	20	74	2	1	1	0	0	0
1760	5	12	96	6	5	0	0	0	0
1770	6	8	108	9	2	0	0	0	0
1780	7	11	111	6	4	0	0	0	0
1790	16	12	105	7	3	0	0	0	0
1800	4	18	122	5	1	0	0	0	0
1810	3	23	129	8	4	0	0	1	0
1820	12	22	154	11	2	1	0	0	0
1830	17	13	172	11	0	1	0	0	0
1840	23	13	182	11	2	0	0	0	0
1850	27	12	213	17	2	1	0	0	0
1860	30	14	207	10	1	0	0	0	0
1870	33	23	185	13	4	1	0	0	0
1880	38	29	225	18	5	1	1	0	0
1890	19	42	227	12	1	0	0	0	0
1900	34	36	306	21	8	1	1	0	0
1910	26	35	231	19	7	0	1	0	0
1920	32	63	299	13	3	0	0	0	0
1930	31	46	256	23	3	1	0	0	0
1940	25	37	261	30	3	0	0	0	0
1950	51	76	345	40	5	1	0	0	0
1960	69	76	287	81	7	0	0	0	0
1970	104	110	304	67	5	0	0	0	0

Reporting has improved markedly in recent decades, especially for smaller eruptions. See note in text (section 3) regarding counting conventions.

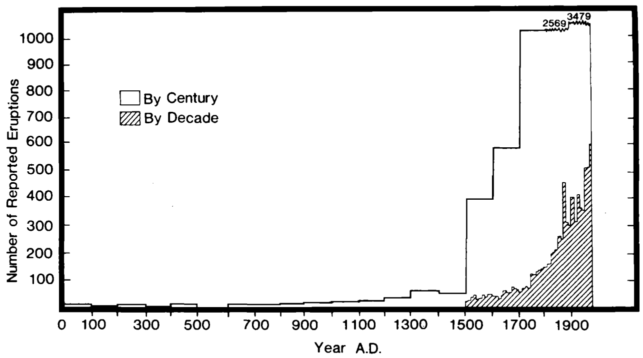

Fig. 1. Total numbers of reported eruptions (VEI 0–8) with time, including reported eruptions for which a VEI has not been assigned due to lack of data. Explanations and implications of apparent trends are discussed in the text. See note in text (section 3) regarding counting conventions.

The Volcanological Society of Japan made suggestions for data to be gathered at modern eruptions and included those data needed for estimating these parameters. However, when one examines the historical record of volcanism, there are but a handful of eruptions (less than 20 out of the more than 122 largest eruptions since 1500) for which the same data is available. A few historical reports contain some but not all of the necessary data; most contain only a brief and often ambiguous description of the eruptions, e.g., 'violent explosions,' 'terrifying darkness,' 'flames and smoke,' or simply 'active.' Some eruptions reports even in recent years have proven to be false, e.g., a reported major eruption on Pagan Island (Marianas) on May 23, 1966, was later shown to have been a grass fire! This is a critical point: the historical record of volcanism contains very little information on which one can base a quantitative estmate of eruption scale. We believe that workers using *Lamb*'s [1970] list are working with derivative numbers much more quantitative than the basic data justify. Lamb noted the limitations of his estimates, but many workers continue to use these estimates without due caution. Furthermore, deposits of all but a handful of the very biggest eruptions are now eroded away or mixed in with sediments beyond the point of recognition. Thus it will be impossible to build a quantitative data base post facto for most eruptions. Certainly it will be impossible to estimate post facto the five parameters of *Walker* [1980] for more than this handful of exceptionally large and/or well-described eruptions.

3. THE VEI: A NEW INDEX OF THE SCALE OF EXPLOSIVE ERUPTIONS

Given inadequacy of the historic volcanic record for estimating specific measures of explosive activity [cf. *Walker*, 1980] but need in various disciplines for some evaluation of past volcanism, we have designed a composite estimate of explosivity using all available data. We have restricted ourselves to consideration of volcanological data (no atmospheric data), but have attempted to stretch that data with a knowledge of volcanic behavior in many regions, so that it might reach far enough back in time to be useful in both studies of climate change and studies of the recurrence frequencies of various types of volcanic activity.

