Commission on

Explosive Volcanism

The CEV Newsletter sponsored by IAVCEI
August 1999

In This Issue

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In this issue, we have decided to try eliciting a debate among our readers. One of the biggest debates at the CEV symposium on maars, diatremes and kimberlites at the meeting in South Africa last year was whether kimberlites are truly different from phreatomagmatically formed maars. Volker Lorenz argued for a phreatomagmatic origin for all kimberlites, citing striking similarities between his group's experiments on fuel/coolant interactions, field data on maars around the world, and descriptions of kimberlites. Barbara Scott Smith argues for a magmatic volatile component causing the explosivity of kimberlites, and sees little to no evidence for fuel/coolant interactions, at most diatremes. It seemed to us that the debate was worth extending to all of our members, so we invited Volker and Barbara to submit articles arguing for their models. They graciously agreed, and their articles make up the bulk of this issue. We would welcome discussion on their models in future issues. If enough people write, we can post comments on the CEV home page to continue the debate.

In addition to the kimberlite debate, we also have an article by Paola Del Carlo, Mauro Coltelli, and Luigina Vezzoli on their work on the Etna Plinian basaltic eruption of 122 BC. They present a model designed to explain how a basaltic magma can have the explosive force to sustain a Plinian eruption column. Their model finds that magmas of compositions similar to those from the 1996 eruption can cause tremendous explosions with little warning.

They suspect that there are more basaltic Plinian deposits around the world, and want to alert other workers to look for them. Comments on their work are also welcome.

There is a great deal of activity in explosive volcanism these days, not only at the volcanoes themselves (e.g., recent explosive activity at Colima, Popocatepetl, Montserrat, Krakatau, and potentially at Taal), but also in the research community. All of this results in publications and symposia. We've included updates on recent books and on several upcoming conferences/symposia in this newsletter.

At the recent IUGG General Assembly in Birmingham (which, unfortunately, neither of us was able to attend), IAVCEI transitioned to a

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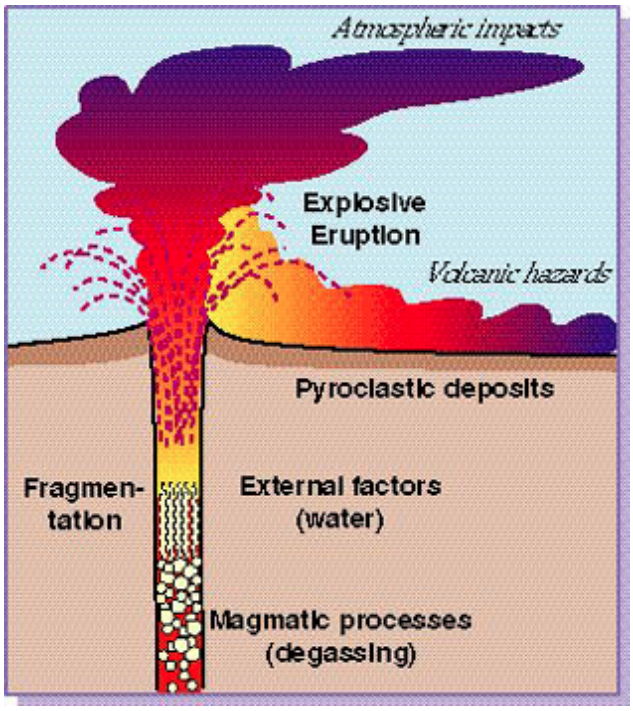
(Issue continued on page 2)

(In this Issue continued from page 1)
new leadership team lead by the Steves (Steve Sparks, President, and Steve McNutt, Secretary General). Many thanks to Grant Heiken and Wally Johnson for their hard work over the past four years! A new executive committee is also in place. All this will be described in upcoming issues of *IAVCEI News*. One of the first actions that the new leadership team is taking is to look at all the IAVCEI commissions and determine if any changes need to be made (e.g., new ones added, existing ones dropped). We'll keep you posted on this as news becomes available.

One thing that did not happen as a result of our not attending IUGG was a CEV working meeting. We had hoped, among other things, to work on the idea of a Numerical Modeling Working Group (NMWG) so that we could define a path forward. Hopefully, one or both of us will be able to attend the IAVCEI Congress in Bali next summer so that we can discuss, as a Commission, the Working Group and other issues. In the meantime, though, we would like to form a core group of 3-6 people who are especially interested in the NMWG idea. One of the short-term goals of this group would be to formulate proposals for funding workshops and other NMWG activities. An opportunity for such a proposal is the Institute for Geophysics and Planetary Physics (IGPP). IGPP funds small research grants and in the past has funded an annual Mantle Convection Workshop that is in much the same spirit as our NMWG concept. If we write a proposal to IGPP, it would



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be due in the late January February time frame, and funding (if successful) would begin in October 2000. Please let us know in the next month if you are interested in being a member of this core group, and are willing to dedicate some time to pulling proposals together.

Enjoy the Newsletter!

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NEAR-SURFACE EMPLACEMENT OF KIMBERLITES BY MAGMATIC PROCESSES

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Kimberlites are unusual magmas. The differences between kimberlites and other more common rock types results in many unique near-surface emplacement mechanisms. There are two main lines of argument to support this suggestion:

(a) although kimberlite eruptions have never been observed, the magma properties which are evident from rocks indicate that many aspects of kimberlite eruption processes are *not* the same as most other magma types, and

(b) the observed products of emplacement, as indicated by the internal geology and textures within kimberlite pipes (pipe is used here as a non-genetic term), are different from those in more common volcanic rocks, indicating contrasting processes of formation.

(a) Nature of the erupting magmas : Kimberlite magmas have a relatively rapid journey from the mantle to the surface that allows them to carry, and preserve, large volumes of xenolithic mantle material, including diamond. Sub-surface magma chambers are not formed. Kimberlite magmas also retain abundant juvenile gases until they reach surface. These gases are dominated by carbon dioxide (up to at least 20 wt.%) but also include significant amounts of water. Kimberlite magmas also have viscosities lower than many more common volcanic rocks, such as basalts, which allows for greater volatile mobility. Viscosities, however, would be influenced by the high crystal content. Kimberlite textures (e.g. Clement 1982, Clement & Reid 1989) and experimental petrological investigations (e.g. Dreibus et al. 1995) show that the carbon dioxide dissolved in kimberlite magmas must exsolve near-surface (<3 km), i.e. during final emplacement.

(b) Observed products of emplacement : At least three types of kimberlite pipes have been identified: (i) deep (up to 2 km), steep-sided pipes which comprise three distinctive zones (crater, diatreme, root; the term diatreme is used here specifically for this zone in this type of pipe), each of which has a different shape and is infilled by contrasting textural varieties of kimberlite (extrusive crater-facies volcaniclastic kimberlite, intrusive diatreme-facies tuffisitic kimberlite breccia and hypabyssal kimberlite, respectively), (ii) shallow pipes (<500m) which comprise only a crater zone and are infilled exclusively with volcaniclastic kimberlite, mainly pyroclastic material, and (iii) small (<600-700m deep), steep-sided pipes filled predominantly with resedimented material and less common pyroclastic kimberlite or, in a few instances, with hypabyssal kimberlite. The type areas for the different types of pipes are (i) Southern Africa, (ii) the Canadian Prairies, and (iii) Lac de Gras, NWT, Canada, respectively. The kimberlite pipe at Jwaneng in Botswana contrasts with the numerous bodies that conform to type (i) and probably belongs to group (iii). Although the type of kimberlite pipe varies, it is important to note that the nature of the pre-eruption kimberlite magma that reaches near-surface is petrographically uniform world-wide. Variations in magma type, therefore, cannot be the main cause for the different types of kimberlite pipes. Certain aspects of the pipe infill for each type of pipe contrast with those of other more common rock types and thus appear to be unique to kimberlites. Such features, for example, include the microlitic textures of diatreme-facies kimberlites in the type (i) pipes or the mega-graded beds (up to 100m) in the type (ii) and (iii) pipes. There is also an absence of features commonly found in other rock types such as extrusive magmatic rocks, plutonic rocks, calderas or ring faulting.

(Scott-Smith
continued on page 4

(Scott-Smith continued from page 3)

Our present knowledge clearly shows :

(1) that kimberlite pipes worldwide have different shapes and contrasting types of infill,

(2) that the kimberlites magmas reaching near-surface prior to eruption are similar worldwide and magma variation cannot explain the diverse products of emplacement,

(3) that each of the contrasting types of kimberlite pipes must result from different emplacement processes,

(4) that more than one emplacement model is required to explain the known pipes,

(5) that any single emplacement model, such as phreatomagmatic processes (as proposed by Lorenz, see companion paper), cannot explain the emplacement of all kimberlite pipes as well as pipes formed by other magma types,

(6) that the hydrogeological environment into which the different types of kimberlites pipes were emplaced is variable,

(7) that kimberlite magmas are unusual and display their own unique styles of near-surface emplacement.

It is important to note that the a*bove conclusions are irrespective of any ideas or hypotheses about the nature of kimberlite emplacement processes*. Over the last two to examination of the geology, often for economic purposes, of the first known primary kimberlite pipes in southern Africa (near Kimberley) that led the pioneers of modern kimberlite geology, Roger Clement and Mike Skinner, to propose their landmark textural-genetic classification and emplacement models for those kimberlites (Clement & Skinner 1979, 1985 and Clement 1979, 1982, Clement & Reid 1989 respectively). Since that time, many other kimberlites in southern Africa have been examined in similar detail and there is a great deal of evidence to support their proposals (e.g. Field & Scott Smith 1998a, in press).

The need for a kimberlite-specific textural classification itself shows that kimberlite emplacement results in different textures to most other rock types and must reflect contrasting processes of formation. The textural classification is an essential part of the understanding kimberlite emplacement and is well tested (Field & Scott Smith 1998b). The detailed internal geology and textures of the southern African kimberlite pipes are complex. To explain the many observed features, the emplacement mechanisms proposed by Clement and co-workers include complex intrusive-extrusive magmatic

three decades there have been two main emplacement mechanisms proposed for kimberlites: by either magmatic (see references by Clement) or phreatomagmatic processes (see references by Lorenz in companion paper).

