Blake, D. H., et al. (1965). "Some relationships resulting from the intimate association of acid and basic magmas." Quarterly Journal of the Geological Society **121**(1-4): 31-49.

Evidence is presented from Guernsey, Iceland, Ireland, and Scotland that basic and acid magmas have commonly come together. Examples of this are found in surface extrusions and tuffs and in intrusions of various sizes formed at different depths. The basic magma has commonly been chilled against the acid, and the relationships indicate that the acid component was highly mobile; these two facts are thought to be intimately related, in that the mobility of the acid magma is due to the transfer of heat from the basic magma.Consequences discussed include the question of the relative age of contiguous intrusions where basic rock is veined by acid: the age-sequence may be the reverse of that normally postulated. The possibility is also considered that basic magma may occasionally be necessary for the uprise of acid magma to high crustal levels.

Blake, S., et al. (1992). "Petrology and Dynamics of the Waimihia Mixed Magma Eruption, Taupo Volcano, New-Zealand." Journal of the Geological Society **149**: 193-207.

The Waimihia pumice deposit was erupted from Taupo volcano about 3.3 ka BP. It comprises a plinian tephra fall deposit divisible into two volumetrically subequal fall units and a late-stage, volume-trically minor, near-vent ignimbrite. About 7.5km3 of magma were erupted at an average rate of c. 8 X 10(8) kg s-1. Whole rock, glass and mineral compositions define three crystal-poor magma types: rhyolite, rhyodacite and andesite. The proportions of the three magmas varies with stratigraphic position in the two fall units. The lower Waimihia fall unit shows a steady upward increase in rhyodacite from < 1 % to 5.5% and a near absence of andesite (< 0.05%). Rhyodacite in the upper Waimihia fall unit decreases upward from 28% to 2% while andesite increases (0.2% to 0.8%) before decreasing (0.3%). The composition of the ignimbrite coincides with that of the top part of the upper fall unit (consistent with its stratigraphic position), suggesting that partial column collapse occurred towards the close of activity. Rhyolite dominates the total Waimihia deposit (c. 92%) and is similar to other post-22 ka Taupo rhyolites in terms of major element, trace element and Sr isotope composition, mineralogy and Fe-Ti oxide temperature and oxygen fugacity. The rhyodacite (c. 7.3%) formed by hybridization of rhyolite and andesite prior to the eruption, and occurs as grey pumices and with rhyolite in streaky pumices. Andesite (c. 0.3%) occurs as black scoria, sometimes containing traces of rhyodacite; it is an unusual high TiO2 tholeiitic andesite whose Sr-84/Sr-86 ratio of 0.7062 is indistinguishable from that of the rhyolite. The heterogeneous pumice and scoria clasts were formed in a second magma mixing process that was active when the magmas were being transported to the surface during the eruption. The order in which the magmas were erupted, and the decoupling of the peaks in rhyodacite and andesite production, are explained by withdrawal from a three-layer sill that had formed following the injection of c. 0. 16 km 3 of andesite into a greater-than-or-similar-to 7.5 km3 sill-shaped rhyolitic magma chamber.

Bodvarsson, G. and G. P. L. Walker (1964). "Crustal drift in Iceland." Geophysical Journal International **8**(3): 285-300.

Booth, B., et al. (1978). "**A quantitative study of five thousand years of volcanism on Sao Miguel, Azores**." Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences **288**(1352): 271-319.

Booth, B., et al. (1975). "Notes on the eruption of Etna in April 1975." United Kingdom Research on Mount Etna. The Royal Society, London: 69-71.

Booth, B. and G. P. L. Walker (1973). "Ash Deposits from New Explosion Crater, Etna 1971." Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences **274**(1238): 147-151.

Canon-Tapia, E., et al. (1994). "Flow Directions and Paleomagnetic Study of Rocks from the Azufre Volcano, Argentina." Journal of Geomagnetism and Geoelectricity **46**(2): 143-159.
Determination of the stable direction of magnetization was made on eight lava flows from the Azufre volcano, Southern Volcanic Zone of the Andes. From these eight paleomagnetic sites, only six independent samples of the geomagnetic field were identified. Combination of these with results of a work made by Creer and Valencio (1969) allowed a better determination of a geomagnetic pole for the Bruhnes chron in this region of the Andes than that previously calculated. The coordinates of the new pole are 87-degrees-N, 236-degrees-E, and have an alpha95 region of confidence of 12-degrees. Statistical comparison of directions of magnetization of groups of flows was used 1) to test the hypothesis of rapid extrusion of flows, and 2) to constrain the age of the lavas sampled in this work to more than 0.4 my. Finally, the utility of the anisotropy of magnetic susceptibility measurements on the determination of flow direction of lava flows was established despite the great scatter on the observations of multiple samples from the same unit. Criteria to determine the size of the region of confidence around the mean maximum susceptibility in order to accept or reject results were developed in analogy with those used in paleomagnetic studies.

Canon-Tapia, E. and G. P. L. Walker (2004). "Global aspects of volcanism: the perspectives of "plate tectonics" and "volcanic systems"." Earth-Science Reviews **66**(1-2): 163-182.
The concept of plate tectonics provides a general framework to fit the distribution and general characteristics of volcanoes. There remain, however, many details of volcanic activity that are difficult to explain solely by this paradigm. For example, plate tectonics predicts that volcanic activity should take place continuously along all convergent and divergent tectonic margins, where in fact we observe a point-like distribution of volcanic centers that does not fit the predictions. Also, it is observed that many volcanoes share common characteristics despite being located in different tectonic settings, while other volcanoes sharing the same tectonic setting display very different behavior. For instance, so far, there is no congruent explanation offered by plate tectonics about why in similar tectonic conditions volcanism is sometimes polygenetic and elsewhere monogenetic.. On the other hand, volcanic activity on a global scale tends to define a series of rules that are independent of the tectonic setting, and therefore should reflect general processes that are not controlled directly by the plate tectonic engine. We show that, by concentrating on the relationship among processes (from the moment of magma generation to the moment of eruption) and by incorporating all of these processes as components of a single system, a coherent picture of volcanism on a global scale emerges and allows us to interpret better many otherwise puzzling aspects of volcanism such as those mentioned above, hence providing a general framework that fills the conceptual gap left between plate tectonics and most (if not all) of the characteristics of volcanic activity at a global scale. (C) 2003 Elsevier B.V All rights reserved.

Canon-Tapia, E., et al. (1995). "Magnetic Fabric and Flow Direction in Basaltic Pahoehoe Lava of Xitle Volcano, Mexico." Journal of Volcanology and Geothermal Research **65**(3-4): 249-263.
We sampled five basaltic lava flow-units from Xitle volcano, Mexico City, to study the variation of anisotropy of magnetic susceptibility within their cooling boundaries. We find that the mean maximum susceptibility parallels the geologically-inferred flow direction in the units that were emplaced on a steeper slope, whereas for those on a negligible slope the mean intermediate susceptibility points in the flow direction. We propose, however, that the maximum

susceptibility always points in the direction of local movement, and that a change in slope produces a deviation of the local motion from that of the unit as a whole. The axis of susceptibility closest to the geologically-inferred flow direction usually plunges upflow in the basal part of the flow unit, comprising an imbrication which clearly marks the flow azimuth of Thus, the scenario of emplacement may influence the results in a predictable way. We suggest that the degree of anisotropy could bear a direct relationship to either the viscosity of the lava, the morphology of the flows or both, based on a comparison with lavas from Azufre (Argentina) and Ko'olau (O'ahu) volcanoes. Also, we suggest that the shape of the susceptibility ellipsoid may be related to the degree of internal deformation of the lava flows. We also compare the two methods currently available to calculate regions of confidence around the mean principal susceptibilities.

Cañón-Tapia, E., et al. (1997). "The internal structure of lava flows—insights from AMS measurements II: Hawaiian pahoehoe, toothpaste lava and'a'ā." Journal of Volcanology and Geothermal Research **76**(1-2): 19-46.

Cañón-Tapia, E., et al. (1996). "The internal structure of lava flows - Insights from AMS measurements .1. Near-vent a'a." Journal of Volcanology and Geothermal Research **70**(1-2): 21-36.
Two small near-vent a'a flows (one from Xitle, Mexico and the other from Mauna Kea, Hawaii) showing a conspicuous pattern of concentric vesicle foliation were used to investigate how anisotropy of magnetic susceptibility (AMS) measurements relates to the internal structure of lava flows. The results show an almost perfect match between the vesicle foliation and the plane containing the maximum and intermediate principal susceptibilities, or plane of magnetic foliation. Both types of foliation can be explained by variations in the relative magnitudes of local shear stresses, assuming a unidirectional velocity within the lava flows. The attitude of the plane of magnetic foliation provides a three-dimensional picture of the dynamic behavior of flowing lava, and might be applicable also in instances when no other foliation is observable. A strong imbrication occurs, marked by the distribution of magnetic foliation parallel to a family of nested cones the axis of which coincides with the flow axis, and the apices of which point down-flow. Flow of lava having, at least in part, a stationary roof and possessing a small yield strength is consistent with the velocity profiles inferred from the orientation of the foliations. A model based on its fluid behavior is proposed to explain the origin of the AMS of lava. At variance with existing qualitative models, our model allows a semi-quantitative systematic explanation of the different circumstances under which any principal susceptibility is parallel to the flow direction.

