Project Title - Supercomputer Modeling of Volcanic Eruption Dynamics

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Reporting Period Begin: 1 Oct. 93 End: 30 Sept. 94

Grant Period Begin: 1 Oct. 93 End: 30 Sept. 94

Preceding Grant Period Begin: 1 Oct. 91 End: 30 Sept. 93

Amount - \$22,000
(none to Kieffer)

Summary of Objectives

The purpose of this research is to adapt LANL simulation codes to include new geometries and equations-of-state in order to constrain processes that occur during volcanic eruptions. In particular we intend to examine the influence of multiphase flow on fluid dynamic behavior, including local temperature, composition, dynamic pressure, and density and to utilize this information for the interpretation of volcanic features and processes on Earth, Io, Triton, Venus, and Mars. The work has been pursued at LANL by Valentine, K. Wohletz, T. McGetchin, and others for over a decade and has reached the point where Kieffer's research on volcanic equations-of-state and planetary geology can be confidently included. M. Morrissey applied the LANL code DASH to investigate the relation between fluid flow in a crack and volcanic long-period seismic signals, and is continuing this work with Bernard Chouet at the USGS in Menlo Park. A new direction of study which has occurred in the past few months is simulation of ejecta emplacement from large meteorite impacts and comparison with volcanic processes gleaned from our modeling studies.

I. Introduction

Our specific goals are to: (1) provide a set of models based on well-defined assumptions about initial and boundary conditions to constrain interpretations of observations of active volcanic eruptions--including movies of flow front velocities, satellite observations of temperature in plumes vs. time, and still photographs of the dimensions of erupting plumes and flows on Earth and other planets; (2) to examine the influence of subsurface conditions on exit plane conditions and plume characteristics, and to compare the models of subsurface fluid flow with seismic constraints where possible; (3) to relate equations-of-state for magma-gas mixtures to flow dynamics; (4) to examine, in some detail, the interaction of the flowing fluid with the conduit walls and ground topography through boundary layer theory so that field observations of erosion and deposition can be related to fluid processes; and (5) to test the applicability of existing two-phase flow codes for problems related to the generation of volcanic long-period seismic signals; (6) to extend our understanding and simulation capability to problems associated with emplacement of fragmental ejecta from large meteorite impacts.

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The only avenue for obtaining these goals is numerical solution of the full set of fluid dynamics equations with the use of high-speed computers. Such computational studies, when coupled with experimental and field research, will form a comprehensive framework for studies of explosive volcanism. The significance of the models will lie in their relation to observed phenomena--whether properties of active eruptions or of products of these eruptions. In the numerical analysis the mass, momentum, and internal energy conservation equations for a compressible gas with dispersed particles are solved to simulate the large-scale dynamics of explosive eruptions. The conservation equations are solved separately for both the gas and the particle fields, which interact with each other via drag forces and heat transfer. The gas properties are represented by an ideal gas equation of state and the particles are assumed to be incompressible. Turbulence is modeled by a simple eddy viscosity formulation. Specific material properties, equations of state, and description of the governing equations are given by Valentine and Wohletz (1989a). The solutions are obtained by a simplified (explicit) variation of the implicit multifield finite difference technique developed in the 1970s in the Fluid Dynamics Group (T-3) at Los Alamos. The numerical implementation of the equations assumes a cylindrical symmetry of the plumes and of objects on the ground surface (Valentine et al., 1991, 1992). The computational domain consists of a rectangular or square half space (symmetry axis forms one of the boundaries) that is evenly divided into finite difference cells. Domain sizes range from 250x250 km for eruptive jets under Io conditions to 250x100 m for small terrestrial fire fountain eruptions and down centimeter scale for new models of flow in cracks.

Building on earlier work (Valentine and Wohletz, 1989a,b; Wohletz and Valentine 1990) we have already investigated and published results on two new terrestrial problems: (1) the effects of an annular caldera rim surrounding a central vent eruption and resulting distribution of pyroclastic debris by density currents (Valentine et al., 1992); and (2) the fluid dynamic effects of topographic barriers on the high altitude buoyant ash plume above an eruption and implications for remote observation (Valentine et al., 1991). Additional terrestrial applications which we are currently exploring include the effects of different orientations of the eruptive jet (e.g., inclined or even horizontal across the ground as occurred at Mount St. Helens in 1980). Such studies have indicated a need for a fully three-dimensional code and we are exploring the possibility of adding this capability.

