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Volcanic Events, when Magma is considered to be a Solution.

The rather old opinion of magma in great rooms (magma chambers, Magmabehälter) in the earth was maintained even less than 20 years ago. Attention was then not paid to the question whether the magma chamber remained empty, when several thousand millions cub. meter had left it. « Dauernd ausgebrannte Vulkane sind ein Wahrzeichen dafür, dass das magmatische Reservoir vollständig erschöpft ist. » (S. GÜNTHER, *Handb. der Geophysik* B. 1. S. 426).

According to the Isostasy-theory we now consider magma to be below the whole lithosphere, and that this sinks, when magma is streaming out. The lowering of the lithosphere is generally very little, as can be seen of the shorelines with regard to volcanoes, situated near the sea, therefore we must conclude the lowered surface to be very great and the viscosity low of the magma.

It is stated that magma contains water, and that water at high temperatures is able to dissolve silicates. If we conceive magma as a solution, it has dissolved to saturation substances of the adjacent rocks, and water vapour from it must have been absorbed into the silica of the rocks, so that these are not only water-tight but also steam-tight, and plastic by this absorption. The specific gravity of the adjacent rocks must be below that of the magma, else great parts of these would sink down into the magma.

From the decreasing basicity upwards into the very great eruptives we conclude that magma, when cooled, is firstly supersaturated by *basic* substances. We will show this by quoting REGINALD A. DALY (*Sills and Laccoliths Illustrating Petrogenesis*. Intern. Geol. Congres Canada 1913. p. 189).

Locality	*Lenght* km.	*Maximum* Thickness. m.	*Rock Species Differentiated.*
Sudbury	65	3000 +	*a*) Micropegmatitic granite and granodiorite, quartzdiorite.
Ontario			*b*) Abnormal intermediate types.
			c) Norite.
			d) Sulphide ores.
Duluth	200	6000 +	*a*) Micropegmatite, granite, syenite.
Minnesota			*b*) Anorthosite, gabbro, norite.
			c) Femic norite, pyroxenite, dunite magnetic ore.
Bushveldt	400	?	*a*) Granite, generally micropegmatitic.
Transvaal			*b*) Norite, gabbro.
			c) Pyroxenite, magnetite ore, chromite ore.

On account of the above, we now proceed from the thesis that *normal magma is a very concentrated and saturated aqueous solution of silicates*, (water the principal solvent) *and, when its temperature is lowered, are precipitated firstly basic substances which combine to basic minerals.*

The cause of volcanic outbreaks. — The lithosphere is floating on the magma. Its greater specific gravity in spite of its considerably great content of light solvents (as will be shown later) ought to be ascribed to an existing violent innerpressure, the result of the attraction between the solvents and the solutes. The attraction by which water is kept into solutions, even to much higher temperatures than that which is critical for pure water.

When the temperature of the magma has been lowered, a part of its basic and heavy solutes has been precipitated. The attraction on the solvents of this part has disappeared, and the decreased innerpressure causes expansion. This together with the loss of the heavy substances has diminished the specific gravity of the magma so that great parts of the adjacent rocks *sink* into it. Magma, taking their place, advances upward into the lithosphere, is further cooled, further diluted be precipitation to still more decreased specific gravity, and is still more unable to carry the roof above it. Magma is thus advancing mile upon mile upward until it, by its increased steampressure (increased because the attraction from the precipitated solutes on the water has disappeared) is able to break the rock above it, when outbreak occurs to the sea or to the air.

The occurrences of volcanoes. — According to our deduction — lowered temperature of the magma is the cause — we find volcanoes, where the loss of heat can be considered to be greater than the normal. *The very greatest part of extinguished and active volcanoes are situated in the oceans*, where the lithosphere is (considered to be) thinnest, and thence less sheltering against loss of heat.

The volcanoes of the continents are situated on anticlinals, on the tops of folds, into which magma has been enclosed, thus releasing heat not only upward but also to both sides of the fold.

It is generally asserted that these volcanoes are situated on fractures in the lithosphere, as they often occur in a row, but a top of a fold also forms an almost straight line. Fractures in the lithosphere are frequently formed without formation of volcanoes. It is evidently that fractures cannot reach great depths. There will be a number of slides and falls which cannot go down through the very lowermost plastic part of the lithosphere and to the magma, and magma cannot possibly rise many miles upward into a crevice. There must be above the magma a roof of so great diameter that it breaks at the small difference in the specific gravity between magma and rock. The diameter of the eruption canal will probably be several kilometers at its base, decreasing upward, and ending with a funnel into the crater. If an outbreak had begun into a crevice during which it was widened, then the products of the first outbreak would consist principally of rocks from the lithosphere probably 100 km. thick on the continents.

Progress and products at outbreaks. — When the magma has reached the top of the lithosphere or the neck of congealed lava into a volcano, there is in the eruption canal an enormeous quantity of magma, increasing to the depth in concentration, temperature, basicity and specific gravity. At the outbreak the uppermost much diluted magma boils, and its solutes which are thrown out with the solvents, form precipitation.