The volcanic explosivity index (VEI) is a general indicator of the explosive character of an eruption. It is a composite estimate of Walker's magnitude and/or intensity and/or destructiveness and/or (less frequently) dispersive power, violence, and energy release rate, depending on which data were available. Eruptions can be assigned a VEI on a scale of 0 to 8 (the maximum number of categories we could realistically distinguish), using one or more of the criteria in Table 1. Criteria are listed in this table in decreasing order of reliability and discriminating power. The overlapping ranges between column heights, descriptive terms, and blast durations of successive VEI values reflect interplay between the intensity, magnitude, and rate of energy release during an eruption.

From the viewpoint of those interested in the effects of eruptions on the stratospheric aerosol layer, no corrections have been made at this stage for latitude or elevation of the source vent. Although these parameters will clearly affect the chances of gas and dust being injected in the stratosphere where it will have more potential effect on radiation, the effect of a lower tropopause at high latitudes may be counterbalanced by the relatively restricted areal (latitudinal) dispersion of aerosol at those same latitudes [*Lamb*, 1970; *Cadle et al.*, 1976]. Neither does the VEI attempt to distinguish between different types of injection to the atmosphere, e.g., injections with different amounts of sulfate aerosol, different particle size distributions, and so on. This information is only now becoming available for well-studied eruptions. Since the abundance of sulfate aerosol is important in climate problems [*Pollack et al.*, 1976; *Self et al.*,

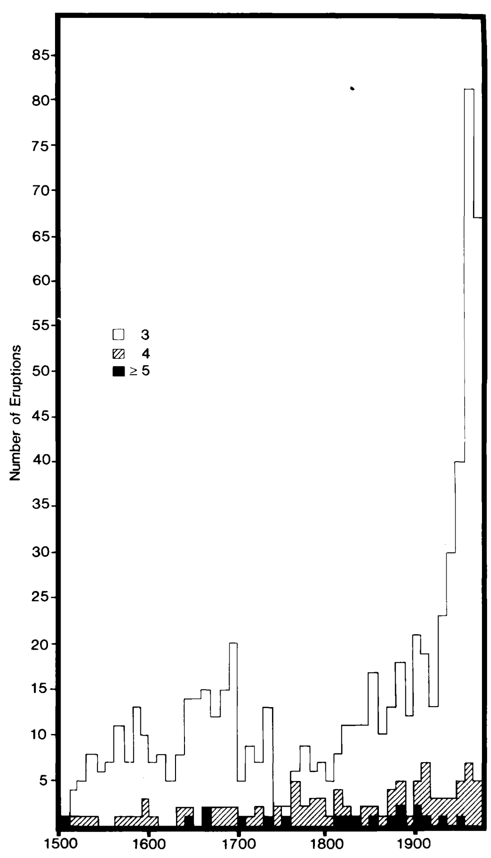

Fig. 2. Numbers of reported VEI 3, 4, and greater than or equal to 5 eruptions since 1500. The reported frequency of moderately explosive eruptions (VEI 3) has increased sharply while that of larger, highly explosive eruptions (VEI greater than or equal to 4) has increased only slightly. See note in text (section 3) regarding counting conventions.

1981], VEI's must be combined with a compositional factor before use in such studies.

We have estimated VEI's for over 8000 eruptions and present these in Simkin et al. (in press). A summary of this data is given in Table 2, and graphical summaries of the numbers of eruptions in each VEI category are shown in Figures 1 and 2. A list of those eruptions with VEI 4 or greater is given in Table 3, for comparison with other lists of major explosive eruptions. In order to provide an overview of activity in any given year or decade, eruptions that continued from one year into the next are counted once for each year they continued. For different purposes, it is desirable to count a long-continued eruption only once [cf. *Simkin et al.*, 1981].

Two conventions have been used in estimating VEI which might lead to erroneous or unsupportable conclusions unless they are recognized:

1. Whenever an explosion (magmatic or phreatic) has been indicated without any further description, a default VEI of 2 has been assigned (for early eruptions, see the second convention, below). There are, as a result, many more VEI 2's than any other VEI value. This is partly an artifact of the default assumption, creating a relatively wide range of characteristics for a VEI = 2 eruption, partly an artifact of reporting (in which very small eruptions may not be reported), and perhaps also an actual relative abundance of VEI = 2 eruptions over all others.

