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OBITUARY

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Bradford Sturtevant, 1933–2000

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Nature does not respect the boundaries imposed by the human division of science into traditional disciplines. It is therefore hardly surprising that major insights in the earth sciences are often achieved by scientists who disregard those same boundaries. The Earth offers a range of awe-inspiring phenomena of beautiful complexity that cannot fail to fascinate those scientists who have retained their youthful open-mindedness and curiosity. Bradford Sturtevant was such a scientist, who brought his expertise as an aeronautical engineer to the study of volcanic eruptions and earthquake dynamics with a characteristic enthusiasm, energy and insight.

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Brad spent his entire professional career at the Graduate Aeronautical Laboratories, Caltech (GALCIT), arriving as a Master's student in Aeronautics in 1955 and joining the Faculty in 1960 after completing his PhD. He was appointed the H.W. Liepmann Professor of Aeronautics in 1995. He was passionate about fluid mechanics – as he was about many things: swimming, athletics, the great outdoors, Caltech, and California, to name just a few. His main research interests were shock waves and non-steady gas dynamics, which he applied to problems from scientific disciplines as disparate as engineering, aeronautics, medicine, and geology.

Brad's interest in volcanology began to emerge when he and Joe Shepherd (one of Brad's PhD students) investigated rapid evaporation (1976–1982). In the course of the study they became aware of the connection between rapid evaporation and steam explosions that occur when magma is brought into contact with water (Shepherd and Sturtevant 1982). Brad was so fascinated by the applications of his fluid dynamics research to volcanology that he tracked down the Proceedings of the Royal Society (at the Huntington Institute) that contained extensive descriptions of the effects of the Krakatau explosion, and closely followed the 1980 eruption of Mount St. Helens. This interest in volcanic eruptions would lead to many fruitful collaborations with volcanologists.

Brad's first collaboration with geologists came through his contact with Sue Kieffer. On a Caltech Alumni Seminar Day in 1981 Sue presented her supersonic flow ideas about the eruption of Mount St. Helens. Brad was in the audience and, after the meeting, challenged Sue's ideas in his own inimitable way. This led to a collaboration doing shock-tube lab experiments in GALCIT on supersonic gas flow, simulating pseudo-gas erupting volcanic plumes. An important result was the varying shapes that volcanic plumes could assume depending on the composition of the volcanic gas and its ratio of pressure to atmospheric pressure (Kieffer and Sturtevant 1984). Brad became a convert to the idea that volcanoes could erupt supersonically.

In 1984, while on a field trip together to Mount St. Helens, Sue noticed some unusual huge erosional furrows scoured into hill slopes by the lateral blast. After a brief discussion in which they decided that the features could not possibly be logging roads, Brad's eyes took on that characteristic look of intellectual joy that his colleagues knew so well, and he yelped "Taylor–Görtler vortices!" This led to a field program documenting, measuring, and interpreting the furrows in which Brad showed superb natural skill as a field geologist. His love of mountain-climbing developed in his youth and at Yale seemed to reveal a suppressed desire to be a volcanologist. Brad's Taylor–Görtler vortex idea held up for the first-discovered slopes and several others, and the boundary layer thickness for the blast could be determined. However, the Taylor–Görtler mechanism, which requires a very special geometry, did not work for a particular large set of furrows on the Central Ridge, and a new hypothesis was reached, namely that the vortices and furrows were produced by the geometry of a nose cone pointing obliquely into the oncoming supersonic flow of the blast. This mechanism confirmed the supersonic nature of the flow and allowed an estimate of flow velocities (Kieffer and Sturtevant 1988).

Brad's interest in simulating volcanic eruptions using the shock tubes continued to grow with the focus now moving to conduit flow processes. He and one of his PhD students (Larry Hill) carried out experimental studies of explosive boiling in a one-component superheated liquid, and tried to apply it to volcanic eruptions (Hill and Sturtevant 1990). This development laid the foundation for moving towards using two-component systems as analogs for volcanic eruptions. Another PhD student, Anilkumar, investigated the gas expansion dynamics of a gas–particle bed when decompressed, which was applied to volcanological problems with Steve Sparks and showed that two-phase volcanic flows are likely to be highly heterogeneous (Anilkumar et al. 1993). Then, two independent lines of research were developed on gas–liquid mixtures and flows that are applicable to conduit flows:

1. Explosion experiments via a chemical reaction were developed in collaboration with Steve Sparks, Heidy Mader, and Jeremy Phillips at Bristol (Mader et al. 1994, 1996). In these experiments, a K_2CO_3 solution is injected into a HCl solution to generate high CO_2 supersaturation, and hence explosive eruption via rapid internal bubble growth. Brad's boundless enthusiasm is fondly remembered by many at Bristol. He did not hesitate to turn his hand to anything practical so that logistical difficulties would not hold up the science: one of Brad's first activities on arriving in Bristol in 1992 was to install Ethernet cables through the basement of the department via a large ventilation that was (and still is) home to a thriving population of pigeons, so that data could be sent from Bristol to Caltech.
2. Experiments using CO_2 supersaturated water (champagne-type experiments) were developed at Caltech in collaboration with Youxue Zhang, Ed Stolper, and David Pyle, who participated in the early stage of the project (Mader et al. 1994; Zhang et al. 1997; Zhang 1998). Later, Heidy Mader, Emily Brodsky, and Danny Howard also worked with Brad and carried out investigations using this second type of experiment (Mader et al. 1997). In these experiments, a CO_2-rich water solution is suddenly decompressed to generate supersaturation, bubble growth, and explosive eruption.