When the upper part of the canal is filled mostly by gas, the pressure is lowered all the way down into the canal, causing boiling to great depth. The pressure of the steam passing through the magma is decreasing upward, and, where there is most steam, is also the greatest adiabatic lowering of the temperature. Deeper down the temperature is sufficiently high for the formation of glassy products of the precipitated solutes.

Thus the outbreak must begin with steam and precipitation, and later, will be thrown out glassy products, finally of magma which at great depth has lost most of its water, and its solutes forming a melting-liquid (by the lowered melting temperature, caused by a remainder of water).

The progress at outbreaks is in accordance with our deduction. It begins violently with steam and volcanic ashes (precipitation) more or less mixed with glassy products, continues with such products forming black glass (obsidean) or pumice. When the gas-stream has decreased, outflow of lava begins, if not so heavy (concentrated) magma has risen into the canal that equilibrium is established at the base of the canal between the rockpressure and the magma pressure. (« Je höher Vulkane sind, um so seltener erfolgen Lavaergusse, um so bedeutender aber sind ihre Asheneruptionen. So haben die hohen Vulkane Quito's mit Ausnahme des Antisana und Sanguay seit Menschengedenken keinen Lavastrom entsendet. Dasselbe gilt von dem hohem Popocatepetl in Mexico. » G. Leipoldt. *Phys. Erdkunde* S. 225).

Magma's content of water. — I. Friedländer calculated the quantities which were thrown out from Vesuvius during 20 hours at the beginning of its outbreak in the year 1906, the steam as equivalent to 1.75 km^3 water, and the solid material at the same time to 0.75 km^3. (*Z. für Vulkanologie*, February 1926). That magma from which the solid material originated did, of course, not contain 70 % water. Most of the water must have come from magma, boiling deeper down, and there converted into more or less water-poor products.

Analyses of black glass have stated contents of water up to 12 % and of pumice (pulverized and dried) up to 12.45 %. Magma from which these products originated cannot have had lower content of water, more probably higher, as a part of its water may have boiled away before the precipitation of these solutes.

The Palagonitic tuff on the Galápagos Islands is remarkable. This is a basic rock, containing almost 21 % water, « which forms craters [1]) on Chatham and James Islands ». From the paper « Rocks of the Galápagos Islands » of H. S. Washington and Mary C. Keyes. (*Geophysical Laboratory Washington* N:o 652), we cite the following description and analyses.

« This tuff is very dense and compact, but most specimens can be readily scratched with a knife, having a hardness of 3 to 4. The color is rather light, yellowish brown and the luster is peculiar-greasy or, as Darwin puts in, resinous. Fragments are slightly translucent on thin edges ».

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1) Darwin estimated the number of craters at about 2000, and several of them have been in eruption during the last hundred years or so.

Analyses.

	(1)	(2)	(3)	(4)
SiO_2 . . .	38.13	38.07	47.45	48.24
Al_2O_3 . . .	14.64	13.03	18.34	15.82
Fe_2O_3 . . .	7.93	9.99	9.94	0.78
FeO . . .	0.87		1.09	9.84
MgO . . .	3.84	6.58	4.78	5.84
CaO . . .	8.97	7.54	11.25	9.84
Na_2O . . .	2.67	0.70	3.34	3.63
K_2O . . .	0.15	0.94	0.19	0.64
H_2O + . .	12.34 } 20.75	23.14	—	0.72
H_2O — . .	8.41 }		—	0.11
CO_2 . . .	none	n. d.	—	—
TiO_2 . .	2.50	n. d.	3.15	3.88
P_2O_5 . . .	0.01	n. d.	0.01	0.16
MnO . . .	0.15	n. d.	0.19	0.20
	100.61	100.00	100.00	99.70

(1) « Palagonitic tuff, Eden Islet, Galápagos Islands. KEYES analyst.

(2) « Palagonite, Galápagos Islands. BUNSEN analyst. (Calculated to 100).

(3) « Analysis N.º 1 calculated to 100, as free from H_2O.

(4) « Andesine basalt, Eden Islet, Galápagos Islands. KEYES analyst.

The tuff contains more water than most of the zeolite-minerals. Thus if a little of such a mineral were in the analyzed samples, it would rather *decrease* than increase the water-content of the tuff.

When the analyses (3) and (4) are compared, we find that, if most of the water had boiled away in the eruption-canal, it would have been andesine basalt instead of tuff.

The basicity of the products increases during the eruption.

According to our thesis, as above said, the basicity of the magma into the eruption canal must increase to the depth. Thus at the top are great content of silica, and *low basicity* of the first products of the outbreak of glass, pumice and the first lavas. The violent stirring by gas bubbles, rising through the magma, can carry upward parts of more basic products, but generally the basicity of out streaming lavas must increase from rhyolite or trachyte to andesite and to basalt, if the outbreak does not cease before this by entering of before named static equilibrium. Gasbubbles into the canal will diminish the weight of its content so much that magma of greater specific gravity than the average of the lithosphere, can be able to rise to the level for outflow, if the altitude of this is not too high.