2. A correction has been made for the inevitable decrease in the quality and completeness of data back in time. There is a certain time in every region before which the completeness of the data decreases markedly [see also *Lamb*, 1970] and thus reports which have survived from before that time may indicate relatively more important eruptions. For example, an explosion reported from Melanesia in 1500 A.D. is likely to have been stronger than an explosion reported from the same region today. To counteract such an imbalance, all VEI values 1 through 4 prior to a certain date in each region have been upgraded by 1 VEI unit unless there is other contradicting information. For the purposes of this study, estimates were made of the current frequency of eruptions in each region and of the date before which the reported frequency was much lower than at at present. In general the date of 1700 A.D. has been used, except in Iceland, Japan, Greece, and Italy (1000 A.D.), parts of Central America and Mexico, including Volcán Fuego and Volcán Popcatépetl (1500 A.D.) and Tonga-Kermadec-Samoa, Melanesia, and Kamchatka (1800 A.D.). A correction will be necessary for Aleutian eruptions, if and when enough data are collected to estimate VEI values. VEI's which have been upgraded are flagged in the work by *Simkin et al.* [1981] with a plus sign. This correction allows for better comparison of individual eruptions, but the reader is cautioned against using upgraded values in a study of VEI through time, because it will introduce an apparent maximum in VEI 3 and 4 eruptions just before the switchover, (e.g., just before 1700 worldwide).

At the other end of the scale, eruptions in the past few decades have been relatively well-documented. When documentation is better, eruptions of that type which once were given a default VEI = 2 can now be given their proper VEI value, and the general effect is to increase the number of VEI = 3 eruptions. Likewise, an eruption which was known to be stronger than a VEI of 2, but was poorly documented, would likely have been assigned a conservative VEI of 3, but now with better documentation it might be assigned a VEI of 4. Due to this effect, it is sometimes difficult to distinguish earlier (e.g., 1700–1950) VEI 2 and 3 eruptions from present-day VEI 3 and 4 eruptions, respectively.

4. Applications

It is beyond the scope of this paper to attempt to evaluate the frequency of various volcanic events or to discuss the possible effects of volcanism on climate (or vice versa: see *Rampino et al.* [1979]). We would like, though, to show briefly how the VEI can assist in evaluating the completeness of the historical record and thereby assist in assessing the validity of studies utilizing this record.

The simplest way to assess the completeness of the historical record is to prepare histograms of recorded eruptions through time (Figure 1). It is immediately obvious that the number of recorded eruptions has increased dramatically with time. *Simkin et al.* [1977, 1981] discuss the various historical factors affecting the reporting of volcanic eruptions.

The question then becomes, has there been a real increase in the frequency of volcanic eruptions or has improved reporting simply increased the number of reported eruptions? Certainly the latter seems more likely, and the VEI can help us test this hypothesis, because the larger an eruption, the greater likelihood that it would be reported and survive in the annals of history.

Consider first a breakdown of eruptions through recent centuries by VEI (Table 2, Figure 2). The number of relatively small, unremarkable eruptions (VEI = 1, 2) has increased dramatically in recent decades, while the number of large, highly explosive, memorable eruptions (VEI = 3, 4, 5,) has only increased slightly over the past two centuries. This is the pattern one would predict if the overall increase is simply an artifact of improved reporting.

A variety of statistical methods have been used to test for completeness in earthquake catalogues [cf. *Knopoff and Gardner*, 1969; *Stepp*, 1973; *Lee and Brillinger*, 1979; and others], and the same methods can be used with VEI's for historic volcanic eruptions. As one simple guide to the completeness of eruption records, assume that eruptions have a Poisson distribution with mean frequencies in each VEI category equal to the frequencies reported for the 1970's. Thus we assume a mean frequency of 104/decade for VEI 0's, 110/decade for VEI 1's, 304/decade for VEI 2's, 67/decade for VEI 3's, and 82/decade for VEI's greater than or equal to 3. The standard deviation (sd) for each 'mean' is simply the square root of each value, and the 95% confidence interval for each estimate is the mean ± 1.96 sd. For the various scales of eruptions these confidence intervals are, respectively, 104 ± 20/decade (VEI 0), 110 ± 21/decade (VEI 1), 304 ± 34/decade (VEI 2), 67 ± 16/decade (VEI 3), and 82 ± 18/decade (VEI ≥ 3). By this guide, reporting as seen in Table 2 is incomplete for VEI 0's and 1's prior to about 1970, for VEI 2's prior to about 1950 or 1960, and for VEI 3's prior to about 1960. Eruptions with VEI's of 4 or greater are too infrequent to be covered by this guide, but a visual examination of Figure 2 indicates that reporting for these larger eruptions has been more or less complete since the late 1800's. Clearly these are not rigorous tests, because