Clough, B. J., et al. (1981). "An Unusual Bed of Giant Pumice in Mexico." Nature **289**(5793): 49-50.

Clough, B. J., et al. (1982). "Morphology and Dimensions of the Young Comendite Lavas of La-Primavera Volcano, Mexico." Geological Magazine **119**(5): 477-485.

Crandell, D. R., et al. (1984). Source book for volcanic hazards zonation.

Dagley, P., et al. (1967). "Geomagnetic polarity zones for Icelandic lavas." Nature **216**(5110): 25-29.

Francis, P. W., et al. (1974). "The San Pedro and San Pablo volcanoes of northern Chile and their hot avalanche deposits." Geologische Rundschau **63**(1): 357-388.

Froggatt, P. C., et al. (1981). "Orientation of Logs in the Taupo Ignimbrite as an Indicator of Flow Direction and Vent Position." Geology **9**(3): 109-111.

Gale, N. H., et al. (1966). "K-Ar ages of acid intrusive rocks from Iceland." Earth and Planetary Science Letters **1**(5): 284-288.

Gass, I. G. and G. P. L. Walker (1966). "Volcanology Research in New Zealand." Nature **209**(5028): 1077-1078.

Gibson, I. L., et al. (1966). Geology of the Fáskrúdsfjördur Area, Eastern Iceland.

Gibson, I. L. and G. P. L. Walker (1963). "Some composite rhyolite/basalt lavas and related composite dykes in eastern Iceland." Proceedings of the Geologists' Association **74**(3): 301-IN303.
Five composite extrusions are described from the Tertiary volcanic outcrop of eastern Iceland. Each has a lower basic and an upper xenolithic acid component, and the two can be shown to have been erupted essentially simultaneously; three flows are visibly joined, and others can be related, to composite dyke-feeders. The acid components of the lavas are generally rich in basalt xenoliths. Evidence is presented to show that the latter were formed by the inclusion of 'blebs' of basalt magma in the host rhyolite prior to the extrusion of the composite lava. The effect and significance of this is discussed.

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Hall, M. L., et al. (1988). Mapas de los peligros volcanicos potenciales asociados con el Volcán Antisana / Cotopaxi / Cuicocha / Guagua Pichincha / Pululagua / Tunguahua, 1:50.000. Quito, Ecuador, UNDRO-USAID-EPN.

Herrero-Bervera, E., et al. (2003). "Reply to the comment made by Aubourg et al." Journal of Volcanology and Geothermal Research **122**(1-2): 145-148.

Herrero-Bervera, E., et al. (2002). "The Nuuanu and Wailau giant landslides: insights from paleomagnetic and anisotropy of magnetic susceptibility (AMS) studies." Physics of the Earth and Planetary Interiors **129**(1-2): 83-98.
The Koolau volcano on the northeastern flank of the Island of Oahu in Hawaii is the source area for one of the largest landslides on Earth, the Nuuanu debris avalanche. The offshore expression of this slide is an extensive rubbly field of debris extending approximately 230 km from the island across the Hawaiian Deep and onto the Hawaiian Arch. We have studied the subaerial lavas of the Koolau volcano as well as the deep-sea sediments on top of the Nuuanu and Wailau landslides by means of magnetostratigraphy and magnetic anisotropy studies to investigate the volcanic evolution, the plumbing of the Koolau volcano and the timing of the Nuuanu detachment. In addition, we have conducted deep-sea magnetostratigraphic studies of a 20 and 7 in piston core recovered by the RV Kana Keoki and the RV Bertha Ann, as well as three 7 m piston cores recovered by the RV Kairei to understand the origins of the giant landslides. The results derived from these investigations indicate that the plumbing of the Koolau volcano is characterized by a very coherent dike complex and by a high dike injection nature. Parts of the Koolau complex are a sheeted dike swarm as in ophiolites as demonstrated by geologic and anisotropy of magnetic susceptibility (AMS) studies. On the other hand, the magnetostratigraphic results of the subaerial part of the Koolau complex indicate that at least one of the normal Reunion Subchrons (ca. Reunion II 2.15 +/- 0.04 to 2.11 +/- 0.04 Ma) had been registered at two different locations. Deep-sea cores have recorded several reversals. The oldest one is the top of the Olduvai Subchron (ca. 1.78 Ma).

Land and deep-sea paleomagnetic and plumbing investigations indicate that the collapse of the Koolau volcano had to be relatively rapid in a period of less than 0.5 Ma due to forceful injection of dikes associated with extension and gravitational effects. Therefore, the timing of the main collapse of the Koolau volcano that originated the Nuuanu landslide had to occur between 2.1 and 1.78 million years ago based on the magnetostratigraphic evidence. (C) 2002 Elsevier Science B.V. All rights reserved.

Herrero-Bervera, E., et al. (2002). "Magnetic fabrics study and inferred flow directions of lavas of the Old Pali Road, O′ahu, Hawaii." Journal of Volcanology and Geothermal Research **118**(1): 161-171.
A section 600–700 m deep in the Koolau tholeiitic lava-shield volcano consists of mostly thin pahoehoe and aa flows cut by occasional dikes and outward-dipping gravity-driven intrusive sheets. A magnetic fabric study of 250 specimens from 18 sites shows a tight clustering of K1 axes for some of the lava flows and is thought to fairly reliably define the lava flow direction. A systematic plunge of the K1 axes appears to define an imbrication and yields a flow azimuth. The azimuth differs by 60° from that anticipated but is readily explained by a change in shape of the Koolau Volcano during growth. The tightest clustering is in massive aa lava flows 5 m thick. Samples collected from near the flow base give the most consistent orientations. Compound pahoehoe lavas with many small flow units give the least tightly clustered anisotropy of magnetic susceptibility (AMS) axes and, in some flows, the orientation is random. The gravity-driven sheet has an AMS fabric indicating a down-dip magma flow direction. After the Koolau Volcano was deeply eroded, a cinder cone and lava flows of nephelinite were formed in the rejuvenation stage of volcanism. The nephelinite is normally magnetized and the AMS fabric indicates a generally downslope flow.

Herrero-Bervera, E., et al. (2001). "Magnetic fabric and inferred flow direction of dikes, conesheets and sill swarms, Isle of Skye, Scotland." Journal of Volcanology and Geothermal Research **106**(3-4): 195-210.
We have measured the AMS of 16 dikes, 35 conesheets and three sills associated with the Cuillin Hills magmatic center of the Isle of Skye in the Inner Hebrides of Scotland and of nine dikes located in the regional dike swarm of Skye. Sixty-three intrusives, totalling 734 samples, were studied to determine the plumbing of the Skye volcanic system. Low-field susceptibility versus temperature (k-T) identified three different mineral phases in the area, namely Ti-rich magnetite, pyrrhotite and titanomaghemite. The petrofabrics of the 63 intrusives yielded coherent how azimuths regardless of their time of emplacement. Three main types of magnetic fabric, (A-C) were found. Fabric Type A (plane K-max-K-int parallel to the dike plane) represents the magma-flow direction within the intrusives and is the dominant fabric (55% of all the intrusives) within the Cuillin Hills magmatic center and its regional dike swarm. The K-max inclinations show that 55% of the intrusives were fed by horizontal to sub-horizontal (AMS inclination of the K-max axis is equal or less than 30 degrees) magma fluxes and the rest of them were fed by inclined to vertical fluxes. Horizontal magma flow means lateral magma injection inside fractures and becomes more probable as the source is located further away. (C) 2001 Elsevier Science B.V. All rights reserved.

Herrero-Bervera, E., et al. (1999). "Detailed paleomagnetic study of two volcanic polarity transitions recorded in eastern Iceland." Physics of the Earth and Planetary Interiors **115**(2): 119-135.
Two sequences of 45 and 49 individual lava flows respectively have been sampled in eastern Iceland. The two sections range in age from 12.09 to 10.21 Ma as reported by Watkins and Walker [Watkins, N., Walker, G.P.L., 1977. Magnetostratigraphy of eastern Iceland. Am. J. Sci. 277, 513-584.] and are labelled as profiles C and D. Stepwise alternating field (AF) and thermal demagnetizations accompanied by investigations of rock magnetic properties indicate

that the magnetization is primarily carried by titanomagnetite. Demagnetization experiments have identified eight and six transitional lavas, respectively, for these profiles. The transitional virtual geomagnetic poles (VGPs) of the (R-N) profile C reversal are located mainly between Patagonia and Antarctica with a tendency of the virtual poles to move towards west coast of South America, subsequently traveling to the northern hemisphere through several discrete steps located in the middle part of South America, then to west Africa and on to central Asia before the poles settle into normal polarity. The second and younger VGP path corresponding to profile D is a path characterized by a reverse-to-normal-to-reverse (R-N-R) motion of the virtual pores. This path is characterized by poles located in west Antarctica, Patagonia and the western and eastern part of South America. The passage from the southern to the northern hemisphere is also through a discrete sets of steps along the southwestern Pacific followed by a rapid motion to the northern Siberian region, continuing to the western equatorial part of South America before moving on to the central region of Asia, followed by a motion to the western Pacific prior to the final move to the eastern part of Antarctica. The data from eastern Iceland based on highly reliable transitional results, as indicated by the demagnetizations and rock magnetic experiments derived from relatively spaced sites and different ages, seem to indicate that the eastern Icelandic high latitude (66 degrees N) profiles studied have several persistent transitional paleofield features that are uniquely observed at those sites particularly when compared to other volcanic records located at lower latitudes. (C) 1999 Elsevier Science B.V. All rights reserved.