II. Progress During the Reporting Period

A. Major Findings

Fast multiphase flow through cracks of complex geometries is thought to be one of the mechanisms by which volcanic long period seismic signals can be generated. Kieffer did not receive funding from IGPP during this reporting period, however the work maintained momentum from past efforts. Meghan Morrissey, an ASU graduate student working partly under this grant, successfully applied the code DASH to this problem by simulating long narrow crack geometries; she has benchmarked the code against a laboratory experiment on supersonic flow in a duct and demonstrated that the code reproduces phenomena observed experimentally (Meier et al., 1978). She has modified the code to compute in cartesian coordinates, and added simple roughness elements along the crack walls to study the possibility that interaction between the fluid and such roughness is a source of tremor (Morrissey, 1994).

Calculations have been carried out to simulate the equivalent of terrestrial caldera-forming eruptions with conditions appropriate for Venus, Mars, Io, and Triton (Kieffer et al., 1991; Kieffer and Morrissey, 1994). Kieffer's background in planetary volcanoes is facilitating this application of numerical modeling. While initial phases of general planetary modeling were nearly complete at the end of last year (Kieffer et al., in prep.), simulation of eruptive processes on Mars, Io, and Triton has continued this year as we continue to increase the resolution and domain size. Figure 1 shows a comparison between equivalent eruptions on Earth and on Mars. It is evident that on Earth some conditions which would generate large pyroclastic flow would, on Mars, create high-standing neutrally buoyant plumes (Kieffer and Morrissey, 1994). We are still "digesting" the information gained from these and other calculations over the past three years, and setting up some new simulations to fill in gaps. However, we anticipate wrapping up this part of our collaboration during 1995 and submitting a major paper for publication (possibly to *Science*, whose editors have invited us to publish the work in that journal).

During the summer of 1994, Valentine made a long (1.5 month) working trip to University of British Columbia, where he and Kieffer focused on two different topics. One of these was modeling of the ascent, phase change, and chemistry of fluids in geothermal wellbores. This problem provides a good, well-controlled starting point from which to begin to tackle more complicated problems of the life and death of geysers and coupling between conduit geometry and hydrodynamics in explosive volcanic eruptions. Kieffer has had an extended effort going on this problem for several years. Although we did not make a tremendous amount of progress in fully coupling the complex chemistry of carbon dioxide with the hydrodynamics, much was learned on the topic (especially by Valentine) that will be useful for future work.

The second topic which we began to pursue is, in some respects, a revisiting of an old issue - the comparison between volcanic and impact-generated features on Earth and other planets. Our initial ideas were partly inspired by the Shoemaker-Levy impact event on Jupiter, which occurred while Valentine was at UBC, and partly by Kieffer's work of the past comparing emplacement mechanisms for volcanic and meteorite-impact ejecta (Simonds and Kieffer, 1993). We began to wonder whether the two-phase flow code that we have used for simulation of explosive eruptions could be applied to the hydrodynamics of fragmental ejecta from large (> 5 km diameter) meteorite impacts. In researching the literature, we found that while there has been a great deal of theoretical work on cratering mechanics (e.g., O'Keefe and Ahrens, 1982) and on the dynamics of plume rise from impact sites (and subsequent atmospheric effects; Jones and Kodis, 1982), the treatment of ejecta processes has been limited to relatively simple ballistics (Oberbeck, 1975; Schultz and Gault, 1982). Field evidence suggests that ejecta emplacement from large events is strongly influenced by density current processes (Chao, 1976; Chao et al., 1978; Hörz et al., 1983). For example, ejecta deposits around the Ries crater (Germany) share many common characteristics of pyroclastic flow deposits (Newsom et al., 1990). In addition to the lack of modeling studies of ejecta emplacement by flow, it appears that most field studies of large fragmental ejecta deposits were carried out 2-3 decades ago. In the time since there have been large advances in the interpretation of pyroclastic deposits around volcanoes. We think it is timely to revisit these issues.

As a first step we have made modifications to our hydrodynamics code so that it will model flow from an annular region (representing the "splash" from an impact) with varying direction and magnitude of velocity. Kieffer is in the process of benchmarking the code to data from small-scale hypervelocity impact experiments (Oberbeck, 1975). Assuming that the benchmarking exercise is successful, the next step will be to set up a

series of simulations that cover a range of ejecta boundary conditions. A major complication will be accounting for the effects of secondary cratering on the generation of flowing debris.