Some years ago, when an analysis of lava was considered to show the chemical composition of the magma from which the lava originated, the deduction above would have been considered as incorrect. As the volcanic islands in the Pacific generally are covered by basalt, the magma below this ocean was said to be basaltic or of Pacific type. During later years both basalt and acid lavas have been found on many islands in the Pacific and in other oceans.

From the before named paper of H. S. WASHINGTON and M. G. KEYES we quote following. « Thus we find such trachyandesites at Hawaii and at other islands, and moreover trachytic lavas occur with basalts at many of them as on Hawaii, Maui, Molokai, in the Hawaiian Islands ; Tutuila in the Samoan group ; Tahiti ; Juan Fernandez Islands ; San Felix ; Nukuhiva, Marquesas ; and several others ». « This very general occurrence of trachytic and trachyandesitic lavas with dominant basalts is a feature of the petrology of the Pacific of very great importance».

Krakatau delivered year 1883 enormeous quantities of rather acid pumice.

The activity of extinguished islands-volcanoes has ended with basalt which forms the plug in the crater. It cannot be stated, if the material of which the crater is built from the bottom of the sea *really* is acid, but sandbanks in the environs indicate it.

Increase in basicity has been stated by H. S. WASHINGTON on Sardinia. « At least three volcanic Cycles, to use the term, introduced by Geikie, denoting recurrent periods in the history of a volcano, in which the progressively changing composition of the lavas repeats itself more or less perfecly and completely ». (Below are cited only the percentage of SiO_2).

The first cycle, of tertiary age, has begun with rhyolite (72.05%). Upon this trachyte (59.92%), andesite (56.60%) and finally basalt (49.00%).

The second cycle, lavas from Monte Archi, has begun with rhyolite (73.09%), later trachyte (65.94%), andesite (56.34%) and finally basalt (52.79%).

The third cycle, lavas from Monte Ferru, has begun with trachyte (58.43%). Upon this phonolite (60.43%), basalt « camptonose » (52.40%) and finally « Leucite-basanite » (44.85%). (Congrès Géol. 1913. Canada p. 229).

In a paper to the same congress JOSEPH P. IDDINGS (p. 209) has shown gradually increasing basicity of lavas in Yellostone National Park.

Concerning *the Lifelength of a volcano as active*, we must conclude that it will be extinguished, when the cause of it has disappeared, i. e. when the temperature of the magma below it is not further lowered. This happens for volcanoes in the oceans, as the bottom of the sea will be covered by hot products of the volcano, with sequence of very slow increase of the temperature in the downward direction in the lithosphere. Yet the abnormal loss of heat of the magma does not cease, before the increase in rock temperature has proceeded down to the magma. It will take a very long time, though shortened by the heat, conducted from the eruption canal. The lithospere, augmented in thickness by the products of the volcano, gives then such shelter to the magma against loss of heat that a volcano built up from the flat sea-bottom will be definitely extinguished.

Magma, in a fold, does not obtain a similar shelter by the products of the volcano above it. The products of a volcano on high altitude will be spread and soon cooled, thence the abnormal loss of heat of the magma continues. The volcano is active anew, or new volcanoes are formed at the top of the fold. The volcano can be definetely extinguished, if the uppermost part of the fold be filled by rock, so that magma does not exist in this, to loss of heat most exposed part of the fold.

As above is suggested, the very greatest part of the numberless volcanoes in the oceans are extinguished, and many old volcanoes might now exist only as coral-banks. Also on the continents occur a number of extinguished volcanoes as in Auvergne and Eifel, but several volcanoes on the continents cannot be considered as extinguished, though they were active already in the tertiary.

A very wide eruption canal can- like a fold- contain enormous masses of magma. The volcano upon it can thus after centuries of inactivity be able to deliver enormous quantities of ashes (of magma, diluted by precipitation during the named period) and later have repeated outflows of lavas.

Volcanoes in islands can also occur on a fold. So might be the case concerning the Aleutian and possibly also the Kuriles and Santorin.

Volcanic events also include Great-earthquafles (Gross-Erdbebens). These, nearly connected with te formation of laccoliths, ought also to be studied from the point of view that magma is a solution, as will be shown in a later paper.

It was studies of mineral associations in rocks and ore deposits which led the author to the opinion that magma is a solution-pronounced by BUNSEN about 60 years ago. When windicating it at the Int. Geological Congress in Canada 1913, it was rejected because of the high temperature of outflowing lavas. This counter-reason led to the study of the properties of much concentrated solutions, and of the dissociation theory, at which studies the author made determinations of different kinds. The result of this research was that probably *so much heat will be liberated at the conversion of magma to lava, that this conversion is almost comparable to combustion, raising the temperature many hund.ed degrees above that of normal magma « in situ »*.

Falun, Sweden, April 1931.