Kimberlite textures, and the processes forming them, are complex. The meaningful interpretation of these textures can only be undertaken on extensive three dimensional fresh exposures. Kimberlite pipes are eroded and all known rocks are now found below the original and present surfaces. Fortunately, kimberlites contain diamonds and suitable exposures are provided by mining and evaluation. In addition to megascopic examinations, the detailed petrographic and mineralogical analysis of kimberlites is crucial to an understanding of these rocks and their emplacement mechanisms. It is the modern detailed

eruptions from closed systems. The country rock geology into which many of the southern African kimberlite pipes were emplaced is similar and schematically shown in Fig. 1. The Clement emplacement model will be briefly described (for more details see Clement 1982, Clement & Reid 1989, Field & Scott Smith 1998a, in press).

During the last ~3 km of its journey to surface, the magma does not rise rapidly, and, prior to final breakthrough, the volatile-rich kimberlite behaves essentially as a closed system. The magma (dashed ornamentation in Fig. 1) rises relatively slowly by stoping and wedging along joints in the country rock. The volatiles migrate to the head of the magma/gas column. Exsolved volatiles concentrate to form a gas cap. The volatiles aid the migration into, and along, discontinuities in the country rock (thin lines within country rock in Fig. 1). There is intensified local fracturing around the head of the intruding magma

(Scott-Smith continued on page 5)

(Scott-Smith continued from page 4)

column (thickened joint lines in Fig. 1). The upward journey of the magma toward surface is intermittent. The magma/gas column rises until it encounters a temporary barrier in the country rock such as a Karoo dolerite sill. Where the rising magma meets a barrier, there is a temporary halt in ascent and further build-up of the gas cap. Eventually, after pressure build-up and further fracturing, breaching of the barrier occurs by more explosive brecciation in an envelope around the head of the magma column (triangle ornamentation in Fig. 1). The breccia contains country rock clasts that have moved little or no distance and the local stratigraphy is retained in these sub-surface breccias (shown by wavy lines within the breccias in Fig. 1).

After breakthrough the upward migration of the magma is re-established as a relatively slow intrusive process. Magma and gas rises through the breccia 'front' and starts to move upward along higher level discontinuities in the country rock. The magma column becomes larger and the process is repeated each time a barrier halts the magma migration (three times in Fig. 1). All the intrusion processes (slow wedging and stoping, faster barrier breaching) gradually affect increasingly large areas of the country rock as the surface is approached. This is due to the increasing volume of magma, the increase in volume of exsolved volatiles, the reduced confining pressure, and the related greater penetration of the volatiles into country rock. Prior to breakthrough to surface, a large volume of country rock has been pre-conditioned by successive sub-surface brecciation fronts (the 'embryonic' pipe, Fig. 1).

The thick Stormberg basalts act as the final barrier to magma ascent (Fig. 1). Explosive breakthrough occurs when the volatile pressure exceeds the confining pressure. A crater is excavated. After breakthrough the

Figure 1 The third figure from a series of six which schematically illustrate the near-surface emplacement model for southern African kimberlites (from Field & Scott Smith in press. After drawings by C.R. Clement, based on Clement 1982, Clement & Reid 1989, Field et al. 1997). This figure illustrates the nature of the pre-breakthrough 'embryonic' pipe in relation to the country rock geology (see text for more details).

uppermost part of the magma column begins to degas. After the pressure release, the volatiles rammed into the country rock prior to breakthrough (black arrows in Fig. 1) now migrate inward. This leads to authigenic brecciation, which is an important process in the modification of the 'embryonic' pipe that is about to form. The carbon dioxide and other volatiles continue to rapidly exsolve from the magma. This massive volatile streaming causes fluidisation of the magma and the formation of magma droplets (pelletal lapilli) in a volatile-rich host. As degassing progresses, the interface between gas and liquid, or the degassing front, moves downward in the magma column while the magma continues to move upward.

(Scott-Smith continued on page 6)

(Scott-Smith continued from page 5

The powerful and turbulent fluidisation process aids the implosion and causes erosion of the country rock to form the smooth-sided diatreme. The diatreme excavation process moves downward with the degassing front and the diatreme is gradually widened. Abundant angular fragments of the country rock are incorporated into the fluidised magma. Thorough mixing occurs. Sinking particles are buoyed upward by the fluidised system. Only larger blocks of country rock move downward. Most of the carbon dioxide is lost from the fluidised system. The fluidisation stage is not long lived. The system cools rapidly. The remaining vapour phase condenses to produce quenched microlitic textures in the matrix of the fluidised kimberlite (for example see Plate 12.7(a) in Clement & Reid 1989; Plates 69 & 70 in Mitchell 1997 and numerous figures in Clement 1982). Much of the country rock, on the order of 50%, remains within the diatreme, ranging from small xenoliths to floating reefs. Fluidisation has shaped the diatreme by incorporating most of the pre-brecciated areas and material produced by authigenic brecciation. The pelletal lapilli, the abundant small angular mixed country rock xenoliths and the magmatic microlitic matrix together form the diatreme infill (usually termed tuffisitic kimberlite breccia or TKB).

As fluidisation wanes, the kimberlite magma below the fluidised system The PK may be poorly bedded. Any remaining vacant areas in the crater are infilled by post-eruption resedimentation processes. The nature of resedimented material is very varied and distinct from the PK below. For example the resedimented volcaniclastic kimberlite (RVK) is commonly well bedded.

The primary pipe infill shows a gradual and progressive change in kimberlite textures with depth from partly bedded PK to intrusive monotonous TKB to HK. Each of these textural types of kimberlite dominates a different shape zone within the pipe. HK and the associated breccias occur in the irregular root zone (up to 500m deep), TKB in the steep-sided diatreme (up to 1000m deep) and PK +/- RVK in the shallower crater (up to 500m deep).

Lorenz (see companion article) has proposed that the same southern African kimberlite pipes were formed by a very different emplacement mechanism, namely by phreatomagmatic maar-like processes. In Lorenz's interpretation, the pipes are explosion craters that were back-filled by erosion of the crater rim deposits. In general, evidence for phreatomagmatic maar/crater formation processes is provided by the nature of the resulting base-surge deposits, which occur mainly in extra-crater deposits surrounding maars. No such deposits are preserved at any known kimberlite locality, so direct evidence does not exist for the southern African or other kimberlite pipes. Lorenz also suggests that one process, namely phreatomagmatism, explains the formation of maars, kimberlites,

crystallises to form hypabyssal kimberlite (HK). The gradational HK to TKB boundary represents the preserved degassing front at the time of solidification. Some of the early formed irregular intrusive contacts and pre-cursor sub-surface breccias are preserved in this root zone when fluidisation has not persisted long enough and deep enough to remove all traces of sub-surface pre-breakthrough activity or the 'embryonic' pipe. Contemporaneous with the post-final breakthrough events described above, some juvenile and xenolithic material is ejected from the crater and forms a pyroclastic eruption cloud and the crater is infilled by pyroclastic kimberlite (PK). Extra crater deposits will also form. The PK is composed of the same constituents as, and resembles, the TKB below. The boundary between the PK and TKB is gradational.

lamproites and other diatremes (sensu lato), irrespective of magma type and nature of the pipe infilling. It is clear that, in certain circumstances, phreatomagmatism is important in crater excavation, but only the sudden release of confined juvenile gases can lead to the formation of the southern African kimberlite diatremes as well as the concomitant fluidisation of the magma. The latter is a magmatic process. Clement (1982) also posed the question "How does sufficient water enter the system sufficiently rapidly to be vapourised and maintain fluidised conditions in major diatremes?", to which there is no ready expla

(Scott-Smith continued on page 7)

(Scott-Smith continued from page 6)

nation.

There is abundant evidence that shows that the main mechanism forming and infilling the southern African kimberlite pipes was not phreatomagmatism. Most maars are shallow craters filled with mainly resedimented material. Resedimentation processes are diverse so the internal geology of each maar is different. In maars, an underlying diatreme is seldom proven/present. Most southern African kimberlite pipes have proven diatremes which are deep, steep-sided and filled with a specific type of *magmatic* material (TKB) that is remarkably uniform worldwide. Also, in his model, Lorenz relies on numerous individual phreatomagmatic blasts to produce the numerous base surge beds in the crater rim deposits. Kimberlite diatremes by contrast commonly display good evidence for one major eruption.

The southern African pipes comprise three zones that have different shapes and contrasting material filling them, which indicates that they formed by varying processes within the one overall emplacement event (root zones by stoping etc., diatremes by fluidisation and craters by explosive breakthrough). The nature of the infilling of both kimberlite diatremes and the few known overlying craters contain no evidence for phreatomagmatism. These features include the monotonous nature of the kimberlite in the diatreme with a distinct lack of sedimentary structures, the consistent presence of magmatic inter-clast matrices in the TKB and textures on a megascopic scale from crater-facies PK to diatreme-facies TKB to root zone HK with depth in the pipe. Also, in the root zones the sub-surface breccias preserve the local stratigraphy and have clearly never been ejected. Kimberlite diatremes are constantly smooth-sided, irrespective of the country rock geology. In contrast, pipes which remain vacant for periods of time during resedimentation have complex shapes depending on the angle of repose of the different country rock units in the pipe wall.