Herrero-Bervera, E., et al. (1996). "Reversal records from Eastern Icelandic lava flows and their geodynamic significance." Surveys in Geophysics **17**(2): 197-206.

Jurado-Chichay, Z., et al. (1996). "The formation of circular littoral cones from tube-fed pahoehoe: Mauna Loa, Hawai'i." Bulletin of Volcanology **57**(7): 471-482.

Pyroclastic cones along the southwest coast of Mauna Loa volcano, Hawai'i, have a common structure: (a) an early formed circular outer rim 200-400 m in diameter composed mostly of scoria and lapilli, and (b) one or more later-formed inner rims composed almost exclusively of dense spatter. The spatter activity locally fed short lava flows that ponded within the outer rims. Based on various lines of evidence, these cones are littoral in origin: relationships between the cones and associated flows; the degassed nature of the pyroclasts; and (although not unequivocal) the position of the cones relative to known eruptive vent locations on Mauna Loa. Additional support for the littoral interpretation comes from their similarity to (smaller) littoral cones that have been observed forming during the ongoing Kilauea eruption. The structure of these Mauna Loa cones, however, contrasts with that of "standard" Hawaiian littoral cones in that there is (or once was) a complete circle of pyroclastic deposits. Furthermore, they are large even though associated with tube-fed pahoehoe flows instead of 'a'(a) over bar. The following origin is proposed: An initial now of tube-fed pahoehoe into the ocean built a lava delta with a base of hyaloclastite. Collapse of an inland portion of the active tube into the underlying wet hyaloclastites or a water-filled void allowed sufficient mixing of water and liquid lava to generate strong explosions. These explosions broke through the top of the flow and built up the outer scoria/lapilli rims on the solid carapace of the lava delta. Eventually, the supply of water diminished, the explosions declined in intensity to spattering, and the initial rim was filled with spatter and lava.

Jurado-Chichay, Z. and G. P. L. Walker (2000). "Stratigraphy and dispersal of the Mangaone Subgroup pyroclastic deposits, Okataina Volcanic Centre, New Zealand." Journal of Volcanology and Geothermal Research **104**(1-4): 319-383.

The Mangaone Subgroup from the Okataina Volcanic Centre consists of silicic plinian pyroclastic units that lie between the Oruanui deposit from the Taupo Volcanic Centre (corrected C-14 calendar age = 26.5 ka) and the Rotoiti (flow)Rotoehu (fall) deposits from Okataina Volcanic Centre (K-Ar age = 64 ka). In this study we present a new stratigraphy for the subgroup that is significantly revised from the earlier work and was developed after extensive held mapping and laboratory study. We now recognize and describe a total of 12 rhyolitic units las opposed to the 8 that had been recognized previously), with a total bulk eruptive volume of approximately 81 km(3). The vents for all the Mangaone Subgroup units were within the Haroharo caldera and possibly migrated through time, first within a roughly north-south trending zone in the central part of the caldera and then toward the eastern part of the caldera. We present new radiometric ages suggesting that the whole sequence was erupted in a relatively short time span (possibly 10-15 ka). Our findings of more eruptions in a shorter time span than in previous work underscores the utility of detailed field studies, particularly when volcanic hazards are being assessed. All the fall units have plinian dispersals but show various degrees of magma-water interaction. The majority of the eruptions were large and intense enough to generate pyroclastic flows, yet flows were observed in only 2 units and is volumetrically small. (C) 2000 Elsevier Science B.V. All rights reserved.

Jurado-Chichay, Z. and G. P. L. Walker (2001). "Variability of plinian fall deposits: examples from Okataina Volcanic Centre, New Zealand." Journal of Volcanology and Geothermal Research **111**(1-4): 239-263.

Plinian eruptions are intense, sustained, open-vent volcanic outbursts that produce extensive beds of generally well-sorted and generally highly vesicular pumice fallen from eruption plumes up to 55 km high. Their deposits tend to be almost homogeneous throughout their thickness, although inverse grading commonly occurs. Here, we detail departures from this near homogeneity that we observed among the Mangaone Subgroup, a group of 12 plinian pumice-fall deposits from Okataina Volcanic Centre (one of the dormant rhyolitic volcanoes in the Taupe Volcanic Zone, New Zealand). We propose that plinian eruptions may pass through seven states, ranging from inception (commencement of activity, or renewed activity following a shutdown), waxing, steady discharge, climax, and waning leading to column collapse or shutdown (decrease to zero intensity). Some deposits include intercalated water-flushed ash-rich beds having a bimodal grain size. Other examples of non-homogeneity include phreatoplinian ashes that may alternate with the plinian pumice as though modulated by a delicate balance in water flux, and still other eruptions may switch completely from dry to wet conditions when the column wanes towards the latest stages of the eruptions. Pink pumice occurs in some deposits and is totally absent in others. We infer that it oxidized during temporary storage in or around the vent. Lithics are ubiquitous, and concentrations of them may indicate vent-wall collapses and explosive ejection of some of the resulting debris. Some lithic-rich horizons neither coincide with apparent variations in the plinian discharge nor interrupt it, as is the case with some rain-flushed bimodal beds. The events that produced these incongruent beds proceeded synchronously with, but independent of, the main plinian discharge, in an isolated portion of the vent system (such as a subsidiary vent). Other variations of density, vesicularity and crystallinity among the eruption products record the pre- and syn-eruptive history of the magma. A local inverse relationship between pumice density and crystallinity of one eruptive unit is inferred to reflect a control by crystals on vesiculation and fragmentation. (C) 2001 Elsevier Science B.V. All rights reserved.

Jurado-Chichay, Z. and G. P. L. Walker (2001). "The intensity and magnitude of the Mangaone subgroup plinian eruptions from Okataina Volcanic Centre, New Zealand." Journal of Volcanology and Geothermal Research **111**(1-4): 219-237.

The rhyolitic Okataina Volcanic Centre in the TVZ experienced 12 plinian eruptions in the period between 31 and similar to43 ka and their deposits are known as the Mangaone Subgroup. These pyroclastic deposits total 77 km(3). The mean Mangaone eruption volume is 6.0 km(3), although erupted volumes alternate between large and small throughout the subgroup and are nearly bimodal (42% are <0.5 km(3) DRE, and the remaining 58% are greater). Peak eruption intensities (mass discharge rates) of most of the plinian eruptions have been determined from lithic size distributions and theoretical models of pyroclast fallout from eruption plumes. Values range over more than an order of magnitude, from 6.2 x 10(7) to 3.9 x 10(8) kg s(-1). The total erupted masses (or 'magnitudes') of the units varies over a range of a factor of 60, from 2.5 x 10(11) to 1.5 x 10(13) kg. There is no apparent correlation between eruption intensities and the presence of pyroclastic flows: only two of the seven deposits with intensities >10(8) kg s(-1) have associated pyroclastic flows. There is a positive correlation between the intensity and the magnitude of the eruption, supporting previous models that suggest that intensity is positively related to the size of the magma chamber feeding the eruption. When compared with plinian eruptions from other volcanoes, the Mangaone Subgroup deposits fali in the middle of both the magnitude and intensity ranges, although they tend to have somewhat higher intensities at a given mass. Some deposits present inverse grading due to an increase in the eruption intensity as the eruption progressed. We examined temporal variations in column height and intensities in two of the 12 eruptions (units D and F) in detail using individual beds that represent successive chronostratigraphic levels. Minimum eruption durations were estimated for all units from modelled whole-deposit isopach data and compared with those from the individual beds of units D and F; the latter appear to result in more realistic eruption durations. The biggest of the Mangaone Subgroup eruptions had relatively high destructive potentials (areas up to 4200 km(2) were buried beneath 1 m of pumice fall). Eruptions like those occurring today could also pose a hazard to major population centres if the wind dispersed them towards such centres. (C) 2001 Elsevier Science B.V. All rights reserved.

Jurado-Chichay, Z. and G. P. L. Walker (2002). "Erratum to: "The intensity and magnitude of the Mangaone subgroup plinian eruptions from Okataina Volcanic Centre, New Zealand" (vol 111, pg 219, 2001)." Journal of Volcanology and Geothermal Research **116**(3-4): 361-362.