These were among the first attempts to use experiments to unravel the turbulent multiphase fluid dynamics inside an erupting volcano during explosive eruptions. The experiments also helped us to understand the dynamics of lake eruptions. The basic techniques used have since become standard tools in experimental volcanology and are now widely applied.

Brad quite naturally also developed other links with researchers within the Division of Geological and Planetary Sciences at Caltech. In 1989 mysterious seismic waves were excited by the re-entry into the Los Angeles basin of the space shuttle Columbia (Cates and Sturtevant 2001). Brad introduced Hiroo Kanamori (a long-time casual acquaintance) and his co-workers to the elegant non-linear wave theory that they then successfully employed to explain the seismic data. From this beginning, Brad continued to apply his broad fluid dynamics knowledge to problems in seismology. The 28 June 1992 Landers, California, earthquake triggered seismicity in geothermal areas as far away as 1,500 km. Such long-distance effects of an earthquake lay completely outside the existing scientific framework and demanded an entirely original explanation. Together with Hiroo and Emily, Brad proposed an elegant interpretation by invoking the well-known engineering mechanism of rectified diffusion. He suggested that volatiles are pumped into bubbles in geothermal reservoirs by the passing seismic waves. If the bubbles are trapped in a closed system, a pressure increase results. This mechanism could also explain the occurrence of seismically triggered volcanic eruptions and harmonic tremor in geothermal systems (Sturtevant et al. 1996; Brodsky et al. 1998). Separately with Sharon Kedar and Hiroo, bubble collapse was proposed as the source of tremor at Old Faithful Geyser (Kedar et al. 1996, 1998). Brad cemented his association with the Geological and Planetary Sciences Division by teaching a class in fluid mechanics to geologists. A homework problem of that class led to his collaboration with Emily and Hiroo to devise a new method to measure volcanic mass discharge rate using seismic data (Brodsky et al. 1999).

Brad's interest in geology was closer to that of the amateur enthusiast, in the best sense of the word; namely someone who was simply fascinated. In the field, he was an acutely accurate observer. He saw geological relationships as manifestations of fluid flow. On one occasion, when seeing a lava surface in Tenerife, Brad explained the swirls as Kelvin–Helmholtz instabilities to all those present using simple fluid mechanical principles. He was a proponent of fluid mechanics as a rigorous intellectual activity that spanned scientific disciplines. His experimental approach was rooted in his engineering background that allowed him to conceive of well-designed and critical experiments to look at fundamental processes. In both his experimental and theoretical research he sought to identify the underlying mechanisms that could explain observation. His contribution to earth science is substantial, although it is perhaps a measure of his modesty that many who are now using the techniques he introduced are not aware of their originator.

Brad was a generous collaborator and contributor. Interactions with him often allowed many of us to explore other problems, the products of which Brad declined to co-author. It has been our pleasure and privilege to have worked with him.

Brad was survived by his wife Carol, daughter Victoria, his two grandsons Jonathan and Thomas Armstrong, his father Julian, and his sister Ann.

References

Anilkumar AV, Sparks RSJ, Sturtevant B (1993) Geological implications and applications of high-velocity 2-phase flow experiments. J Volcanol Geotherm Res 56:145–160

Brodsky EE, Sturtevant B, Kanamori H (1998) Earthquakes, volcanoes, and rectified diffusion. J Geophys Res 103(B10): 23827–23838

Brodsky EE, Kanamori H, Sturtevant B (1999) A seismically constrained mass discharge rate for the initiation of the May 18, 1980 Mount St Helens eruption. J Geophys Res 104(B12): 29387–29400

Cates JE, Sturtevant B (2001) Seismic detection of sonic booms. J Acoust Soc Am (in press)

Hill LG, Sturtevant B (1990) An experimental study of evaporation waves in a superheated liquid. In: Meier GEA, Thompson PA (eds) Adiabatic waves in liquid–vapor systems. Springer, Berlin Heidelberg New York, pp 25–37

Kedar S, Sturtevant B, Kanamori H (1996) The origin of harmonic tremor at Old Faithful geyser. Nature 379:708–711

Kedar S, Kanamori H, Sturtevant B (1998) Bubble collapse as the source of tremor at Old Faithful Geyser. J Geophys Res 103(B10):24283–24299

Kieffer SW, Sturtevant B (1984) Laboratory studies of volcanic jets. J Geophys Res 89(B10):8253–8268

Kieffer SW, Sturtevant B (1988) Erosional furrows formed during the lateral blast at Mount St Helens, May 18, 1980. J Geophys Res 93(B12):14793–14816

Mader HM, Zhang Y, Phillips JC, Sparks RSJ, Sturtevant B, Stolper E (1994) Experimental simulations of explosive degassing of magma. Nature 372:85–88

Mader HM, Phillips JC, Sparks RSJ, Sturtevant B (1996) Dynamics of explosive degassing of magma: observations of fragmenting two-phase flows. J Geophys Res 101(B3):5547–5560

Mader HM, Brodsky EE, Howard D, Sturtevant B (1997) Laboratory simulations of sustained volcanic eruptions. Nature 388:462–464

Shepherd JE, Sturtevant B (1982) Rapid evaporation at the superheat limit. J Fluid Mech 121:379–402

Sturtevant B, Kanamori H, Brodsky EE (1996) Seismic triggering by rectified diffusion in geothermal systems. J Geophys Res 101(B11):25269–25282

Zhang Y (1998) Experimental simulations of gas-driven eruptions: kinetics of bubble growth and effect of geometry. Bull Volcanol 59:281–290

Zhang Y, Sturtevant B, Stolper EM (1997) Dynamics of gas-driven eruptions: experimental simulations using CO_2–H_2O–polymer system. J Geophys Res 102(B2):3077–3096