The lack of vesicles in the pelletal lapilli within the diatreme-facies kimberlite is used by Lorenz to argue that the lapilli cannot have formed from a melt that was exsolving volatiles. In contrast, in the magmatic model it is proposed that the lapilli form as a result of massive, and usually complete, degassing of the carbon dioxide above the root zone. The degassing is clearly illustrated at the interface between the root zone and the overlying diatreme. There is a gradual progression from uniform HK, to segregationary HK to TKB. The well crystallised volatile-rich segregationary HK contains abundant irregular pools or segregations of late crystallising primary serpentine and calcite. As the interface is approached, the abundance of segregations (and volatiles) increases. The individual segregations begin to coalesce, thus isolating discrete bodies of the silicate matrix which, after degassing, form the pelletal lapilli in the TKB. The inter-pelletal lapilli matrix, which is composed of microlitic clinopyroxene set in a base of serpentine, crystallised

some PK, the consistent nature of that matrix (diopside and less common phlogopite microlites set in a serpentinous carbonate-poor base), the absence of exotic fines that are typically present in reworked material, the consistent pelletal not blocky shape of the juvenile lapilli, the lack of accretionary lapilli, the complete range in size of xenolithic material from small to very large floating reefs, the carbonate cement in xenoliths which were brecciated prior to incorporation into the kimberlite, and the absence of ring faults surrounding kimberlite pipes.

Another important feature that contradicts phreatomagmatic processes is the gradation in rapidly, or quenched, from the residual magmatic fluids. No carbonate is present in the TKB indicating that the carbon dioxide has been lost from the upper part of the magma. These textural variations clearly illustrate the transition from volatile-bearing HK to fluidised and degassed TKB within a single overall diatreme-forming magmatic event. The interface represents a degassing front preserved at the time when the kimberlite condensed and emplacement ceased.

The above discussion is based on the long known, and well studied, kimberlites of southern Africa. Other kimberlite pipes elsewhere in the world are

(Scott-Smith continued on page 8)

(Scott-Smith continued from page 7)

similar and must have been emplaced by similar processes. Comparable products of emplacement also occur in melilitite pipes, suggesting that they were emplaced by similar processes. The fact that melilitites are the only other silicate magma which contains abundant carbon dioxide during eruption offers support for the magmatic model discussed above. Over the last decade intense exploration has led to the discovery of many new kimberlites, particularly in Canada. It is clear that many, but not all, of these kimberlites are different from those of southern Africa. The contrasting types of pipes must result from different types of emplacement mechanisms, which will only be discussed briefly here.

There appears to be a correlation between the type of kimberlite pipe and the nature of the country rocks into which they were emplaced (Field & Scott Smith 1998a, in press). The geological settings for the three types of pipes listed in section (b) above are: (i) competent country rocks that commonly contain igneous rocks, (ii) poorly consolidated sediments, and (iii) basement covered by a veneer of poorly consolidated sediments (respectively). This correlation suggests that the near-surface geological setting is a major factor in determining the emplacement process of each kimberlite. Different emplacement mechanisms are proposed that take into account the combination of pipe variety and geological setting. Setting (i) provides the closed systems that are an pyroclastic kimberlite is texturally very different from that found in the southern African pipes, indicating that a different style of magmatic eruption must have occurred. Fluidisation and diatreme-formation did not occur. Based on the nature of the pyroclastic kimberlite, it is proposed that because of the absence of any barrier-forming igneous or other rocks, the magmas erupted from open systems by more 'normal' processes (Hawaiian/Strombolian-like) as well as other kimberlite-specific more explosive styles of eruption (e.g. producing mega-graded beds). With the absence of any preserved extra-crater deposits, there is no direct evidence to indicate the nature of the initial crater excavation event. Based on circumstantial evidence only, it seems likely that the craters were excavated by phreatomagmatic eruptions relating to well known aquifers in the poorly consolidated sediments into which they were emplaced. The evidence includes the fact that the shape and size of the craters are comparable to maars and that they flare from the known aquifer. This is the only instance among the many kimberlites examined to date by this author where it appears justified to propose that phreatomagmatic processes may be involved in kimberlite emplacement.

A third mechanism that does not conform to either of the other two processes, but is as yet poorly constrained, must apply to kimberlites emplaced into setting (iii). Other

integral part of the proposed intrusive-extrusive magmatic eruption mechanisms for the emplacement of the southern Africa pipes discussed above. Competent country rock barriers result in the sub-surface build up of juvenile volatiles, and after breakthrough, massive degassing of carbon dioxide with fluidisation of the magma below and the contemporaneous formation of the deep steep diatreme.

In contrast, the kimberlites in setting (ii) are formed by a two stage process: complete crater excavation and subsequent, separate crater infilling. The magmatic eruptions which formed the predominantly pyroclastic infilling are clearly not of phreatomagmatic origin (e.g. lack xenoliths and fines, contain vesicular and/or amoeboid juvenile lapilli as well as mega-graded beds up to 100m). The emplacement mechanisms may be required to explain other well exposed kimberlites, such as in Yakutia.

Concluding remarks

This brief discussion should help to dispel the notion that the emplacement of the different types of kimberlite pipes that have been recognised can all be explained by phreatomagmatic processes as suggested by Lorenz. At the very least, the review shows that contrasting emplacement processes must have been involved to form the different types of kimberlite pipes, irrespective of the nature of the processes. The complex intrusive-extrusive magmatic emplacement model of Clement and Skinner best explains the observed nature of the majority of

(Scott-Smith continued on page 9

(Scott-Smith continued from page 8)

the southern African kimberlite pipes (and some pipes elsewhere in the world). This author believes that the evidence supporting this magmatic model is overwhelming and that workers who suggest that phreatomagmatic processes are able, when considering the real structure of diatremes, to extend such processes to depths of 1-2 km. Further it is unrealistic to claim that experimental studies of water-magma interactions at low pressures (1-30 bar) are suitable models for high pressure (>1000 bars) fluid-magma interactions in carbon dioxide-rich systems. The

essential in the emplacement of these, and many other known, kimberlites are ignoring the geological evidence.

It is time to move on from the detrimental, two decade stalemate between the opposing models and to advance the understanding of kimberlite emplacement using other aspects of volcanological research. Perhaps an impartial, independent detailed review of the two models is required. Much of the data for kimberlites are collected by economic geologists (such as myself) whose priority is not publication. As a result much of the detailed information is not in the public domain, however, it would probably be available for review. Also the detailed observations and ideas on the emplacement of these unusual carbon dioxide-rich magmas should have a contribution to make to the understanding of explosive volcanic processes in general.

Roger Clement reviewed an earlier draft of this article (on the day of his retirement) and added the following comment : "Lorenz's erroneous and simplistic elevation of phreatomagmatism to the status of the universal, unquestionable explanation of the formation and infilling of kimberlite (and other rock types) pipes reflects a glaring omission in his approach. Lorenz has failed to examine and understand the detailed petrography and mineralogy of the rocks he seeks to interpret".

Roger Mitchell, author of three books on kimberlites (e.g. Mitchell 1997), wrote the following after reviewing this article : "I consider that the weight of the observational evidence provided by current impasse between magmatists and phreatomagmatists will only be resolved by new approaches. It would be particularly useful if volcanologists and petrologists with experience of other magmatic systems could bring novel, and hopefully bias-free, recommendations and concepts to the resolution of the problem of kimberlite emplacement. "

Although it is proposed here that the main emplacement mechanisms for kimberlites are magmatic and driven by juvenile volatiles, this does not exclude the possibility that phreatomagmatic processes may contribute and, sometimes, be important in certain circumstances (e.g. crater excavation in the kimberlites of the Canadian Prairies).

Acknowledgments

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the actual geological structure and petrographic character of kimberlitic volcaniclastic rocks currently favours hypotheses of emplacement which are dominated by magmatic processes. These studies have clearly indicated that more than one process must be involved in near-surface emplacement. There is no doubt that phreatomagmatic processes may occur in some near-surface environments but it is unreason

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(Scott-Smith continued on page 10)

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DISCUSSION ON THE FORMATION OF KIMBERLITE PIPES: THE PHEATOMAGMATIC MODEL

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Introduction

Kimberlite pipes have not erupted since early Tertiary time. Thus, the actual physical aspects of their eruptions and emplacement cannot be established from direct field observations and measurements. Geological and volcanological research, especially in the context of exploration and mining of kimberlites, provides a large data base on the geometry and the composition of the usually highly altered, diverse kimberlite rocks found inside the pipes, from hypabyssal kimberlite inside pipes and neighboring dikes. There are three crucial aspects in the formation of kimberlite pipes: 1) Removal of the country rocks that originally occupied the pipe volume; 2) Intensive fragmentation of the country rocks involved and the kimberlite magma fed into the pipe; 3) The typical lack of vesicles in the juvenile clasts as well as in the near-surface dikes, sills, and plugs. Each model for the formation of kimberlite pipes must be able to explain these aspects with the use of proper physical mechanisms, i.e. these mechanisms have to be generally accepted and experimentally proved. Since 1973 there has been a competition between the "magmatic" and the "phreatomagmatic" models. In this short paper, the present-day phreatomagmatic model is briefly presented. More details can be found in the references.

The phreatomagmatic model

In this model, low viscosity kimberlite magma (typically containing only about 50 % melt and 50 % solids), rises along a fissure of ordinary size, i.e. of restricted (e.g. 0.6 to 1 m) width and an effective length of several 10's of meters, possibly up to 100 m. Close to the earth's surface, opening of a fissure commonly makes use of or intersections of joints or faults, many of which are hydraulically active. Thus, with a high probability, magma/water interaction will occur . At hydrostatic pressures < 2-3 MPa, explosive interaction can take place (Fletcher 1995; Lorenz 1985, 1986). In many kimberlite volcanic fields, old Proterozoic/Archean basement is overlain by jointed platform rocks (sedimentary and volcanic rocks where applicable), such as the Karoo in southern Africa, the lower Paleozoic in Siberia, the Upper Proterozoic and lower Paleozoic in China, the Proterozoic in northern European Russia, and uppermost Cretaceous and Lower Tertiary in the NWT of Canada. Groundwater commonly occurs in joint aquifers in these sedimentary and volcanic rocks, once in a while in karstic carbonate rocks, less frequently in porous, permeable sediments. It is this groundwater that is primarily invoked for the explosive interaction with kimberlite magma. In the underlying jointed basement rocks, there also exist hydraulically active joints, the water within which might have participated in the later part of the eruptive history of the pipes. It is also important to realize that it is

not today's hydrogeological situation which is important. It is the hydrogeology at the time of the eruptions which has to be taken into account, but which

(Lorenz et al. continued on page 12)

(Lorenz et al. continued from page 11)

frequently can be judged from today's situation or by analogy.