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Moberly, R. and G. P. L. Walker (1987). Coastal and volcanic geology of the Hanauma Bay area, Oahu, Hawaii. Cordilleran Section of the Geological Society of America. M. L. Hill, Geological Society of America. **1:** 5-10.
The Hanauma Bay-Koko Fissure area occupies the southeastern tip of the island of Oahu, Hawaii (Fig. 1), and is shown on the Koko Head 71/2-minute Quadrangle. The Geologic Map of Oahu (1:62,500; Stearns, 1939) is out of print. A 1:500,000 colored geologic map of the state and generalized chart shows the Honolulu and Koolau volcanic groups-relative to other rock units (Bennison, 1974).Access is easy by automobile. Buses of No. 1 route, marked “Lunalilo Home Road,” give frequent service from Honolulu to the Lunalilo Home Road point described below as mileage point zero. Buses of No. 58 route travel from Waikiki to that point. Traffic on the winding, narrow highway between stops 2 and 4 demands caution as does high surf on the seacliff. The area is within a park offering generally free access.

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Rowland, S. K. and G. P. L. Walker (1987). "Toothpaste lava: Characteristics and origin of a lava structural type transitional between pahoehoe and aa." Bulletin of Volcanology **49**(4): 631-641.
Toothpaste lava, an important basalt structural type which illustrates the transition from pahoehoe to aa, is particularly well displayed on the 1960 Kapoho lava of Kilauea Volcano. Its transitional features stem from a viscosity higher than that of pahoehoe and a rate of flow slower than that of aa. Viscosity can be quantified by the limited settling of olivine phenocrysts and rate of flow by field observations related to the low-angle slope on which the lava flowed. Much can be learned about the viscosity, rheologic condition, and flow velocity of lavas long after solidification by analyses of their structural characteristics, and it is possible to make at least a semiquantitative assessment of the numerical values of these parameters.

Rowland, S. K. and G. P. L. Walker (1988). "Mafic-Crystal Distributions, Viscosities, and Lava Structures of Some Hawaiian Lava Flows." Journal of Volcanology and Geothermal Research **35**(1-2): 55-66.

Rowland, S. K. and G. P. L. Walker (1990). "Pahoehoe and Aa in Hawaii - Volumetric Flow-Rate Controls the Lava Structure." Bulletin of Volcanology **52**(8): 615-628.

Self, S., et al. (1974). "1973 Heimaey Strombolian Scoria Deposit, Iceland." Geological Magazine **3**(6): 539-548.

Self, S., et al. (1996). "A new model for the emplacement of Columbia River Basalts as large, inflated pahoehoe lava flow fields." Geophysical Research Letters **23**(19): 2689-2692.
Extensive flows of the Columbia River Basalt (CRB) Group in Washington, Oregon, and Idaho are dominantly inflated compound pahoehoe sheet lavas. Early studies recognized that CRB lavas are compound pahoehoe flows, with textures suggesting low flow velocities, but it was thought that the great thickness and extent of the major flows required very rapid emplacement as turbulent floods of lava over a period of days or weeks. However, small volume (<1 km(3)) compound pahoehoe flows on Kilauea, Hawai'i, demonstrate that such flows can thicken by at least an order of magnitude through gradual inflation and the same mechanism has been proposed for larger (10-20 km(3)) pahoehoe flows in Iceland. The vertical distribution of vesicles and other morphologic features within CRB lava flows indicate that they grew similarly by inflation. Small pahoehoe lobes at the base and top of many CRB pahoehoe lava flows indicate emplacement in a gradual, piecemeal manner rather than as a single flood. We propose that each thick CRB sheet flow was active for months to years and that each group of flows produced by a single eruption (a flow field) was emplaced slowly over many years.

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Sparks, R. S. J., et al. (1973). "Products of ignimbrite eruptions." Geology **1**(3): 115-118.

Sparks, R. S. J. and G. P. L. Walker (1973). "Ground Surge Deposit - Third Type of Pyroclastic Rock." Nature-Physical Science **241**(107): 62-64.

Sparks, R. S. J. and G. P. L. Walker (1977). "Significance of Vitric-Enriched Air-Fall Ashes Associated with Crystal-Enriched Ignimbrites." Journal of Volcanology and Geothermal Research **2**(4): 329-341.

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Wadge, G., et al. (1975). "Output of Etna Volcano." Nature **255**(5507): 385-387.

Walker, G. P. L. (1948). "A Preliminary Note on the Metamorphic Rocks of the Portmuck Area, Islandmagee, County Antrim." The Irish Naturalists' Journal: 165-168.

Walker, G. P. L. (1951). "The amygdale minerals in the Tertiary lavas of Ireland. I. The distribution of chabazite habits and zeolites in the Garron plateau area, County Antrim." Mineralogical Magazine and Journal of the Mineralogical Society **29**(215): 773-791.
The origin of the zeolites and associated minerals in vesicles in lavas is a subject on which there is considerable difference of opinion. In general there are two main views: that they are due to the action of percolating surface waters upon thc original minerals of the rock; or are associated with some stage of the cooling processes, as an after-effect of volcanism.

Walker, G. P. L. (1958). "Geology of the Reydarfjordur area, Eastern Iceland." Quarterly Journal of the Geological Society **114**(1-4): 367-393.
A succession of nearly 15,000 feet of volcanic rocks, mostly plateau-basalt lavas, is described from the Reydarfjordur area. This area is in the middle of the large Tertiary outcrop of eastern Iceland, and the rocks described constitute the lower parts of the exposed succession there. They dip uniformly west-south-west at 3-7 degrees. Tholeiites, olivine-basalts, and porphyritic basalts rich in phenocrysts of basic plagioclase make up the bulk of the lava pile, and there is little sign of any systematic distribution of these types. Lavas of a particular type tend to form groups of flows, and these can be readily mapped in the field and clearly have a wide horizontal extension. Two long periods of acid volcanism are distinguished, both having given rise to a considerable bulk of acid and intermediate lavas and pyroclastic rocks. Two more acid volcanic episodes are represented in the mapped ground by acid tuffs, and a fifth is represented by the copious outpourings of acid and intermediate lavas and pyroclasts of the Thingmuli central volcano which was later built on the platform of plateau lavas described in this paper. The bulk of the lavas are regarded as the product of fissure eruption, and two examples have been found of a lava connected to its dyke feeder. The dyke swarm in the area is estimated to contain over 500 dykes, mostly basic, with a general northerly trend.

Walker, G. P. L. (1959). "Some observations on the Antrim basalts and associated dolerite intrusions." Proceedings of the Geologists' Association **70**(2): 179-205.

Walker, G. P. L. (1959). "The amygdale minerals in the Tertiary lavas of Ireland. II. The distribution of gmelinite." Mineralogical magazine and journal of the Mineralogical Society **32**(246): 202-217.

Walker, G. P. L. (1960). "The amygdale minerals in the Tertiary lavas of Ireland. IV. The crystal habit of calcite." Mineralogical magazine and journal of the Mineralogical Society **32**(251): 609-618.

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Walker, G. P. L. (1960). "Zeolite Zones and Dike Distribution in Relation to the Structure of the Basalts of Eastern Iceland." The Journal of Geology **68**(5): 515-528.
Amygdale minerals in the Tertiary basalt lavas of eastern Iceland have a well-marked zonal distribution; the flat-lying zones mapped in the field bear no relationship to the lava stratigraphy and are inferred to be approximately parallel to the original top of the lava pile. An independent method of deducing the position of this is available, depending on the fact that the intensity of the Tertiary dike swarm in the area everywhere diminishes upward; extrapolation gives the altitude of zero intensity, which is in good agreement with the altitude of the original top of the lavas deduced from the mineral zones. Both support the observation that the lavas thin up-dip, and the implications of this on the interpretation of the structure and geology of Iceland are discussed.

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Walker, G. P. L. (1962). "Low-potash gismondine from Ireland and Iceland." Mineralogical Magazine and Journal of the Mineralogical Society **33**(258): 187-201.

Walker, G. P. L. (1962). "Tertiary welded tuffs in Eastern Iceland." Quarterly Journal of the Geological Society **118**(1-4): 275-290.

The welded acid tuffs that are a minor constituent of the volcanic pile are hard felsitic rocks, usually highly vesicular, with a basal glassy layer. They usually have the characteristic microtexture of welded tuffs, but field criteria are more reliable in distinguishing them from lavas and non-welded tuffs. An isopach map is given of the Skessa tuff, which is the product of a single subaerial eruption. The original extent of the welded parts of this tuff is estimated to have been 100 square miles, and its average thickness 25 to 30 feet ; peripheral outcrops are not welded, and cover an additional 70 square miles. In the welded parts the tuff particles were deformed, roughly aligned, and welded together under their own weight and momentum and the accumulated tuff remained plastic long enough for vesicles to form.A classification of tuff deposits into five grades is proposed which is based on the plasticity and temperature of the tuff particles. The Skessa tuff is a representative of the rather rare grade in which the particles had the highest plasticity and, presumably, temperature. Bubbles of basaltic glass that occur in the tuff appear to indicate simultaneous eruption of acid and basic magma.

Walker, G. P. L. (1963). "The Breiddalur central volcano, eastern Iceland." Quarterly Journal of the Geological Society **119**(1-4): 29-63.

