MINERALOGY AND THE CHALLENGER DISASTER

I would like to elaborate on Ian Parsons' interesting commentary on the Space Shuttle Challenger accident that occurred on January 28, 1986 (*Elements* 3: 155-156, June 2007). As part of my asbestos studies in the 1980s, I inquired into the cause of this accident. The essential flaw in the shuttle system was the sealing of the booster rocket joints with a special type of putty. In successful space shuttle launches the spent booster rockets and external fuel tank fall into the Atlantic Ocean, later to be recovered for examination. It was during the examination of the recovered boosters from the 15 space shuttles launched during 1984 and 1985 that NASA engineers became increasingly alarmed about "blowholes" in the "Randolph" putty being used at that time to seal the booster joints and resulting in burned O-rings. To quote from an engineering memo of February 28, 1984: "ZCP (type II Randolph zinc chromate putty) failure to provide a thermal barrier can lead to burning both O-rings and subsequent catastrophic failure." The purpose of the putty was clearly explained in NASA review documents. The putty must prevent the hot gases from flowing through the booster joints and impinging on the delicate O-rings. The Challenger accident was caused by hot gases from one of the Challenger booster rockets penetrating the Randolph putty, the O-ring seals and finally the outside casing of the booster rocket. The gas flame leaving the booster casing impinged on the adjacent external fuel tank causing a rupture and release of liquid hydrogen and oxygen which ignited explosively.

The putty defects clearly laid out in these engineering reports lead back to a curious point of origin: the 1977 Consumer Products Safety Commission ban on retail asbestos products and the impending ban on all asbestos use by the U.S. Environmental Protection Agency. For the first nine successful shuttle missions, NASA employed a special asbestos-bearing putty manufactured by the Fuller O'Brien Company of San Francisco. But in the wake of the developing notoriety of asbestos-bearing products and the fear of law suits, Fuller-O'Brien stopped manufacturing the putty that had served the shuttle so well. Early in 1984, having run through their stock of Fuller-O'Brien putty, NASA engineers turned to another type of putty manufactured by Randolph Products of Carlstadt, New Jersey, which, ironically, also contained asbestos. The Challenger exploded because this substitute putty failed to prevent hot gases from passing through the booster joints to the O-ring seals. The Fuller-O'Brien putty was initially also used in the Titan 34-D booster rocket joint seals, similar in design to those in the Challenger. However, by 1985 it too had been replaced by the substitute putty. The result of this substitution, following a string of 50 successful Titan launches, was a devastating explosion of the next two Titan rockets, one launched in August of 1985 and the other in April of 1986.

From my examination of the Fuller-O'Brien and Randolph putties in 1994, it became clear why one failed and the other did not. The Fuller-O'Brien product was very sticky, even when exposed for 24 hours to a temperature of -12°C. It clung tenaciously to the surrounding material. The Randolph putty, by contrast, was stiff to the touch. At -12°C it was almost hard: it did not cling. At the near-freezing launch temperature, it is not surprising that the Randolph putty failed.

Richard Feynman, a member of the Presidential Commission on the Space Shuttle Challenger Accident, made an independent analysis of the accident. Dr. Feynman dipped an O-ring into a pitcher of ice water, squeezed it with a clamp and then released it. This experiment, performed before the Commission members, showed that the O-ring lost its resilience when immersed in ice water. Feynman then suggested that the inability of the booster O-rings to flex rapidly enough during the freezing conditions at launch time would prevent them from protecting the booster joints from the hot gases. However, as described above, the putty was inserted within the joint channels leading to the O-rings to protect the O-rings from the hot gases. The O-rings alone could never stand up to gases at temperatures as high as 3300°C. Even if the O-rings were somehow less resilient than expected, hot gases would not have reached the O-ring seals if the Fuller-O'Brien putty had been in place, as demonstrated by previous successful launches of the space shuttles and the Titan rockets.

Because of the previous engineering reports and Dr. Feynman's cogent observations, NASA in 1989 redesigned the booster rocket joint systems so as to contain three sets of O-ring seals instead of two, a new more convoluted joint system with a pressure-sensitive adhesive (instead of putty) applied within the joint interfaces, and heaters to maintain a temperature of 24°C at the booster joints before launch. The same type of O-ring is used. The Challenger disaster tells us that measures aimed at lessening risk—in this case the removal of the Fuller-O'Brien product because of the impending ban on asbestos-bearing products, and the hasty substitution of the Randolph putty—can actually increase risk, even create risk.

Malcolm Ross
Washington, DC

ERRATUM

Adele Boskey Profile

MEDICAL MINERALOGY AND GEOCHEMISTRY

In volume 3, number 6 of *Elements*, Dr. Boskey's bio paragraph and picture were inadvertently omitted from the "Meet the Authors" page. We apologize to Dr. Boskey for this oversight. The electronic file has been corrected (see *Elements*' website).

Adele L. Boskey is the Starr Chair in Mineralized Tissue Research at the Hospital for Special Surgery in New York. She holds professorships in biochemistry, physiology, biophysics, and systems biology at Weill Medical College and the Graduate Medical School of Cornell University (Ithaca, NY), and in the field of bioengineering at Cornell and City College of New York. A physical chemist by training, her research focuses on understanding bone and tooth formation in vitro and in vivo. A Fellow of the American Association for the Advancement of Science, she introduced infrared microspectroscopy and imaging to bone research.