Experimental investigations of many different metal, ionic, and silicate melts (including remelted hypabyssal kimberlite) interacting explosively with water suggest the following sequence of events (Buettner & Zimanowski 1998, Kurszlaukis et al. 1998b, Lorenz et al. 1994, 1999, Zimanowski et al. 1986, 1991, 1995, 1997a-c):

Contact of magma with groundwater in a confined geometry, such as in a fissure close to the surface (several 10's of meters up to perhaps 200-300 meters), leads to the entrapment of water batches by magma. In such a configuration, the groundwater is thermally insulated from the surrounding magma by a stable vapor film of low heat conductivity (Leidenfrost phenomenon). A low energy pressure wave (e.g., derived from volcanoseismicity) leads to collapse of the vapor film (Fletcher 1995, Kobayashi et al. 1996, Zimanowski et al. 1997c) with the to a two-phase (liquid-gas) state and the consequence is its thermal and mechanical decoupling.

Prior to vaporization, this fragmentation process results in the formation of small blocky juvenile fragments, called interactive particles, typically being in the size range < 100μm. It is very important to note that this brittle fragmentation of the magma is associated with the emittance of strong shock waves due to the formation of the new fracture surfaces. The larger the total fracture surface generated is, the larger the energy of the shock waves emitted will be - a situation similar to the relationship between the size of the area of a newly generated earthquake fault plane and the magnitude of the associated earthquake (i.e. energy emitted). From the experiments it is also obvious that once the supercritical water starts vaporizing, the system decouples and the eruption starts via expansion of the vapor: i.e. the eruption follows the explosion (Buettner & Zimanowski 1998, Buettner et al. 1997, Zimanowski et al. 1997a). The experiments have also shown that the energy emitted by

result that the magma and water are now hydraulically and thermally coupled, i.e. so-called direct contact between both liquids is established.

Because under direct contact conditions, the heat transfer rate from melt to water increases by approximately 2 orders of magnitude, part of the water gets heated almost instantaneously (in terms of μs) and its pressure consequently rises dramatically (1st law of thermodynamics) due to its hydraulic coupling to the surrounding magma. As a consequence the locally involved magma cools down (at > 10^6 K/s) with contraction rates much lower than the expansion rates of the heated water (Buettner et al. 1998). Now a combination of thermally induced stresses and increasing load pressure acts onto the magma. Once these stresses exceed the temperature-dependent critical shear strength of the cooling magma, the magma breaks like a solid body. Highly mobile pressurized superheated water will now intrude the fractures once they form, thus increasing the contact area and the heat transfer rate. A positive feedback mechanism establishes that is sustained until finally water starts to vaporize. Formation of vapor transforms the system from a single phase (liquid-liquid) the shock waves represents by far the major part of the total kinetic energy released, i.e. about 80 %. Only the remaining 20 % is released with the following eruption.

In the phreatomagmatic model, the thermohydraulic explosions occur at the transition of the feeder dike into the diatreme, i.e. inside the root zone, causing the kimberlite magma to fragment into tiny interactive particles. The emitted high energy shock waves have the quality required to fragment large amounts of the surrounding country rocks in a "spherical space" of a radius of up to several 10's of meters around the locus of explosion, producing country rock fragments with the observed grain sizes and angular shapes (>1 m down to dust size) (Lorenz & Kurszlaukis 1997). For example, at the ultrabasic Eifel maars, about 80 % of the ejected tephra consist of fragmented country rocks. The localization of explosions in the root zones has also been advocated in the magmatic model by Clement (1982).

Rapid expansion of the initially highly pressurized water vapor toward ambient pressure results in

(Lorenz et al. continued on page 13)

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acceleration and fragmentation of overlying magma, which hitherto was out of contact with water (Zimanowski et al. 1997). The mainly hydrodynamic fragmentation processes result in larger and more spherical clasts. Spherical juvenile ash grains and lapilli cool down significantly less rapidly than angular interactive fragments. These spherical juvenile tephra clasts are thus indicative of their formation in an expanding system and of the action

Fig. 1: Schematic model of a fully grown kimberlite pipe (and other pipe associated with other magma types). Inside the model pipe, for reasons of simplicity, syn- and postdiagenetic faults and subsided large blocks of country rocks (floating reefs) have been omitted. Details of the boundary between the upper bedded diatreme facies and lower unbedded diatreme facies are unknown. The geology of the country rocks and syneruptive faults and joints formed syneruptively in the immediate vicinity of the pipe have also been omitted. Scale: height to width about 1:1, e.g. crater diameter: 1200 m, depth of pipe about

of surface tension in a sh
time, prior to solidificati
outermost shell. Rapid e
vapor and involvement o
amounts of cold country
cause the whole system t
into the low temperature
below 200° C, which ex
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clasts, e.g. of unaltered c
bituminous shale. The lo
explosions will be in diff
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length of the feeder dike
system), wherever water
the melt. Once a thermol
explosion has fragmente
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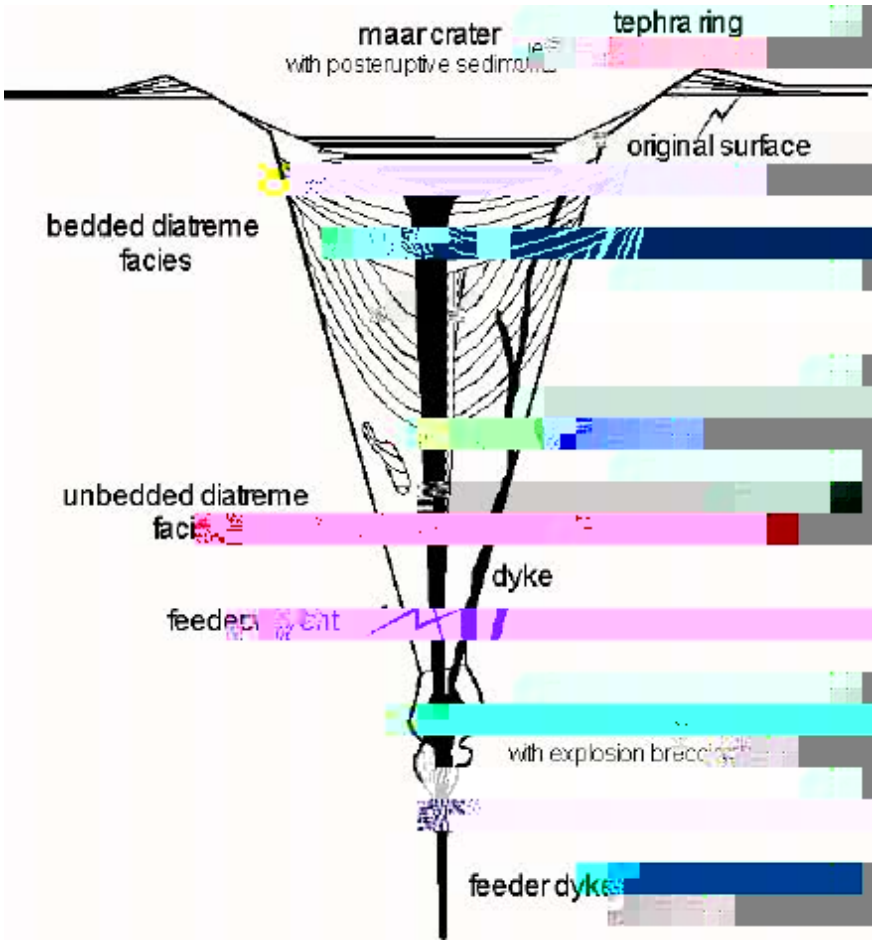

Fig. 1: Schematic model of a fully grown kimberlite pipe (and other pipe associated with other magma types). Inside the model pipe, for reasons of simplicity, syn- and postdiagenetic faults and subsided large blocks of country rocks (floating reefs) have been omitted. Details of the boundary between the upper bedded diatreme facies and lower unbedded diatreme facies are unknown. The geology of the country rocks and syneruptive faults and joints formed syneruptively in the immediate vicinity of the pipe have also been omitted. Scale: height to width about 1:1, e.g. crater diameter: 1200 m, depth of pipe about

Depending on the time a
the next explosion, the n
magma intrudes the unco
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many country rock clasts
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form a typical hypabyssa
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(Kurszlaukis et al. 1998;
On the other hand, if the
supply of groundwater, t
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ideal sites for newly risi
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groundwater to generate
thermohydraulic explosi
juvenile clasts with inco
country rock xenoliths a
(e.g. as cored lapilli).

Ejection of large amount
fragmented mass

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toward the surface results in a mass deficiency at the sites of the thermohydraulic explosions in this consequently irregularly shaped root zone. When the root zone has grown enough and has reached a critical mass deficiency, it will ultimately become rock-mechanically unstable. The overlying rocks will collapse and subside into the root zone in order to compensate for this mass deficiency. This is the beginning of the formation of the regular cone-shaped diatreme, which in principle represents a subsidence structure like a sink hole. This process of subsidence of the rock masses above the root zone into the partly evacuated root zone will repeat itself as long as the thermohydraulic explosions continue and tephra is ejected by the eruption clouds. The site of explosions will penetrate downward with time (Lorenz 1985, 1986, 1998). The consequence is that the overlying diatreme will collapse and enlarge downward again and again and repeatedly incorporate the upper parts of the vertically elongate root zone and its enclosed rock debris. Thus, the lower part of the diatreme cannot contain bedded tephra. Despite the growth of diatremes by downward penetration into the receding root zones, the diatreme walls of small or large kimberlite diatremes are systematically inclined toward the interior about 80-82 ^{o} (Hawthorne deposits then subside inside the growing diatreme and show up only as facies with some different grain size characteristics, possibly with some clast alignment or even imbrication of clasts. Only when repeated growth of the diatreme has resulted in a maar crater large enough that it can act as a new depocenter, tephra gets deposited directly from the eruption clouds, dominantly by base surges, some larger lapilli and blocks by ballistic transport, and some restricted amounts of ash and lapilli by tephra fall, forming primary thinly bedded pyroclastic beds on the maar crater floor. Repeated enlargement and subsidence of the underlying diatreme causes repeated collapse of the inner crater walls and overlying tephra deposits and, of course, of the inner parts of the tephra ring surrounding the crater. The moist debris from the collapsing tephra will form viscous debris flows/lahars and thus thick beds on the crater floor. These lahars also result in mixing of clasts of all different stratigraphic levels that have been penetrated by the diatreme and its root zone. These lahars get interbedded with the primary pyroclastic beds. This association of primary and reworked tephra on the crater floor is the crater facies described in many kimberlite publications. However, their subsidence inside the growing diatreme makes them automatically an integral

1975). Growth of the diatremes results almost always in the same systematic shape. Expanding tephra clouds rise repeatedly through the subsided rock debris of the diatreme because of new phreatomagmatic eruptions. Thus new feeder vents for the rising clouds form. After an eruption, unstable/unconsolidated clastic material surrounding the narrow feeder vents will collapse into the vent and fill it. New tephra rising through collapsed vents will mix with material previously filling it, a process in part responsible for mixing of different clast types.