The Tertiary central volcano of Breiddalur, the first to be described of several--perhaps many--such volcanoes in Iceland, has a volume of about 100 cubic miles of basic, intermediate, and acid lavas and pyroclastic rocks, with a maximum thickness of 5000 to 6000 ft. The basic lavas are unusually thin owing to the fact that they were erupted on a sloping surface. The central volcanicity contrasts with the flood-basalt fissure-eruptions of the surrounding country; at times the volcano stood up as a co ne above the flood-basalt plains, but flood-basalts were all the time being erupted; they were interdigitated with the products of the volcano (so strikingly that the term cedar-tree volcano' seems appropriate), and later completely buried it. The core of the volcano is marked by a profusion of acid lavas, pyroclastic rocks, and minor intrusions; in it the rocks are drastically altered and show variable and sometimes abnormally high dips indicative of cauldron-sub- sidence. A swarm of dykes locally constituting as much as 20 per cent of the country passes through the core. The rocks above the core probably in part occupy a crater or caldera; they include agglomerate containing blocks of granophyre, granite, and gabbro from inferred syngenetic intrusions below the volcano; a palagonite-tuff and breccia with basalt pillows, probably form- ed in a crater lake; two welded acid tufts; and a thick rhyolite flow joined to its plug-feeder. Acid rocks are mostly concentrated in or near the core, except for a spectacular group of parasitic rhyolites in which all stages in uncovering of the plug-feeders by erosion are seen. Simultaneous eruption of basic and acid magma from the same orifice is evidenced by one rock, which represents an emulsion of the two magmas, and also by a composite lava, with basic and acid components, which was erupted from a composite dyke.

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Walker, G. P. L. (1965). "Some aspects of Quaternary volcanism in Iceland." Trans. Leicester Liter. & Phil. Soc. **59**: 25-39.

Walker, G. P. L. (1966). "Acid volcanic rocks in Iceland." Bulletin Volcanologique **29**(1): 375-402.
Acid rocks make up about 10% of the whole Tertiary volcanic pile in eastern Iceland, or some 800 km1 of rocks between sea level and the summit level. Approximately half are extrusive flows, which range in form from steep-sided domes to tabular flows and have individual volumes of up to 2.5 km1. Most of the other half consists of acid pyroclastic rocks, in which ignimbrites (pyroclastic flow deposits) and air-fall tuffs or agglomerates are equally abundant. Composite lavas and mix-lavas, in which basic and acid magmas were erupted together, are common and so are the corresponding minor intrusions and pyroclastic rocks.

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Walker, G. P. L. (1967). "Volcanics of Eastern Iceland." Spectrum **December**: 9-13.

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Walker, G. P. L. (1970). "Climate Accidents in Landscape-Making and Volcanoes as Landscape Forms - Cotton, CA." Geographical Journal **136**(Dec): 633-634.

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Walker, G. P. L. (1973). "Volcanoes and Man." Royal School of Mines Journal **22**: 29-35.

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Walker, G. P. L. (1975). "Intrusive sheet swarms and the identity of Crustal Layer 3 in Iceland." Journal of the Geological Society **131**(2): 143.

The remarkable swarm of inclined basic intrusive sheets found in the deeply dissected part of SE Iceland is believed to constitute part of a widespread layer which, in other parts of the country, occurs below sea level as the 6.35 km s^{-1} crustal layer revealed by seismic refraction studies. A simple mechanism for the generation of the sheet swarm is proposed, based on the contrasted density gradients of crust and uprising magma: basic magma rises to the surface when its density is everywhere less than the bulk density of the rocks it cuts, otherwise it is often diverted laterally to form an intrusive sheet where its density equals that of the country rock. Once initiated, density relations in the crust are such that the swarm is strongly self-perpetuating in nature. It is believed that more than half of the uprising magma in Iceland has been so diverted to form the sheet swarm. One corollary is that the crust in Iceland “filters” the magmas entering it so that only the lighter or those which rise at a high volumetric rate succeed in passing through to the surface. Confluent sheet gabbro intrusions may develop when the frequency of uprise of magma batches is high. Sheet swarm cupolas or perched swarms also occur in central volcanoes, in which the low-density acid volcanic rocks “capture” uprising magmas.

Walker, G. P. L. (1975). "Excess Spreading Axes and Spreading Rate in Iceland." Nature **255**(5508): 468-471.

Walker, G. P. L. (1975). "A new concept of the evolution of the British Tertiary intrusive centres." Journal of the Geological Society **131**(2): 121-141.

Walker, G. P. L. (1975). "Birth of an island. Review of Surtsey: Evolution of life on a volcanic island by Sturla Friðriksson." New Scientist **67**(959): 222.

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Walker, G. P. L. (1979). "Volcanic Ash Generated by Explosions Where Ignimbrite Entered the Sea." Nature **281**(5733): 642-646.

Walker, G. P. L. (1980). "The Taupo Pumice - Product of the Most Powerful Known (Ultraplinian) Eruption." Journal of Volcanology and Geothermal Research **8**(1): 69-94.

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Walker, G. P. L. (1987). "Pipe Vesicles in Hawaiian Basaltic Lavas - Their Origin and Potential as Paleoslope Indicators." Geology **15**(1): 84-87.

Walker, G. P. L. (1987). The dike complex of Koolau volcano, Oahu: internal structure of a Hawaiian rift zone. Volcanism in Hawaii. R. W. Decker, T. L. Wright and P. H. Stauffer, U.S. Geological Survey Professional Paper **1350:** 961-993.

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Walker, G. P. L. (1988). Entries: "Palagonite" and "Explosive volcanic eruptions classification". The Encyclopedia of Igneous and Metamorphic Petrology. D. R. Bowes. New York, Van Reinhold.

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Walker, G. P. L. (1989). "Spongy Pahoehoe in Hawaii - a Study of Vesicle-Distribution Patterns in Basalt and Their Significance." Bulletin of Volcanology **51**(3): 199-209.

Walker, G. P. L. (1990). Modern volcanic concepts-Basalt volcanic systems. Pacific Rim Congress, Parkville, Victoria, Australia, Australasian Institute of Mineralogy and Metallurgy.

Walker, G. P. L. (1990). "Geology and volcanology of the Hawaiian Islands." Pacific Science **44**: 315-347.

Walker, G. P. L. (1990). Geology. Manual of the Flowering Plants of Hawaii. W. L. WWagner, D. R. Herbst and S. H. Sohmer. Honolulu, University of Hawaii Press.

Walker, G. P. L. (1990). Entries: "Koolau", "Honolulu Vents", "Kalaupapa and Mookuhooniki". Volcanoes of North America. C. A. Wood and J. Kienle, Cambridge Unviersity Press**:** 324-327, 330-331.

Walker, G. P. L. (1991). Origin of vesicle type and distribution patterns in the Xitle pahoehoe basalt in Mexico City. Am. Geophys. Un., Min. Soc. Am., Fall Meeting, Baltimore, Programme with Abstracts, 1991.

Walker, G. P. L. (1991). "Structure, and origin by injection of lava under surface crust, of tumuli, “lava rises”, “lava-rise pits”, and “lava-inflation clefts” in Hawaii." Bulletin of Volcanology **53**(7): 546-558.
Tumuli are positive topographic features that are common on Hawaiian pahoehoe lava flow fields, particularly on shallow slopes, and 75 measured examples are presented here to document the size range. Tumuli form by up-tilting of crustal plates, without any crustal shortening, and are thus distinguished from pressure ridges which are up-buckled by laterally directed pressure. The axial or star-like systems of deep clefts that characterize tumuli are defined here as “lava-inflation clefts”; their tips advanced into red-hot lava and they widened as uplift proceeded and while the lava crust was thickening. Flat-surfaced uplifts, formed like tumuli by injection of lava under a surface crust, were previously called pressure plateaus, but “lava rise” is proposed instead. The pits that abound among lava rises, previously attributed to collapse or subsidence, are generally formed because the lava around them rose, and the name “lava-rise pit” is proposed. Unique examples of tumuli and lava rises, from which lava drained out under a surface crust 1.5 to 2.5 m thick, are described from Kilauea caldera. These examples show that in tumuli and lava rises the crust floats on considerable bodies of fluid lava, and is able to

do so because of its higher vesicle content: the fluid lava loses many of its gas bubbles during residence beneath the crust. The bulk densities of samples from tumuli show a general downward increase. The form of the density profile is consistent with the relationship that for any given crustal thickness the density of fluid lava closely matched the average density of that crust, suggesting that the lava was stably density-stratified. It is inferred that stable stratification was regulated by out-flows of the more vesicular lava fractions, loss of bubbles through the lava-inflation clefts, and entry of injected lava at its level of neutral buoyancy. Below the uppermost meter the downward decrease in vesicularity closely conforms with that expected by compression of a uniform mass of gas per unit mass of lava.

Walker, G. P. L. (1992). "Morphometric Study of Pillow-Size Spectrum among Pillow Lavas." Bulletin of Volcanology **54**(6): 459-474.