TABLE 3. Chronological List of Largest Explosive Eruptions Since 1500, VEI Greater Than or Equal to 4

Volcano	Latitude, degrees	Longitude, degrees	Date	Elevation, m	VEI
Hekla	+63.98	−19.70	July 25, 1510	1491	4
Cotopaxi	−0.65	−78.43	June –, 1534	5897	4
St. Helens	+46.20	−122.18	– –, 1540 ± 70	2549	5
Agua de Pau	+37.77	−25.47	June 28, 1563	948	4
San Salvador	+13.74	−89.29	– –, 1575?	1850	4?
Kelut	−7.93	+112.31	– –, 1586	1731	4
Galeras	+1.22	−77.30	Dec. 7, 1590	4482	4
Raung	−8.12	+114.04	– –, 1593	3332	4?
Ruiz	+4.88	−75.37	March 12, 1595	5389	4
Hekla	+63.98	−19.70	June 3, 1597	1491	4
Huaynaputina	+16.58	−70.87	Feb. 19, 1600	4800	4
Furnas	+37.77	−25.32	Sept. 3?, 1630	805	4
Vesuvio	+40.82	+14.43	Dec. 16, 1631	1281	4
Llaima	−38.70	+71.70	Feb. –, 1640	3124	4?
Komaga-take	+42.07	+140.68	July 31, 1640	1140	4
Awu	+3.67	+125.50	Jan. 4, 1641	1320	5?
Guagua Pichincha	−0.17	−78.60	Oct. 27, 1660	4794	4
Quilotoa	−0.85	−78.90	Nov. 28, 1660	3914	4?
Usu	+42.53	+140.83	Aug. 16, 1663	725	5
Tarumai	+42.68	+141.38	Aug. 6, 1667	1024	5
San Salvador	+13.74	−89.29	– –, 1671	1850	4?
Gamkonora	+1.38	+127.52	May 20, 1673	1635	4
Tongkoko	+1.52	+125.20	– –, 1680	1149	4
Iwate	+39.85	+141.00	Feb. 29, 1686	2041	4
Chikurachki	+50.33	+155.47	– –, 1690 ± 10	1817	4
Hekla	+63.98	−19.70	Feb. 13, 1693	1491	4
Long Island	−5.36	+147.12	– –, 1700 ± 100	1304	6
Fuji	+35.35	+138.73	Dec. 16, 1707	3776	4
Chirpoi group	+46.52	+150.88	– –, 1712?	624	4?
Katla	+63.63	−19.03	May 11, 1721	1363	4
Oraefajökull	+64.00	−16.65	Aug. 3, 1727	2119	4
Tarumai	+42.68	+141.38	Aug. –, 1739	1024	5
Oshima-o-shima	+41.50	+139.37	Aug. 23, 1741	714	4
Cotopaxi	−0.65	−78.43	Nov. 11, 1744	5897	4
Katla	+63.63	−19.03	Oct. 17, 1755	1363	5
Jorullo	+19.03	−101.67	Sept. 9, 1759	1330	4
Peteroa	−35.25	−70.57	Dec. 3, 1762	4090	4
Jorullo	+19.03	−101.67	– –, 1764	1330	4
Komagatake	+42.07	+140.68	– –, 1765	1140	4
Hekla	+63.98	−19.70	April 5, 1766	1491	4
Cotopaxi	−0.65	−78.43	April 4, 1768	5897	4
Papandayan	−7.32	+107.73	Aug. 11, 1772	2665	4
Raikoke	+48.25	+153.25	– –, 1778	551	4
Asama	+36.40	+138.53	May 9, 1783	2550	4
Lakagigar	+64.07	−18.25	June 6, 1783	500	4
Asama	+36.40	+138.53	July 26, 1783	2550	4
Alaid	+50.80	+155.50	– –, 1793	2339	4
San Martin	+18.58	−95.17	March 2, 1793	1550	4
Pogromni	+54.57	−164.70	– –, 1795	2286	4
St. Helens	+46.20	−122.18	– –, 1802	2549	4
Soufriére (St. Vincent)	+13.33	−16.18	April 27, 1812	1178	4
Mayon	+13.25	+123.68	Feb. 1, 1814	2462	4
Tambora	−8.25	+118.00	April 5, 1815	2851	7
Beerenberg	+71.08	−8.17	– –, 1818	2277	4
Colima	+19.42	−103.72	Feb. 15, 1818	3960	4
Usu	+42.53	+140.83	March 9, 1822	725	4
Galunggung	−7.25	+108.05	Oct. 8, 1822	2168	5?
Isanotski	+54.75	−163.73	– –, 1825	2480	4
Cosiguina	+12.98	−87.57	June 20, 1835	859	5
Hekla	+63.98	−19.70	Sept. –, 1845	1491	4
Purace	+2.37	−76.38	Dec. –, 1849	4590	4
Chikurachki	+50.33	+155.47	Dec. –, 1853	1817	4
Sheveluch	+56.78	+161.58	Feb. 17, 1854	3395	5
Komagatake	+42.07	+140.68	Sept. 25, 1856	1140	4
Purace	+2.37	−76.38	Oct. 10, 1869	4590	4
Sinarka	+48.87	+154.17	– –, 1872	934	4
Grimsvötn	+64.42	−17.33	Jan. 8, 1873	1719	4
Askja	+65.03	−16.75	March 29, 1875	1510	5