The initial diatreme formed when rocks collapsed/subsided into the initial high level root zone. Subsidence is propagated upward and consequently causes the surface to subside, forming a small crater. Such a crater of subsidence origin is a maar crater. This initial maar crater is so small that the eruption clouds will rise above it and deposit almost their total load outside. But such a small crater collects debris collapsing from the inner crater wall and these mass part of a diatreme: the upper bedded diatreme facies. Finely bedded base surge deposits loaded with accretionary lapilli are interbedded with debris flow deposits of reworked kimberlite tephra in a sequence several hundred meters thick and found also several hundred meters below the former crater floor in a number of the Diavik kimberlite pipes at Lac de Gras, NWT, Canada.

The bedded upper diatreme facies is commonly underlain by an unbedded lower diatreme facies, as has been described above. This facies is generally composed of several columns of different facies characteristics cutting each other depending on the age sequence. It is commonly along the margins (i.e. at the diatreme walls) that large masses of country rocks occur subsided from higher stratigraphic levels - the so-called floating reefs (Clement 1982). These subsided floating reefs can only be explained

(Lorenz et al. continued on page 15)

(Lorenz et al. continued

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if the clastic kimberlite inside the diatreme walls also subsided.

The massive appearance of the lower diatreme facies is probably formed by a number of different processes, without all processes active in each case. Part of the lower diatreme facies can be derived by incorporation of root zone rocks within the enlarging and downward-penetrating diatreme. Some of the rocks may be derived from subsiding debris flow deposits and their bedding features escaped recognition. Some subsided bedded tephra may lose bedding features due to water escape and liquefaction. Part of the bedded rocks can collapse along the margin of active feeder vents and thus lose their bedding. The expanding vapor from the thermohydraulic explosions can cause inflation of the lower parts of the diatreme fill, and the consequent eruption then will cause deflation and both processes may also cause loss of bedding features.

At the earth's surface, a large part of the superheated vapor in the expanding eruption cloud will condense rapidly and, in combination with ejected excess water, drastically lowers the transport capacity. Much of the solids within the wet cloud will collapse back to the surface and form moist to wet base surge clouds and their deposits in the maar crater and on the surrounding tephra ring. Some fines, however, will drift away.

Gravity-induced compaction during and after the eruptions produces differential subsidence of the pipe contents, formation of pre-diagenetic faults and syn- and post-diagenetic 1975). These diagenetic and hydrothermal alteration processes not only cause unconsolidated clastic kimberlite to transform into hard diatreme rocks but also the obliteration of many important details like the existence of tiny interactive clasts consisting of highly unstable glass.

The many thinly bedded tephra beds typical of base surge deposits that occur in a number of the NWT kimberlites and in Jwaneng make it obvious that there were many (hundreds to thousands) eruptions/explosions with a small juvenile tephra volume production per unit eruption because only a small volume of magma rises through the feeder dike per unit time. This is easily conceivable if one considers that the feeder dike is rather small in width and short in effective length. Continuous phreatomagmatic activity also requires a sufficient recharge of water per unit time. At the type locality of maar volcanoes, in the groundwater-poor Eifel District, rather restricted volumes of groundwater from joint aquifers were sufficient to drive continuous phreatomagmatic explosions.

The physical volcanological model described above does not require involvement of exsolved volatile phases. The only direct proof for the existence of a gas phase in the magma during explosive fragmentation would be vesicles in the juvenile fragments. In kimberlite pipes, as well as in all other diatremes, general lack of vesicles is a typical feature. Vesicular juvenile kimberlite clasts have only been observed in the kimberlite deposits at Fort à la Corne, Saskatchewan (Scott Smith 1997; Field & Scott Smith 1998)

faulting with the generation of slickensides. In contrast to other magma types, hydration of the olivine-rich kimberlite clastic diatreme rocks and their hypabyssal intrusives cause a dramatic volume increase of the diatreme fill and further differential faulting and slickensides. Influx of groundwater into the originally permeable clastic pipe fill and its involvement in the formation of the serpentinite matrix and serpentine replacement of olivine phenocrysts and xenocrysts is indicated by isotope ratios of H, C, O, and Sr ((Barret & Berg 1975, Sheppard & Dawson and in the Buffalo Hills diatremes in Alberta (Carlson et al. 1998),. This proves beyond doubt that a) kimberlite magma can exsolve volatile phases in near-surface environments and that b) even moderate chilling of the clasts is able to preserve such vesicles. In addition melting experiments at atmospheric pressures under low oxygen fugacity using hypabyssal kimberlite from Hanaus 2 have shown that 0.5 kg of this material could easily be melted without a detectable loss of mass due to exsolution of volatiles. In contrast, the same material in small masses and in a powdered form showed a

(Lorenz et al. continued on page 16)

(Lorenz et al. continued from page 15)

loss of ignition of >16 wt.% under oxidizing conditions (Kurszlaukis et al. 1998b).

Conclusion

Kimberlite pipes in principal are not any different from pipes associated with other magmas. The unifying aspect for all these maars and diatremes is that it is the special mechanism of conversion of thermal energy of the respective magmas into kinetic energy which is responsible for their formation.

We would like to state that our model for the formation of kimberlite pipes is not in contradiction with the field observations. Furthermore all basic physical mechanisms used in the model are experimentally verified and generally accepted by the society of physicists and volcanologists.

Acknowledgments

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ARE PLINIAN BASALTIC ERUPTIONS SO RARE?

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We used to think that basaltic explosive volcanism only produced Strombolian activity, ranging from mild explosions to more energetic fire fountain eruptions. In Italy, Stromboli and Etna volcanoes give excellent examples of this type of activity. Plinian eruptions are normally associated with volcanoes that erupt evolved magmas. Until now, most volcanologists have believed that the explosivity of an eruption is dependent on the magma composition, because most silicic magmas are emitted during explosive eruptions whereas most basaltic magmas are emitted in effusive eruptions. This widespread opinion has led scientists to not accept the field evidence of unusual volcanic deposits and, consequently, to underestimate the occurrence of anomalous behavior at some basaltic volcanoes. Two pioneer papers on basaltic Plinian eruptions (Williams, 1983; and Walker et al., 1984) were published more than a decade ago and no work has been published on this topic since. Now, the discovery of a Plinian basaltic eruption of Roman age at Etna (Coltelli et al., 1998) raises important issues for previous hazard assessments at Etna and other basaltic volcanoes.

Studying the pyroclastic succession of Etna, we found a coarse-grained scoria fall bed on the southeastern flank, which we used as a guide-horizon for the late Holocene stratigraphy of the volcano (Coltelli et al., 1995). Its thickness (from 0.1 to 2 m), stratigraphic position and southeastward dispersal (Fig. 1) agree with Roman chronicles that describe a large eruption in 122 BC (Fig. 2), after eighteen years of strong effusive activity (Alessi, 1830; Ferrara, 1835). The chronicles reported a lapilli fallout over the ancient town of Catania that caused fires and roof collapse, and hid the sun behind an ash cloud for days. Damage suffered by the inhabitants was so severe that they were exempted from paying taxes to Rome for ten years. Field data, radiocarbon age (2180±60 yr. BP), and historical reports led us to the conclusion that this thick and widespread deposit was produced during the 122 BC eruption.

The succession of the 122 BC eruption deposits comprises both scoria and ash- fall layers, divided into seven units (A-G). The basal unit A is a thin, black coarse ash fall bed. Unit B is a few-centimeter thick, yellowish tuff bed. The Plinian fallout deposit is formed by two similar units (units C and E) separated by a thin yellowish vesiculated tuff (unit D). Units C and E represent the most voluminous part of the 122 BC sequence. They are composed of sub-rounded, black poorly vesiculated lapilli and lava lithics. The scorias are hawaiitic in composition, characterized by large plagioclase phenocrysts. The lithic content in the Plinian fall layers is small (13 and 17 wt%), suggesting that the fragmentation was caused by magmatic gas expansion. The eruption ended with a complex phreatomagmatic phase that produced the upper tuff (unit F). Surge and fallout deposition alternated to produce this unit. Unit G, a massive tuff, probably formed during post-eruption phreatic activity inside the caldera through the remobilization of the fine material deposited on the upper southwest flank of the volcano.