Measurements of H and V (dimensions in the horizontal and vertical directions of pillows exposed in vertical cross-section) were made on 19 pillow lavas from the Azores, Cyprus, Iceland, New Zealand, Tasmania, the western USA and Wales. The median values of H and V plot on a straight line that defines a spectrum of pillow sizes, having linear dimensions five times greater at one end than at the other, basaltic toward the small-size end and andesitic toward the large-size end. The pillow median size is interpreted to reflect a control exercised by lava viscosity. Pillows erupted on a steep flow-foot slope in lava deltas can, however, have a significantly smaller size than pillows in tabular pillowed flows (inferred to have been erupted on a small depositonal slope), indicating that the slope angle also exercised a control. Pipe vesicles, generally abundant in the tabular pillowed flows and absent from the flow-foot pillows, have potential as a paleoslope indicator. Pillows toward the small-size end of the spectrum are smooth-surfaced and grew mainly by stretching of their skin, whereas disruption of the skin and spreading were important toward the large-size end. Disruption involved increasing skin thicknesses with increasing pillow size, and pillows toward the large-size end are more analogous with toothpaste lava than with pahoehoe and are inferred from their thick multiple selvages to have taken hours to grow. Pseudo-pillow structure is also locally developed. An example of endogenous pillow-lava growth, that formed intrusive pillows between 'normal' pillows, is described from Sicily. Isolated pillow-like bodies in certain andesitic breccias described from Iceland were previously interpreted to be pillows but have anomalously small sizes for their compositions; it is now proposed that they may lack an essential attribute of pillows, namely, the development of bulbous forms by the inflation.of a chilled skin, and are hence not true pillows. Para-pillow lava is a common lava type in the flow-foot breccias. It forms irregular flow-sheets that are locally less than 5 cm thick, and failed to be inflated to pillows perhaps because of an inadequate lava-supply rate or too high a flow velocity.

Walker, G. P. L. (1992). "Coherent Intrusion Complexes in Large Basaltic Volcanos - a New Structural Model." Journal of Volcanology and Geothermal Research **50**(1-2): 41-54.

Highly concentrated "coherent intrusion complexes" consisting of thousands of small mafic intrusions occur in probably all major basaltic volcanoes and play an important role in volcano development. Magma excursions from the high-level chamber travel laterally along a sur-face of neutral buoyancy at the margin of a complex and cause the complex to grow. The limited distance, however, that narrow intrusions can propagate before becoming blocked causes complexes to be wedge like. Intrusive-dike complexes underlie rift zones, and asymmetric growth of the dike wedge causes rift zones of shield volcanoes to become non-collinear and may initiate a third rift zone in the obtuse angle. Downbowing of stress trajectories across complexes causes dikes to be non-vertical and results in axial subsidence. Intrusive-sheet complexes form instead of dike complexes in volcanic systems that have a restricted ability to expand laterally and accommodate intrusions by expanding vertically instead. Downbowing of

stress trajectories causes sheets to be non-horizontal, and this combined with subsidence increasing toward the thicker part of the sheet wedge produces the inward and inwardly increasing dip that characterizes cone-sheet complexes. This mechanism for cone sheets differs considerably from previously proposed mechanisms. Successive injections of sheets at the top of a sheet complex probably offers the most efficient means of powering a high-intensity geothermal field such as the 5000 MW Grimsvotn system in Iceland.
It is inferred that similar mechanisms to those in major basaltic edifices operate in spreading ridges; study of basaltic edifices has the potential to contribute significantly to the understanding of spreading ridges.

Walker, G. P. L. (1992). "Puu Mahana near South Point in Hawaii is a primary Surtseyan ash ring, not a sandhills-type littoral cone." Pacific Science **46**(1): 1-10.

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Walker, G. P. L. (1993). "Re-evaluation of inclined intrusive sheets and dykes in the Cuillins volcano, Isle of Skye." Geological Society, London, Special Publications **76**(1): 489-497.

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Walker, G. P. L. (1994). Mountains of Fire. Mountains. The Illustrated Library of the Earth. Emmaus, PA, Rodale Press**:** 42-54.

Walker, G. P. L. (1995). "Plant Molds in Hawaiian Basalts - Was Oahu a Desert, and Why?" Journal of Geology **103**(1): 85-93.
Plant molds are common in the basaltic lavas of Hawaii, and this study quantitatively documents their distribution in terms of the number of molds per unit length of section. The number varies with lava structural type, being lower in distal-type aa than in pahoehoe or proximal-type aa. This study defines the expectation of finding plant molds among the lava flows of Oahu given a climatic and volcanic regime like today's in Hawaii. Plant molds prove to be very scarce on Oahu, only 2% of the expected number being found. The exposed parts of the volcanoes on Oahu are smaller, causing lava flows to be superposed at shorter intervals, but this can account for only a small part of the discrepancy. Oahu was evidently a near-desert 3.9 to 1.8 m.y. ago when its Waianae and Koolau shield volcanoes were active. This conclusion is supported by the virtual absence of earthy soils among, and the negligible contemporaneous chemical weathering of, the shield-building flows. It is proposed that when it formed, Oahu stood 2000 m or more higher than today. It projected above the Trade Winds and hence was arid, just as the upper parts of Mauna Kea, Mauna Loa, and Heleakala are arid today.

Walker, G. P. L. (1995). Flood basalts versus central volcanoes and the British Tertiary Volcanic Province. Milestones in Geology. M. J. Le Bas, Geological Society of London. **16:** 195-202.

Walker, G. P. L. (1999). "Volcanic rift zones and their intrusion swarms." Journal of Volcanology and Geothermal Research **94**(1-4): 21-34.

Most volcanoes have rift zones, underlain by swarms of dykes or other minor intrusions. This paper reviews the subject and presents some new data and ideas. It plots rift zone width against length for different volcano types, and finds that the zones on strato- and central volcanoes are on the whole narrower and shorter than on other types. Among the longest and narrowest zones are those on Hawaiian shield volcanoes; then are several reasons for the focussing. Hawaiian rift zones however become diffuse when volcanic activity declines. Monogenetic volcano fields include some that have clearly identifiable rift zones, and others that have vent-fields lacking fissures or dykes. Here the vent-field justifiably can be taken to proxy for a rift zone. The zones visited in several volcanic areas, (including the Azores and Samoa), are localised by deep crustal structures or tectonic activity, and often involve strike-slip faults. This paper then suggests how insertion of dykes could cause structural changes such as bending or initiation of a rift zone, and how departures from the 'normal" balance between magma flux and extensional strain rate could determine whether rift zones are vertical or horizontal. This leads to a possible mechanism fur the circumferential (annular) rift zones of some Galapagos volcanoes, (C) 1999 Elsevier Science B.V. All rights reserved.

Walker, G. P. L. (1999). Some observations and interpretations on the Deccan Traps. Deccan Volcanic Province, Geological Society of India, Bangalore, Memoir 43**:** 367-396.

Walker, G. P. L. (2000). Basaltic volcanoes and volcanic systems. Encyclopedia of Volcanoes. H. Sigurdsson. San Diego, Academic Press**:** 283-289.

Walker, G. P. L., et al. (1965). "Evidence of crustal drift from Icelandic geology." Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences **258**(1088): 199-204.

Walker, G. P. L. and D. H. Blake (1966). "The formation of a palagonite breccia mass beneath a valley glacier in Iceland." Quarterly Journal of the Geological Society **122**(1-4): 45.

A mass of palagonite breccia, with associated palagonite tuffs, basalt pillows, and large bodies of columnar basalt, is described from southeastern Iceland. It rests upon a glacially striated surface, with or without a thin intervening tillite layer. The mass is probably of early Pleistocene age and the evidence shows that the basalt which gave rise to it flowed down a valley beneath a valley-glacier. The mass has a present volume of 1.5 km3 (the original volume must have been several times this) and the basalt flowed certainly for 22 km, and probably for 35 km, beneath the ice. It is believed to have flowed through a central conduit along the valley bottom, and the breccia and contained pillows mainly developed by escape of the basalt upwards and sideways from this conduit into the glacier or its melt-waters.

Walker, G. P. L., et al. (1983). Volcanic Hazard on São Miguel, Azores. Forecasting Volcanic Events. H. Tazieff and J. C. Sabroux, Elsevier.

Walker, G. P. L., et al. (1999). "Origin of vesicle layering and double imbrication by endogenous growth in the Birkett basalt flow (Columbia river plateau)." Journal of Volcanology and Geothermal Research **88**(1-2): 15-28.

The 40-m thick Birkett basalt pahoehoe flow at Sentinel Gap in the Columbia River Plateau has an unusually thick (greater than or equal to 15 m) upper vesicular zone. This zone includes a striking layering in which the layers have contrasted vesicle abundances and sizes. Most layers show a reverse grading of vesicle size and abundance. The layering is interpreted to

have grown endogenously by the cyclic injection of vesicular lava layers under the growing top crust, accommodated by uplift of that crust. Grading of the layers resulted from vesicle growth and ascent. Each injection occurred at or near the boundary between vesicular and non-vesicular lava of the preceding layer and split that layer into an upper vesicular part and a lower non-vesicular part. Critical to this interpretation are (1) a pervasive foliation and lineation, defined by the parallelism of strongly flattened and elongate vesicles, transects the vesicle layers obliquely; and (2) the magnetic fabric (the anisotropy of magnetic susceptibility) is oriented similarly to the vesicle foliation, and also defines a cryptic foliation in the non-vesicular zone having a dip opposed to that in the layered zone. These foliations are interpreted to be opposed imbrications and indicate the flow azimuth of the lava. They strongly support the concept of lava growth by successive thin sill-like insertions of fresh vesicular lava between hot but static and effectively solid floor and roof. (C) 1999 Elsevier Science B.V. All rights reserved.