TABLE 3. (Continued)

Volcano	Latitude, degrees	Longitude, degrees	Date	Elevation, m	VEI
Suwanose-Zima	+29.53	+129.72	– –, 1877	799	4
Cotopaxi	−0.65	−78.43	June 25, 1877	5897	4
Nasu	+37.12	+139.97	July 1, 1881	1917	4
Krakatau	−6.10	+105.42	Aug. 26, 1883	300	6
Augustine	+59.37	−153.42	Oct.6, 1883	1227	4
Tungurahua	−1.47	−78.45	June 11, 1886	5016	4
Tarawera	−38.23	+176.51	June 10, 1886	1111	5
Bandai	+37.60	+140.08	July 15, 1888	1819	4
Suwanose-Zima	+29.53	+129.72	Oct. 2, 1889	799	4
Dona Juana	+1.52	−76.93	Nov. 13, 1899	4250	4
Mt. Pelée	+14.82	−61.17	May 2, 1902	1397	4
Soufriére (St. Vincent)	+13.33	−61.18	May 6, 1902	1178	4
Mt. Pelée	+14.82	−61.17	May 8, 1902	1397	4
Santa Maria	+14.75	−91.55	Oct. 24, 1902	2700	6
Thordarhyrna	+64.27	−17.60	May 28, 1903	1660	4
Ksudach	+51.83	+157.52	March 28, 1907	1079	5
Tarumai	+42.68	+141.38	April 12, 1909	1024	4
Taal	+14.00	+121.00	June 27, 1911	300	4
Novarupta (Katmai)	+58.28	−155.17	June 6, 1911	2285	6
Colima	+19.42	−103.72	June 20, 1913	4100	4?
Sakurazima	+31.58	+130.67	June 12, 1914	1118	4
Agrigan	+18.77	+145.67	April 9, 1917	965	4
Tungurahua	−1.47	−78.45	April 4, 1905	5016	4
Katla	+63.63	−19.03	Oct. 12, 1918	1363	4
Manam	−4.10	+145.06	Aug. 11, 1919	1300	4
Puyehue	−40.58	−72.10	Dec. 13, 1921	2240	4
Raikoke	+48.25	+153.25	Feb. 15, 1924	551	4
Komaga-Take	+42.07	+140.68	June 17, 1929	1140	4
Kliuchevskoi	+56.18	+160.78	March 25, 1931	4850	4
Fuego	+14.48	−90.88	Jan. 21, 1932	3763	4
Quizapu (Cerro Azul)	−35.67	−70.77	April 10, 1932	3810	5
Rabaul	−4.27	+152.20	May 29, 1937	229	4?
Kliuchevskoi	+56.18	+160.78	Jan. 1, 1945	4850	4
Sarychev	+48.10	+153.20	Nov. 9, 1946	1497	4
Hekla	+63.98	−19.70	March 29, 1947	1491	4
Lamington	−8.94	+148.17	Jan. 15, 1951	1780	4
Ambryn	−16.25	+168.08	Sept. –, 1951	1334	4
Bagana	−6.14	+155.19	Feb. 29, 1952	1702	4
Mt. Spurr	+61.30	−152.25	July 9, 1953	3375	4
Nilahue	−40.35	−72.07	July 26, 1955	400	4
Bezymianny	+56.07	+160.72	March 30, 1956	2800	5
Agung	−8.34	+115.50	March 17, 1963	3142	4
Sheveluch	+56.78	+161.58	Nov. 12, 1969	3395	4
Taal	+14.00	+121.00	Sept. 28, 1965	300	4
Kelut	−7.93	+112.31	April 26, 1966	1731	4
Oldoinyo Lengai	−2.75	+35.90	Aug. –, 1966	2880	4
Awu	+3.67	+125.50	Aug. 12, 1966	1320	4
Fernandina	−0.37	+91.55	June 11, 1968	1495	4
Tiatia	+44.35	+146.25	July 14, 1973	1822	4
Fuego	+14.48	−90.88	Oct. 10, 1974	3763	4
Plosky Tolbachik	+55.93	+160.47	July 6, 1975	3085	4
Augustine	+59.37	−153.42	Jan. 22, 1976	1227	4
Bezymianny	+56.07	−160.72	Feb. 11, 1979	2800	4
St. Helens	+46.20	−122.18	May 18, 1980	1920	5