We mapped the Plinian fall deposit accurately on land (Fig. 1). From the isopach and isopleth maps, the vent was located in the Etna Central Craters area, named Cratere del Piano. Cratere del Piano, which was an ancient

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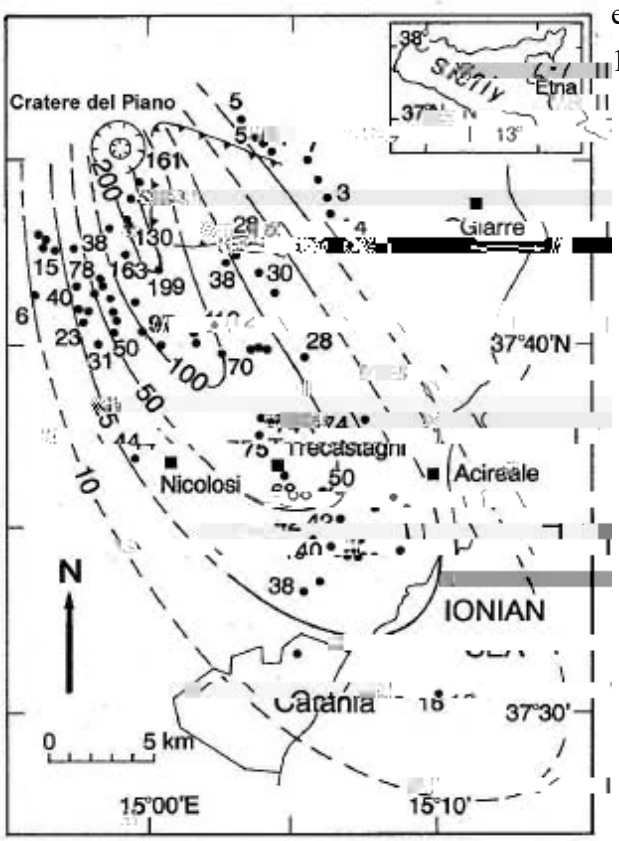
(Del Carlo et al. continued from page 18) summit depression still visible in the last century, probably formed during this eruption. The Plinian fall volume of the deposits on land, fallout area beyond the 0.1 m isopach to estimate the volume up to the 0.01 m thickness. The value obtained is

calculated from a thickness versus square root of isopach area plot, is 0.285 km^3. However, its thinning rate suggests a remarkable fine-fraction enrichment in the distal area, on the Ionian Sea. A best-fit straight line of deposit thickness on land versus distance intercepts the 0.01 m thickness at 60 km, whereas we found a 0.02-m-thick deposit on Alfeo Seamount and 0.01-m-thick deposit on the Malta Rise (Ionian Sea), respectively, at 140 and 400 km from the vent along the dispersal axis. We extrapolated the fine fraction larger than 1 km^3 and greatly exceeds that calculated from the deposit on land. The dense rock equivalent of the Plinian deposit juvenile fraction is about 0.4 km^3, using a measured bulk density of 0.9-1.2 g/cm^3 and a rock density of 2.7 g/cm^3.



The column height ranged from 24 to 26 km, with a wind velocity >20 m s^{-1} for the dispersal of 1.6, 3.2, and 6.4 cm lithic clasts, based on the method of Carey and Sparks (1986). The mass eruption rate is estimated as 5-8.5 x 10^7 kg s^{-1}, using the methods of Wilson et al. (1978) and Sparks (1986). These data have provided conclusive evidence of the Plinian magnitude of the 122 BC eruption.

The 122 BC eruption of Mt. Etna mainly produced a thick fallout with minor flow deposits, similar to the few other documented basaltic Plinian eruptions (Masaya Caldera, Nicaragua, Williams, 1983; and Tarawera, New Zealand, Walker et al., 1984). The 122 BC eruption interrupted a period of high effusive activity, similar to that seen in recent years at Etna. It involved a volume and chemical composition of hawaiitic magma comparable to that of recent large effusive eruptions at Etna. Consequently chemical composition is not sufficient to explain the dramatic change from gentle lava effusion to high explosive eruption.

Why did this basaltic magma produce a Plinian eruption?

The explanation of the eruptive mechanism we developed tries to put together deposit features and Etna geological structure.

Figure 1. Isopach map (in centimeters) of the 122 BC Plinian fall deposit (units C and E). Dashed lines are extrapolated isopachs because of lack of exposures due to lava flow cover and human activity. Thickness of representative sections is reported. Line with triangles is Valle del Bove rim; innermost hachured circle shows present-day summit craters; outermost hachured circle is the buried Cratere del Piano rim (from Coltelli et al., 1998).

Plinian eruptions are characterized by a very high rate of magma discharge with respect to the classical basaltic eruptions (typically 103-104 kgs^{-1} for lava flows, 105-106 kg s^{-1} for fire fountains, 107-108 kg s^{-1} for Plinian eruptions) and imply a high magma ascent rate. Although the physical properties and the volatile content of basaltic magmas normally do not allow Plinian eruptions (Wilson et al., 1980), the sudden decom

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(Del Carlo, et al. continued from page 19)

pression of a basaltic magma may cause the nucleation of a large number of bubbles that rapidly increase the viscosity and reduce the density of the magmatic mixture. At low magma ascent rates, gas separates from the low-viscosity melt and bubbles coalesce during the ascent, producing the explosion of large bubbles (Strombolian activity, fire fountains). Conversely, high speeds in basaltic magmas prevent bubble coalescence and affect the eruptive style (Roggensack et al., 1997). In conclusion, different paths of decompression of initially similar magmas may strongly influence the eruptive style.

Examining the recent activity of Etna, we have found an interesting similarity between 122 BC and 24 September, 1986, eruptions, in spite of their very different volumes (AD 1986, 3 x 10^6 m^3 vs. 122 BC, >1 x 10^9 m^3). The 1986 explosive event began with the collapse of an active summit Strombolian cone when a set of graben-style open fissures cut the volcano summit (Romano et al., 1986). After a few hours, an explosive phase cleared the conduit and formed a 10-km-high eruptive column. A link between the opening of the fissures on the upper northeastern flank, the drain-back of the magma in the volcanic conduit, and the following major explosive eruption is evident. We

Figure 2. Picture of the 122 BC Plinian fall deposit at Catania northern suburbs burying a Roman amphora.

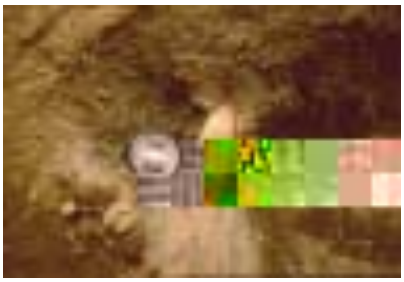

Figure 2. Picture of the 122 BC Plinian fall deposit at Catania northern suburbs burying a Roman amphora.

Following these arguments, we suggest that, during the emplacement of the 122 BC magma within the volcanic pile, a nonelastic deformation due to the powerful buoyancy of the large magma body produced a major permanent displacement of the eastern upper flank of the volcano. A void space passed through the magma chamber, causing it to suddenly decompress. Immediately following this, a large portion of the magma in the chamber became foam, which, due to its low density, rose at high speed through the conduit as a pyroclastic mixture, forming the Plinian eruptive column.

infer that it could be a typical behavior of Etna volcano and that the magnitude of the related eruptions depends on the volume of the magma batch involved and the rate of its decompression. Studying Holocene tephrostratigraphy of Etna, at least 25 sub-Plinian eruptions have been recognized (Coltelli et al., 1999) and several of these may have had the same trigger mechanism of 122 BC and 1986 eruptions.

The finding of a Plinian-type eruption at Etna, which is mostly known for its frequent lava flow eruptions, points out a new unexpected behavior of the volcano. Understanding of the triggering mechanisms of Plinian basaltic eruptions is of fundamental importance in order to assess the probability of future, large explosive events at basaltic volcanoes. Moreover, the identification of high-energy explosive eruptions outlines that, under particular conditions, quiet effusive basaltic volcanoes may produce catastrophic events. Now, we can say that Plinian and sub-Plinian basaltic eruptions are not so rare, at least at Etna volcano. What about at other very active basaltic volcanoes around the world?

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Exploring Volcanoes:

Utilization of their resources

and

Mitigation of their hazards.

** Topics of symposium :*

- utilization of energy and other volcanic resources

- volcanogenic sediments

- volcano geophysics

- volcano seismology

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- hazard mitigation

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- structure of volcanic island arcs

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Auckland, New Zealand

February 12th 16th, 2001

An international meeting to bring together volcanologists, sociologists, psychologists, emergency managers, economists and city planners to re-evaluate volcanic crises preparedness and management in cities and densely populated areas.

Organised by the Institute of Geological & Nuclear Sciences (IGNS) Auckland Regional Council (ARC), Massey University, The University of Auckland, and International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI)

This meeting will be held from Monday, February 12th to Wednesday February 14th 2001, at the Sky City Conference Centre in Auckland, New Zealand. Following the meeting, 2 days of field trips (on Thursday 15th and Friday 16th of February 2001) are scheduled.

TOPICS:

Education

Emergency Management / Crisis Management

Hazard and Risk Assessment

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Volcanic Processes

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Montagne Pelée 1902 - 2002:

Explosive volcanism above subduction zones.

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A workshop will be organised in 2002 by the Institut de Physique du Globe

de Paris sponsored by IAVCEI, the territorial authorities of French Antilles, the Institut National des Sciences de l'Univers (CNRS), to commemorate the 1902 eruption of Montagne Pelée. This workshop will be located in Martinique (French Antilles) the week before or after May 8, 2002. It will be preceded and followed by field trips.

Tentative Topics:

1. Eruption regimes

· lava domes : growth and explosivity

· Plinian eruptions

· transport and deposition of pyroclastic flows

· flank failure of volcanoes

· impact of fluids on eruption regimes

(Physical modelling will be widely developed in these topics).

2. Volcanism and tectonics

· tectonics and seismicity in subduction zones

· relationship between tectonics and volcanism

3. Genesis and evolution of calc-alkaline magmas.

· sources (mantle, subducted crust, sediments)

· melting and differentiation, contamination, magma mixing

· impact of fluids

4. Man facing volcanoes, crisis management, and case histories.

· socio-economic aspects of eruptions

· volcanic plumes and hazards to aircrafts (modelling and case histories)

5. Surveillance of volcanoes and eruption forecasting

· surveillance monitoring : present and future

· geological, geophysical and geochemical precursors to volcanic eruptions

· eruptive history of volcanic eruptions

· eruptive scenarios

To receive the first announcement, you must express your interest and

send your co-ordinates to: Obs.volcanologiques@ipgp.jussieu.fr

Due to space limitations, the workshop will be limited to about 150 people.