Walker, G. P. L. and I. S. E. Carmichael (1962). "Garronite, a new zeolite, from Ireland and Iceland." Mineralogical Magazine and Journal of the Mineralogical Society **33**(258): 173-186.
A new zeolite closely related to phillipsite and gismondine is recorded from thirty localities in the Tertiary basalts of Antrim and eastern Iceland, and the name garronite is proposed. Four chemical analyses indicate a composition of NaCa2·5A16Si10O32.13·5H2O. Garronite differs chemically from phillipsite in having a very low content of potash, and from gismondine in containing less lime, alumina, and water; optically garronite is intermediate between these two zeolites.

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Walker, G. P. L. and R. Croasdale (1971). "Characteristics of some basaltic pyroclastics." Bulletin Volcanologique **35**(2): 303-317.
The pyroclastic deposits of strombolian/hawaiian-type basaltic activity are readily distinguished from those ofsurtseyan type (i.e., the type exemplified by the opening stages of the Surtsey eruption of 1963–4) by being coarsergrained and better sorted. Moreover the fragments in the former have an external form in part controlled by surface tension — the termachnelith is proposed for such particles — whereas in the latter the fragments are clasts bounded by fracture surfaces. Other differences include the common occurrence of accretionary lapilli and « bomb sags » and the generally more thin-bedded character of the surtseyan deposits. The distinction between these two types of basaltic activity is important in palaeogeographic reconstructions.

Walker, G. P. L. and P. R. Eyre (1995). "Dike complexes in American Samoa." Journal of Volcanology and Geothermal Research **69**(3-4): 241-254.
Coherent dike complexes in which dikes make up more than 50% of the total rock occur in American Samoa in two volcanoes on Tutuila and in Ofu-Olosega volcano in the Manu'a Islands, The dikes are remarkably narrow (median width 0.24-0.36 m; average width 0.46-0.56 m, based on 860 measured dikes), significantly narrower than dikes in the Koolau volcano (Oahu, Hawaii), the most closely comparable volcano for which quantitative data are available. The vesicularity of these narrow dikes indicates that they were injected at shallow depths below the land surface: depths of 200-900 m are inferred from the topography. Many dikes have prominent bands of vesicles parallel with their margins. They tend to form clusters where the weakness of the vesicular rock favored center injection of one dike up the center of another, Examples are found of center injection repeated up to eight times. Local breccias, often composed largely of dike fragments evidently brecciated in situ, occur where irregular dikes were accommodated

by deforming the host rocks. We see evidence for two dike facies: (1) narrow and vesicle banded, early formed and shallow-injected "clustered" dikes in the dike complexes, which are cut by (2) scattered broad and almost nonvesicular deep-injected "solitary" dikes. Surface eruptions were fed by solitary dikes. The ENE-trending dikes and elongation of Tutuila Island contrast with the WNW trend of rift zones and island elongation elsewhere in Samoa. Tutuila is nearly in line with the North Fiji transform fracture zone suggesting that at 1.5-1.0 Ma, when Tutuila was formed, the volcanism of Tutuila was guided by a temporary extension of this fault zone into the Pacific Plate. Fault movement offset the Samoan hotspot trace by 45 km. The en-echelon arrangement of dike exposures on Tutuila is consistent with left-lateral transcurrent motion above this concealed fracture zone.

Walker, G. P. L., et al. (1995). Nearly congruent dike-width populations in diverse large basaltic volcanoes. Third International Conference on the Physics and Chemistry of Dikes, Balkema, Rotterdam.

Walker, G. P. L., et al. (1995). "Travel of Pyroclastic Flows as Transient Waves - Implications for the Energy Line Concept and Particle-Concentration Assessment." Journal of Volcanology and Geothermal Research **66**(1-4): 265-282.

We here consider the precept that pyroclastic flows travel as transient waves or pulses. We provide simple geometric models to estimate the wave height that may form under specified conditions and how it may vary with progression away from the vent. A main uncertainty is the length of the wave relative to the total travel distance, but the simple sequence of segregation layers observed in many ignimbrites may enable crude constraints to be placed on the wavelength. Application of these models to actual ignimbrites suggests wave heights of tens to hundreds of meters. A corollary is that a wave is able to surmount obstacles less high than itself, irrespective of its velocity. The wave may also possess momentum which confers an additional landscape-surmounting capability. Thus, a part of the obstacle-crossing ability of a pyroclastic flow is due to the height of the wave, and a part is due to the velocity of the wave. Another corollary is that the deposit will normally be much thinner than the wave height; estimates of the degree of expansion of pyroclastic flows (or surges) based on the relationships of the height of a trimline to the depth of a deposit may therefore be invalid. This is important, as at El Chichon, when diagnosing whether a deposit was laid down by a pyroclastic flow or surge. Care must also be taken not to confuse a trimline or upper limit of a veneer (which exists, and is a wave-height level) with an energy line (which is a theoretical concept). Application of the wave concept helps explain many observed features of pyroclastic flows and their deposits, for example, drainage of a wave off topographic highs to generate the "secondary" valley ponds, such as were observed in the Mount St. Helens 1980 blast flow deposit.

Walker, G. P. L., et al. (1981). Latest major eruptions of Rabaul volcano. Cooke-Ravian volume of volcanological papers. **10:** 181-193.

Walker, G. P. L., et al. (1980). "Ignimbrite Veneer Deposits or Pyroclastic Surge Deposits - Reply." Nature **286**(5776): 912-912.

Walker, G. P. L., et al. (1980). "Low-Aspect Ratio Ignimbrites." Nature **283**(5744): 286-287.

Walker, G. P. L. and G. P. Leedal (1954). "The Barnesmore granite complex, County Donegal." Scientific Proceedings of the Royal Dublin Society **26**: 207-243.

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Walker, G. P. L. and J. V. Ross (1954). "A xenolithic monchiquite dyke near Glenfinnan, Inverness-shire." Geological Magazine **91**(6): 463-472.

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Walker, G. P. L., et al. (1984). "Tarawera 1886, New-Zealand - a Basaltic Plinian Fissure Eruption." Journal of Volcanology and Geothermal Research **21**(1-2): 61-78.

Walker, G. P. L. and R. R. Skelhorn (1966). "Some associations of acid and basic igneous rocks." Earth-Science Reviews **2**: 93-109.
The type of association with which this review article is mainly concerned is one in which, there is reason to believe, acid and basic materials were both in the condition of magmas when they came in contact with one another. Examples of such occurrences are widespread and varied in their manifestations. In many instances a mixture of the two magmas has taken place; sometimes, although intimately co-mingled they have preserved their separate identities, whereas in other cases the mixing has been so thorough as to produce a homogeneous rock-type. Implications of the coming-together of acid and basic magmas are discussed.

Walker, G. P. L. and N. D. Watkins (1976). "Indications of a Possible Relationship between Volcanism on the Reykjanes Ridge and Volcanism in Eastern Iceland." Transactions - American Geophysical Union **57**(4): 335-335.

Walker, G. P. L. and C. J. N. Wilson (1983). "Lateral Variations in the Taupo Ignimbrite." Journal of Volcanology and Geothermal Research **18**(1-4): 117-133.

Walker, G. P. L., et al. (1980). "Fines-Depleted Ignimbrite in New-Zealand - the Product of a Turbulent Pyroclastic Flow." Geology **8**(5): 245-249.

Walker, G. P. L., et al. (1981). "An Ignimbrite Veneer Deposit - the Trail-Marker of a Pyroclastic Flow." Journal of Volcanology and Geothermal Research **9**(4): 409-421.

Walker, G. P. L., et al. (1971). "Explosive Volcanic Eruptions .1. Rate of Fall of Pyroclasts." Geophysical Journal of the Royal Astronomical Society **22**(4): 377-&.

Walker, G. P. L., et al. (1981). "Pyroclastic geology of the rhyolitic volcano of La Primavera, Mexico." Geologische Rundschau **70**(3): 1100-1118.
Explosive eruptions of this large Quaternary rhyolitic volcano have produced voluminous pumice fall deposits and ignimbrites. A stratigraphie study reveals more than 30 fall deposits, totalling more than 90 km3, which have come from many different vents. Some are of plinian type, and one is among the largest known in the world. The main ignimbrite (Rio Caliente) is of intra-plinian type. In all, 140 km3 of rhyolitic material were erupted during the past 105 years, of

which 50 km5 are dispersed well outside the volcano. The dense rock equivalent volume is 60 km3, of which fall deposits, ignimbrites and lava bodies comprise 45 %, 25 % and 30 % respectively. The average output rate of 0.06 km3 per century is nearly an order of magnitude less than for the most productive rhyolitic volcanoes known. A circular area 10 km across in the centre of La Primavera contains updomed lacustrine ashes and associated sediments, including a remarkable giant pumice bed, which probably accumulated in a caldera lake. La Primavera has no record of historical eruptions, and hot springs are the only signs of present activity, but the updoming is thought to be due to the uprise of a new acid pluton beneath the volcano and future eruptions are probable.