B. Conclusions

This work has now been funded for about three years (beginning with FY 92) by IGPP and is becoming increasingly more productive as resources, our experience, and the number of Kieffer's students involved has increased. We expect to continue this work for a number of years into the future - such modeling is the main goal of Kieffer's long-term research efforts at UBC. In addition, this research compliments Valentine's programmatic efforts in magma/eruption dynamics applied to the Yucca Mountain Project and in his long-term basic research. During the next year we anticipate wrapping up and reporting the planetary volcanism studies and focusing on the impact ejecta processes described above using both modeling and field approaches.

C. Equipment Obtained and Facilities Used

Numerical implementation was first performed on a Cray XM-P for terrestrial runs, with a viable option to also run on Sparc workstations, and then the code was adapted for data parallel operations on the MasPar MP-1 series of massively parallel supercomputers at Arizona State University. The code DASH has been extensively benchmarked by the ASU team on a variety of machines including various Crays, Suns, a Next-Dimension, and a Convex. Performance scaling was carried out on the MasPar machines to compare with other computers (Kieffer et al, 1993). This past year most of our calculations have been carried out on Sun and IBM RS-6000 machines, which have become available at ASU and throughout LANL including two machines in Valentine's group, and SGI workstations at UBC.

D. Tangible results

3. Refereed journal articles in preparation

Kieffer, S.W., Morrissey, M.M., and G.A. Valentine, Numerical models of volcanic eruptions on Earth, Venus, Mars, Io, and Triton. To be submitted to *Journal of Geophysical Research*..

Soderblom, L.A., Kirk, R.L., Brown, R.H., and Kieffer, Susan W., Triton's eruptive plumes: discovery, characteristics, and models, chapter for book "Neptune and Triton", ed. D. Cruikshank and M.S. Matthews, Univ. of Arizona Press, submitted December, 1993.

4. Other publications published

Kieffer, S.W., and M.M. Morrissey, Exploring Earth with new data and tools, *Geotimes* 38, 15-17, 1994.

Morrissey, M.M., Magmatic fluids and long-period seismicity: a geological and fluid dynamical perspective, Ph.D. Thesis, Arizona State Univ., 124 pp., 1994.

Fink, J.F., and Kieffer, Susan W., Pyroclastic flows generated by lava dome collapse, *Nature*, v. 363, 612-615, June, 1993.

5. Other articles in press or submitted

Kieffer, S.W., Valentine, G.A., Rajan, M., and R. Casey R., Simulations of explosive eruptions on a massively parallel computer, *MasPar Application Note*, 12 pp., in prep.

7. Invited technical presentations

Kieffer, S.W., and M.M. Morrissey, Planetary pressure cookers: geysers, volcanoes, and supercomputers, *EOS Trans.* **75**, 51.

8. Contributed technical presentations

Morrissey, M.M., Chouet, B.A., and S.W. Kieffer, Shock-pattern oscillations as the triggering mechanism for long period seismicity at Redoubt volcano, Alaska, 1989-90, *EOS Trans.* **74**, 649.

E. Intangible Results

Our research over the past three years has played an important role in the general increase in numerical approaches to address magma dynamics. An excellent example is the group in Pisa, Italy, headed up by Dobran, Macedonio, and others. They have taken similar numerical approaches and are successfully addressing a wide range of volcanic processes and applications to hazards mitigation.

III. Future of Project

We plan to continue this work into the next few years, with the long term focus on hydrodynamics and field observations of fragmental ejecta blankets from large impact craters. We believe that a revisitation of the properties of impact ejecta blankets in light of studies of volcanic stratified flow deposits will prove highly enlightening. Our goal is to generate sufficient funding for this work to fund a major effort on the part of Kieffer, Valentine, and perhaps one student or postdoc. This will entail more funding (on the order of \$150-200K) per year over a period of three years. We are currently planning on targeting three sources of funding: IGPP and NASA in the U.S., and NSERC in Canada.

IV. Funds Received as a Result of IGPP-Sponsored Research

Valentine has received funding from DOE's Yucca Mountain Project partly due to the groundwork research carried out in this IGPP grant. This funding currently amounts to \$740K for FY95.

V. Los Alamos Facilities Used for this Project

EES-5 LAN, including Sun workstations and IBM RS 6000.

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