Symposium on Modeling of Volcanic Transport Processes

At the

Fall Meeting of the American Geophysical Union

December 13-17, San Francisco.

Volcanic transport processes involve mass, momentum, and energy transfer during magma segregation and ascent through the lithosphere; magma storage, differentiation, and stability of underground storage reservoirs; magma ascent towards the surface and interaction with its surroundings that may involve water stored in underground acquifers; thermo-mechanical effects in volcanic systems; transport of pyroclastic products in the atmosphere and along the slopes of volcanoes. All of these processes are complicated to describe in terms of physical and chemical laws because of the complex material behavior involving many components and several phases subjected to varying temperature and pressure conditions.

Recent modeling works do not address: magma chamber and stability processes; thermo-mechanical effects of volcanic systems; multiphase flow turbulence

modeling; flow in porous media; non-isothermal and phase change flows in conduits; constitutive equations for magma fragmentation and tephra transport suitable for inputs into physical models; suitability of different multiphase flow models employed in modelling magma chambers and volcanic columns; lahar and lava flow modeling; proper utilization of kinematic, dynamic, and thermal similitude conditions in laboratory studies of volcanic processes; standards for verification and validation of complex thermo-mechanical and multiphase flow computer codes, etc.

The purpose of the Symposium is to provide a forum for critical discussions pertaining to the modeling of volcanic processes with realistic physical and chemical models and laboratory experiments. Another objective of the symposium is to transform the contributions into original articles for inclusion into a scholarly journal.

Call for contributions:

1. Critical reviews dealing with different themes of the symposium.

2. Experimental studies with the objectives of realistically simulating the volcanic processes.

3. Theoretical studies aimed at developing complex thermo-mechanical and multiphase and multicomponent flow models.

4. Numerical studies that properly address verification and validation.

5. Global simulation studies aiming at volcanic eruption forecasting.

In the preliminary call for contributions we received many responses from around the world and look forward to a very productive session. Several contributors have already agreed not only to present their research but also reviews that should be beneficial to those who may wish to enter into the modeling field.

Abstracts deadline: September 2, 1999 (Postal/Express Mail), or September 9, 1999 (Interactive Web Form) (see *http://www.agu.org/meetings* or contact one of the conveners)

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FROM MAGMA TO TEPHRA: Modelling Physical Processes of Explosive Volcanic Eruptions

Edited by Armin Freundt, and Mauro Rosi

ISBN: 0-444-82959-8 334 pgs NLG 285.00 (euro 129.33)US$ 135.00

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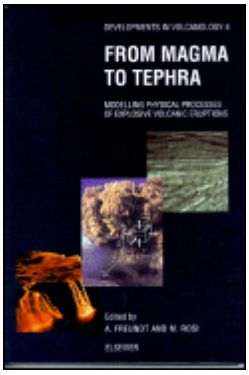


Included in series **Developments in Volcanology, 4**

Hot magma rising through the Earth's crust releases gases that expand and may come into contact with external water that vaporizes. The magma is then fragmented into an accelerating gas-particle/droplet mixture that is shot into the atmosphere, possibly in an overpressured state, where it may buoyantly rise up into the stratosphere as an ash plume, partially or totally collapse back to the surface, or rapidly expand sideways, or undergo a combination of these processes. Tephra is then deposited on the Earth's surface by pyroclastic fall, flow or surge, or some hybrid mechanism. The combination of processes that operate from the degassing of magma to the emplacement of tephra makes an explosive volcanic eruption, and the physical characterization of these processes is the scope of this book.

In this book we summarize the insights into key aspects of explosive volcanic eruptions gained from physical modelling to date. The seven chapters are arranged in an order reflecting the sequence from processes acting within the volcanic conduit through dynamics of eruption and transport through the atmosphere to

mechanisms of emplacement on the Earth's surface.

Excellent reading for research volcanologists, private scientists, professionals, university libraries, government research institutes, graduate students and researchers.

Partial Contents

Magma Degassing and Fragmentation: Recent Experimental Advances. Nucleation. Bubble Growth. Accelerating two-phase flows. Brittle failure. Post-fragmentation effects. Non-explosive degassing. Relaxation geospeedometry of volcanic glass. Bibliography. **Phreatomagmatic Explosions**: Explosive phreatomagmatic volcanism. Physics of volcanic MFCI. Diagnosis and monitoring of phreatomagmatic explosions (volcanic MFCI). **Volcanic Conduit Dynamics:**. Magma ascent models. Magma ascent dynamics in steady state explosive eruptions. **Eruption Column Physics**. Multiphase flow and the multifield approach. Multifield governing equations. Closure of governing equations. Approaches to analysis of eruption column dynamics. Steady state dynamics. Time-dependent dynamics with constant eruption rate. Time-dependent dynamics with transient eruption rate. Influence of the ambient medium. Conclusion**. Plinian Eruption Columns:** Particle Transport and Fallout. Models of particle transport in Plinian columns. Clast dispersal in crosswinds. Assessment of eruption parameters. **Pyroclastic Flow Transport Mechanisms**: Characteristics of ignimbrites and pyroclastic flows. Transport processes of sedimenting particulate flows. Pyroclastic flow models. From model flows to ignimbrites: complexities during emplacement. Concluding remarks. **Pyroclastic Surges and Compressible Two-Phase Flow**. Observations. Theory. Origin of the SFT equations. Analysis of surge steam condensation. References. Subject index.

The Geological Society is distributing a new

video

By David Lea and Professor Steve Sparks.

http://bookshop.geolsoc.org.uk (see New Books)

Montserrat's Andesite Volcano 1995 to 1998.

David Lea has documented the eruption from its beginnings in 1995, and his spectacular video images provide the backdrop for this unique, educational project. The film not only tells the story of the eruption, but also looks into the major volcanic processes of andesite volcanoes, describes the products and effects of the eruption, introduces modern methods of monitoring an active volcano, and shows the human consequences of volcanic activity on a small island community.

Professor Steve Sparks of Bristol University (UK) explains the phenomena and then takes you on a video field trip where you will learn about the plate tectonic origin of andesite volcanoes, lava dome growth, the chemistry and mineralogy of andesite, pyroclastic flows, explosive eruptions, ash fall, debris avalanche, volcanic blasts, lahars and volcanic hazards. Outstanding video of each phenomenon is followed by explanations of the deposits, effects, and hazards in the field.

This educational video was created for university students taking introductory courses in geology, earth science, and environmental sciences. However the authors feel that it will be enjoyed by a much wider audience, interested in understanding volcanoes and appreciating these great spectacles of nature.

There will be a free guide accompanying the video, which will be in Acrobat pdf format, and will be available for downloading on September 1, 1999. The booklet, which will be free whether or not you buy the video, includes an explanatory text of the Montserrat volcano, maps, and a glossary.

Melting the Earth

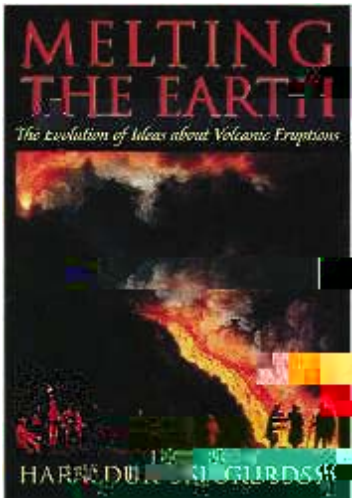
The History of Ideas on Volcanic Eruptions

By Haraldur Sigurdsson

272 pp. $30.00 ISBN 0-19-510665-2 June 1999

Oxford University Press

http://www.oup-usa.org/index/index.html



From prehistoric times to the fiery destruction of Pompeii in 79 AD and the more recent pyrotechnics of Mt. St. Helens, volcanic eruptions have aroused fear, inspired myths and religious worship, and prompted heated philosophical and scientific debate. Melting the Earth chronicles humankind's attempt to understand this terrifying phenomenon and provides a fascinating look at how our conception of volcanoes has changed as knowledge of the earth's internal processes has deepened over the centuries.

A practicing volcanologist and native of Iceland, where volcanoes are frequently active, Haraldur Sigurdsson considers how philosophers and scientists have attempted to answer the question: Why do volcanoes erupt? He takes us through the ideas of the ancient Greekswho proposed that volcanoes resulted from the venting of subterranean windsand the internal combustion theories of Roman times, and notes how thinking about volcanoes took a backward, symbolic turn with the rise of Christian conceptions of Hell, a direction that would not be reversed until the Renaissance. He chronicles the 18th-century conflict between the Neptunists, who believed that volcanic rocks originated from oceanic accretions, and the Plutonists, who argued for the existence of a molten planetary core, and traces how volcanology moved from "divine science" and "armchair geology" to empirical field study with the rise of 19th century naturalism. Finally, Sigurdsson describes how 19th and 20th century research in thermodynamics, petrology, geochemistry and plate tectonics contribute to the current understanding of volcanic activity. Drawing liberally from classical sources and firsthand accounts, this chronicle is not only a colorful history of volcanology, but an engrossing chapter in the development of scientific thought.

Haraldur Sigurdsson is Professor in the Graduate School of Oceanography at the University of Rhode

Island and the author of Caribbean Volcanoes: A Field Guide and editor-in-chief of Encyclopedia of

Volcanoes.