Watkins, N. D., et al. (1975). "Geomagnetic Time Scale - Detection and Dating of Epoch-5, Epoch-6, and Anomaly-5 in Iceland." Transactions - American Geophysical Union **56**(12): 974-975.

Watkins, N. D. and G. P. L. Walker (1977). "Magnetostratigraphy of eastern Iceland." American Journal of Science **277**(5): 513.
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Wilmoth, R. A. and G. P. L. Walker (1993). "P-Type and S-Type Pahoehoe - a Study of Vesicle Distribution Patterns in Hawaiian Lava Flows." Journal of Volcanology and Geothermal Research **55**(1-2): 129-142.
Two main types of Hawaiian pahoehoe lava, P-type (pipe vesicle-bearing) and S-type (spongy), are characterized. Their origin is inferred from features of the vesicle sizes and abundances, particularly in their chilled margins which record, frozen in, the vesicle population at the time and place of solidification. S-type margins are distinctly more vesicular than P-type. Porosity and vesicle size and range in S-type margins are highest at the vent. Vesicle size reaches a minimum in medial areas, and then increases while porosity decreases onto the flatter ground of the coastal terrace. The vesicles are inferred to be part of the complement of bubbles that was present at the vent, modified by loss and coalescence during travel in lava tubes. The minimum porosity occurs on the coastal terrace and is the result of degassing during a longer residence time in lava tubes there. The systematically lower porosity of P-type margins than S-type is attributed to a still longer residence, allowing more time for bubble coalescence and loss. P-type pahoehoe is common only on flatter ground, such as the coastal terrace. It is found where tumuli and lava rises are widespread and where extensive networks of lava-expansion clefts occur through which lava moving below the surface crust can lose gas without significant cooling. Additionally, P-type pahoehoe shows clear evidence that a strong inward movement and growth of bubbles took place from the outermost selvage into an inner selvage concentration zone. A mechanism that might cause this inward movement is surface tension, operating against deforming forces in the steep viscosity gradient of flow margins, causing down-gradient bubble translation. Inward movement does not usually occur in the upper crust of thick (> 2 m) flow-units because of the absence of strong deforming forces in the shallow velocity gradient there. Many of the larger bubbles that entered the inner selvage rose buoyantly to form pipe vesicles.
P-type pahoehoe is characterized by sampled profiles across 20 flow-units. Continued gas loss through surface clefts caused a general overall reduction in vesicle content within each flow-unit to less than that in the upper crust, and the pronounced depletion of vesicles from its lower half is attributed to scavenging by ascending pipe bubbles. In a small proportion of flow-units, overall gas loss was small and a median gas blister fed by pipe bubbles developed instead.

Wilson, C. J. N., et al. (1980). "A New Date for the Taupo Eruption, New-Zealand." Nature **288**(5788): 252-253.

Wilson, C. J. N., et al. (1981). "Did Taupo's Eruption Enhance European Sunsets - Reply." Nature **293**(5832): 491-492.

Wilson, C. J. N. and G. P. L. Walker (1981). Violence in Pyroclastic Flow Eruptions. Tephra Studies, Dordrecht, Springer Netherlands.
Three parameters, magnitude, intensity, and violence, can be used to characterise pyroclastic flow eruptions. Violence reflects the vigour with which a pyroclastic flow is emplaced. It is described quantitatively by the height of hills climbed by the flow (yielding flow-velocity estimates), the overall morphology of the deposit and by the proportion of the flow which forms an ignimbrite veneer deposit. Using the Taupo ignimbrite (New Zealand) as an example of an extremely violent flow, we relate violence to the eruption intensity. We consider that eruption magnitude and intensity control the gross distribution of a pyroclastic flow deposit.

Wilson, C. J. N. and G. P. L. Walker (1982). "Ignimbrite depositional facies: the anatomy of a pyroclastic flow." Journal of the Geological Society **139**(5): 581.
A model is presented for the depositional regimes in a pyroclastic flow, to explain the origin of facies in the Taupo ignimbrite and to compare these with other published examples. In this model, a pyroclastic flow consists of a head, a body and a tail. The head, which is where fluidization caused by air ingestion occurs, generates layer 1 deposits. On lithological grounds these are divided into layers 1(P) which is fines-depleted and rich in pumice, and 1(H) which is fines-depleted and rich in lithics and crystals. Layer 1(P) represents material thrown forwards from the flow head and is termed the jetted deposits. Layer 1(H) represents material sedimented from within the flow head and is termed the ground layer. The body represents the bulk of the flow and the tail is its trailing part which is slowed by ground friction; these parts generate the layer 2 deposits which include the valley-pond ignimbrite and its associated ignimbrite veneer deposit. Localized depositional modes within the body and tail generate distinctive coarse pumice concentration zones and pumiceous lee-side lenses behind obstacles. At its outer limits all of the flow on interfluves is affected by air-ingestion fluidization, producing the distant facies which combines features of both layer 1 and 2 deposits. One important conclusion of this work is that the thicknesses and compositions of the various facies are not related in any simple way to the thickness and composition of the parent flow.

Wilson, C. J. N. and G. P. L. Walker (1985). "The Taupo Eruption, New-Zealand I. General Aspects." Philosophical Transactions of the Royal Society a-Mathematical Physical and Engineering Sciences **314**(1529): 199-+.

Wilson, L., et al. (1980). "Explosive volcanic eruptions — IV. The control of magma properties and conduit geometry on eruption column behaviour." Geophysical Journal International **63**(1): 117-148.
Plinian air-fall deposits and ignimbrites are the principal products of explosive eruptions of high viscosity magma. In this paper, the flow of gas/pyroclast dispersions and high viscosity magma through various magma chamber/conduit/vent geometries is considered. It is argued that after the first few minutes of an eruption magma fragmentation occurs at a shallow depth within the conduit system. Gas pressures at the fragmentation level are related to exsolved gas contents by consideration of the exsolution mechanism.The sizes of blocks found near vents imply that gas velocities of 200 to 600 m s^{-1} commonly occur. These velocities are greater than the effective speed of sound in an erupting mixture (90-200 m s^{-1}) and the transition from subsonic to supersonic flow is identified as occurring at the depth at which the conduit has its minimum diameter. The range of values of this minimum diameter (~ 5 to ~ 100 m) is estimated from observed and theoretically deduced mass-eruption rates.The energy and

continuity equations are solved, taking account of friction effects, for numerous geometries during the evolution, by wall erosion, of a conduit. Conduit erosion ceases, near the surface, when an exit pressure of one atmosphere is reached. Eruption velocities are found to depend strongly on exsolved magma gas content and weakly on radius of conduit and friction effects. Assuming water as the main volatile phase, velocities of 400-600 m s^{-1} for plinian events imply magma water contents of 3-6 per cent by weight.Three scenarios are presented of eruptions in which: (1) conduit radius increases but gas content remains constant; (2) conduit radius increases and gas content decreases with time; and (3) conduit radius remains fixed and gas content decreases. These models demonstrate that the reverse grading commonly observed in plinian air-fall deposits is primarily a consequence of conduit erosion, which always results in increasing eruption intensity and eruption column height with time. The models also show that a decrease in gas content as deeper levels in a magma chamber are tapped or an increasing vent radius as conduit walls are eroded leads to the prediction of a progression from air-fall activity through ignimbrite formation to cessation of eruption and caldera collapse.

Wilson, L. and G. P. L. Walker (1987). "Explosive volcanic eruptions - VI. Ejecta dispersal in plinian eruptions: the control of eruption conditions and atmospheric properties." Geophysical Journal International **89**(2): 657-679.
A simple model is developed to relate the maximum down-wind and cross-wind ranges of pyroclasts forming a plinian airfall deposit to the dynamic processes in the eruption cloud from which they fall and the atmospheric wind conditions in the area. The eruption cloud dynamics are in turn related to the eruptive conditions in the vent (vent radius, exsolved magmatic volatile weight fraction, velocity with which material passes through the vent, and mass eruption rate), some or all of which can be deduced if the appropriate field measurements can be made. Some aspects of the stability of convecting volcanic eruption clouds are investigated, and the effects on eruption cloud height of the local atmospheric temperature profile and the value adopted for the entrainment constant (which relates the horizontal flow speed of atmospheric air entering the column to the vertical rise speed of the column material) are explored. It is confirmed that eruption-cloud rise height and pyroclast dispersal are mainly controlled by the mass eruption rate (per unit length of active fissure in the case of linear vents) and, hence, the heat input rate to the cloud; but a significant subsidiary dependence on the amount of exsolved magma volatiles is also found. The eruption cloud model is validated by application to observed historic eruptions, and its use in the analysis of palaeo-eruptions is discussed.

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Wright, J. V. and G. P. L. Walker (1978). "Ignimbrite Source Problem - Significance of a Co-Ignimbrite Lag-Fall Deposit - Reply." Geology **6**(5): 260-260.

Wright, J. V. and G. P. L. Walker (1981). "Eruption, Transport and Deposition of Ignimbrite - a Case-Study from Mexico." Journal of Volcanology and Geothermal Research **9**(2-3): 111-131.