Notes: Volcano name is the name generally used for the volcano which produced the eruption, not the name of the individual vent or the eruption itself. Positive latitude is north; negative, south. Positive longitude is east; negative, west. Dashes in the date column indicate unknown months and days. Elevation is from sea level; If the vent was very different in height (e.g., Santa Maria, 1902) from the volcano itself, the vent height is given.

the actual frequencies are not known; rather, these and the simple histograms serve as guides to completeness relative to recent records.

Where decades with incomplete reporting follow decades with what appears to be complete reporting, as for VEI 2 eruptions in the 1900's (possibly complete) and 1910's (incomplete), two explanations are possible. Either the process is not Poissonian, or there was actually a deterioration in reporting. Given the overall suspect nature of the historical record, plus reasonable historical explanations for most of these cases [*Simkin et al.*, 1981] we conclude that reporting has deteriorated on occasion and that for volcanism over the past few centuries at least the Poisson distribution remains the most likely. We do not deny that there may be special peaks or lulls in the record, especially in specific regions, but do note that in most cases of apparent change, reporting is too incomplete to know whether the change is real or not.

To use the VEI in assessing the validity of volcanological or climatological studies, one must ask whether the historical record of volcanism is reasonably complete for the time span and purposes of each study. A simple test such as that described above enables one to determine the period for which the record is complete (or, strictly speaking, for which the record is as complete as it has ever been). For example, the set of eruptions which needs to be considered for volcano-climate studies is probably the set with VEI's greater than or equal to 3, from 1755 to the present. From the above, the reporting of VEI = 3 eruptions is incomplete prior to 1960, and therefore the data set in consideration is incomplete prior to about 1960.

5. Summary

The preceding discussion has a dual purpose. It is meant to introduce the VEI as a useful tool for comparing the relative explosivity of historic eruptions and to illustrate applications of the VEI to studies utilizing the historical record of volcanism. In these applications, one message is clear: the historical record is generally incomplete. The VEI can help detect incompleteness and reporting biases and can help one select subsets of the historical record suitable for each study. We would like to be more optimistic and propose a fully quantitative VEI, but we conclude that for the present a more immediate need is to improve the raw quantitative data that we gather on eruptions. For historic explosive volcanism we will have to turn not only to conventional historic reports and the near-volcano geologic record, but also toward new techniques (such as ice core analysis, cf. *Hammer et al.* [1980]). An even more promising direction is toward better reporting in the future. More quantitative descriptions of future eruptions will aid not only in their classification, but also in suggesting the best parameters to search for in the records of past eruptions.

Acknowledgments. We thank Robert W. Decker, who suggested that a simple scale for eruptions be devised, and we thank Tom Simkin, Michael Rampino, Richard E. Stoiber, and Lee Siebert for their help throughout this project. Computer time was provided by the Kiewit Computation Center, Dartmouth College. This work was performed under NASA Grant NSG5145.

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(Received June 1, 1981;
revised August 24, 1981;
accepted August 24, 1981.)