Encyclopedia of Volcanoes

Edited by Haraldur Siggurdson, Bruce Houghton, John Stix and Steve McNutt

Academic Press

ISBN: 012643140X, August 1999

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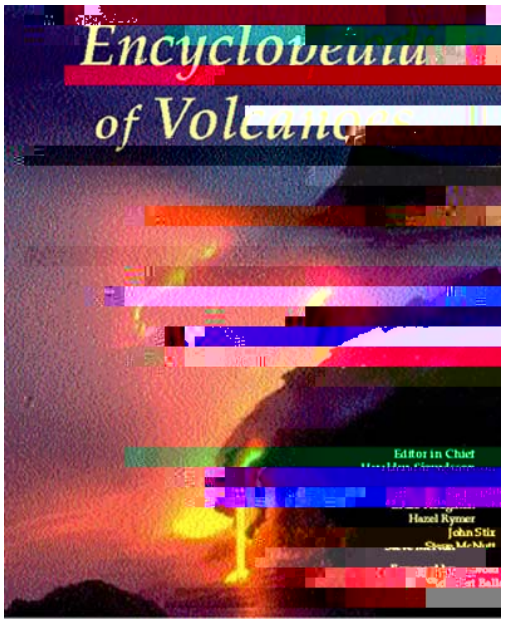

Volcanoes are unquestionably one of the most spectacular and awe-inspiring features of the physical world. Our paradoxical fascination with them stems from their majestic beauty and powerful, if sometimes deadly, destructiveness. Notwithstanding the tremendous advances in volcanology since ancient times, some of the mystery surrounding volcanic eruptions remains today. The Encyclopedia of Volcanoes summarizes our present knowledge of volcanoes. Through its thematic organization around the melting of the earth, it provides a comprehensive source of information on the multidisciplinary influences of volcanic eruptions - both the destructive and the beneficial aspects. The book contains: More than 1,400 pages of informative text, arranged in nine different thematic sections; comprehensive overview articles, all of them commissioned especially for this volume and thoroughly peer reviewed for accuracy; figures and tables to support and amplify the text, including a series of special color plates; and a comprehensive and up-to-date catalog of historically active volcanoes.

Partial Contents:

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Fragmentation. S. Vergniolle and M. Mangan, *Strombolian and Hawaiian Eruptions*. M.M. Morrissey and L.G. Mastin, *Vulcanian Eruptions*. Cioni, P. Marianelli, R. Santecroce, and A. Sbrana, *Plinian* Eruptions. J.D.L. White and B. Houghton, *Pyroclastic Eruptions*. B.F. Houghton, C.J.N. Wilson, R.T. Smith, and J.S. Gilbert, *Phreatoplinian Eruptions*. S. Carey and M.I. Bursik, *Volcanic Plumes*. C.J.N. Wilson and B.F. Houghton, *Pyroclastic Transport and Deposition*. B.F. Houghton, C.J.N. Wilson, and D.M. Pyle, *Fall Deposits*. G. Valentine and R.V. Fisher, *Deposits of Surges and Directed Blasts*. A. Freundt, S.N. Carey, and C.J.N. Wilson, *Ignimbrites and Deposits of Block-and-Ash Flows*. J.W. Vallance, *Lahar Deposits*. T. Ui and M. Yoshimoto, *Debris Avalanche Deposits*. S. Carey, *Volcaniclastic Sedimentation Around Island Arces*. P.W. Lipman, Calderas. J.P. Davidson and S. Da Silva, *Composite Cones*. D. Vespermann and H.U. Schmincke, *Scoria Cones and Tuff Rings*. **Extraterrestrial Volcanism:** P.D. Spudis, *Volcanism on the Moon*. R. Lopes-Gautier, *Volcanism on IO*. L. Crumpler, *Volcanism on Venus*. J.R. Zimbelman, *Volcanism on Mars*. P. Geissler, *Cryovolcanism in the Outer Solar System*. **Volcano Interactions:** P. delMelle and J. Stix, *Volcanic Gases*. F. Goff and C. Janik, *Geothermal Systems*. P. Browne *and M. Hochstein, Surface Manifestations*. *D*. Butterfield, *Submarine Hydrothermal Vents*. P. delMelle and A. Bernard, *Volcanic Lakes*. N.C. White and R.J. Harrington, *Mineral Deposits Associated with Volcanism*. **Volcanic Hazards**: T.P. Miller and T.J. Casadevall, *Volcanic Ash Hazards to Aviation*. M.J. Mills and O.B. Toon, *Volcanic Aerosol and Global Atmospheric Effect*. S. Nekada, *Hazards from Pyroclastic Flows and Surges*. K. Rodolfo, *Lahars and Jokulhlaup Hazards*. H. Rymer and G. Williams-Jones, *Volcanic Gas Hazards*. J.E. Beget, *Volcanic Tsunamis*. S.R. McNutt, *Volcanic Seismicity*. P. Baxter, *Impacts of Eruptions on Human Health*. M. Arthur, *The Volcanic Contribution to the Sulfur and Carbon Geochemical Cycle*. I. Thornton, *The Ecology of Volcanoes-Biological Recovery and Colonization*. M. Rampino and S. Self, *Volcanism and Biotic Extinction*. **Eruption Response and Mitigation:** J.B. Murray, C.A. Locke, and H.Rymer, *Ground Deformation, Gravity, and Magnetics*. J. Stix and H. Gaonach, *Gas, Plume, and Thermal Monitoring*. S. McNutt, J. Stix, and H. Rymer, *Synthesis of Volcano Monitoring*. C. Newhall, *Volcano Warnings*. S. de la Cruz, R. Quaas, and R. Meli, *Volcanic Crisis Management*. R. Blong, *Volcanic Hazards and Risk Management*. D. Johnson and K. Ronan, *Risk Education and Intervention*. **Economic Benefits and Cultural Aspects of Volcanism:** S. Arnorsson, *Exploitation of Geothermal Resources*. C-l. Ping, Volcanic Soils. J. Dehn and S.R. McNutt, *Volcanic Materials for Commerce and Industry*. H. Sigurdsson & R. Lopes-Gautier, *Volcanoes and Tourism*. S. Harris, *Archaeology and Volcanism*. H. Sigurdsson and R. Lopes, *Volcanoes in Literature and Film*.

The Physics of Explosive Volcanic Eruptions

Edited by R. S. J. Sparks and

J. S. Gilbert

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The Physics of Explosive Volcanic Eruptions includes review papers that outline our current understanding of the physical processes affecting magma during volcanic eruptions. The book highlights research areas where our understanding is incomplete, or even completely lacking, and where work of volcanic processes is to be substantially improved. Topics include the physical properties of silicic magma, vesiculation processes, conduit flow and fragmentation, gas loss from magmas during eruption, models of volcanic eruption columns, tephra dispersal and pyroclastic density currents. Readership: Volcanologists, geologists, environmental scientist and physicists

Contents

· Future research directions on the physics of explosive volcanic eruptions

· Recent experimental progress in the physical description of silicic magma relevant to explosive volcanism

· Vesiculation processes in silicic magmas

· Conduit flow and fragmentation

· Gas loss from magmas through conduit walls during eruption

· Observations and models of volcanic eruption columns

· Tephra disposal

· Pyroclastic density currents

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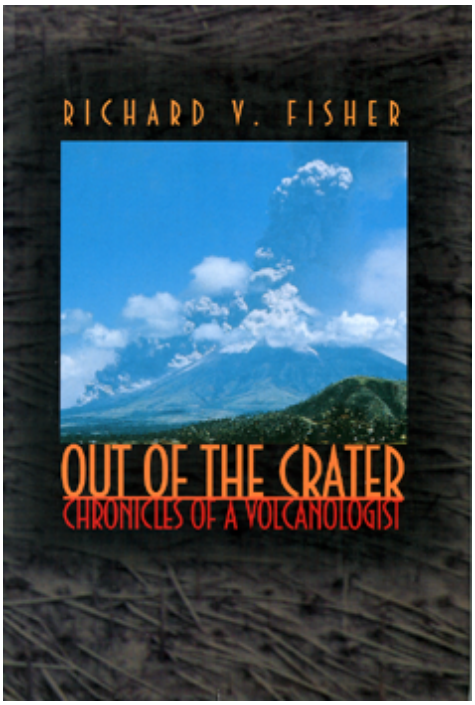
Out of the Crater: Chronicles of a Volcanologist

By Richard V. Fisher, 1999.



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Volcanologists venture to treacherous volcanoes the world over in the pursuit of their science. They work around craters of boiling magma and amidst smoke, flames, scorched rocks, and clouds of noxious gasesbalancing personal risk against advancing knowledge about one of nature's most dangerous and unpredictable forces. Richard Fisher, a world-renowned volcanologist, has had more than forty years of experience in the field. In this book, he blends autobiography with clear, accessible science to introduce

readers to the basics of volcanology and to the wonders of volcanoes that he has studied and learned to both fear and admire.

In the course of the book, we follow Fisher as he descends into the steaming crater of the Soufriére Volcano on the island of St. Vincent, as he conducts research on lava flows on the desolate south shore of the Island of Hawaii, and as he struggles to understand the explosion at Mount St. Helens. We learn about his pioneering work on pyroclastic flows and surgesthe hurricanes of gases, molten lava, and volcanic debris that cause most of the death and destruction when volcanoes explode. He tells of solving a historic scientific problem at Mount Pelee, Martinique, where 29,000 people were killed in a pyroclastic flow in 1902. Fisher also offers a volcanologist's view of the explosion of Mount Vesuvius that devastated Pompeii and Herculaneum. He writes about the cultural rewards and challenges of conducting research in isolated areas of such countries as Argentina, Mexico, and China. And he discusses the early influences that steered him toward volcanologyincluding his army experiences as a witness to two atom-bomb explosions at Bikini atoll.

Out of the Crater is written in an inviting, nontechnical style. With its deft combination of personal stories and scientific information, it is an inspiring account of a remarkable life and a compelling examination of some of the most spectacular forces shaping the face of the Earth.

Richard V. Fisher is Professor Emeritus of Geological Sciences at the University of California, Santa Barbara, where he has taught and researched since 1955. In 1997, he was awarded the Thorarinsson Medal, the highest honor of the International Society of Volcanologists. Fisher is the coauthor, with Grant Heiken and Jeffrey B. Hulen, of Volcanoes: Crucibles of Change (Princeton). He also wrote Pyroclastic Rocks with H.-U. Schmincke and coedited Sedimentation in Volcanic Settings with G. A. Smith.