VIII. Post-NASA

After leaving NASA, my time was divided among administrative chores as chairman of the University of Houston geology department, teaching courses in our graduate and undergraduate programs, and my own research. Along with two colleagues and several student assistants, I worked with soil samples from all the Apollo missions and regularly presented and published our results either in the Lunar and Planetary Science Conference *Proceedings* or in major journals. Sooner or later we would inevitably run out of good research ideas for the lunar samples, and we did.

For a couple of years, much of my spare time was spent preparing a textbook on the geological aspects of space sciences.[32] This

[32]E. A. King, *Space Geology: An Introduction* (New York: John Wiley & Sons, 1976).

work evolved from courses I taught at the graduate level, and it was convenient to have this material available in a single volume. However, the book soon became out-of-date as well as out-of-print. Others wrote similar texts that I used, because updating a text every few years is not an appealing task to me.

Slowly, but surely, the group began to disperse. I left the space agency shortly after Apollo 11. Warner stayed on to work on future PETs and perform a variety of research tasks, but eventually left to join an oil company research lab. Clanton continued work on lunar samples, U-2 recovery of micrometeoroids, and a variety of other topics, but finally took a job with the Department of Energy. Dietrich remained with NASA and eventually became lunar sample curator. A single interest had united us for several years, but in the end most of the Apollo group split up and went separate ways.

Meanwhile, the discovery of lunar chondrules in the Apollo 14 samples sparked my old interest in meteorites. I began to work with stony meteorites again, particularly on the origins of meteoritic chondrules, which led to a series of solar furnace experiments at a laboratory in the French Pyrenees, a marvellous location for scientific work, high in the lovely mountainous countryside only a couple of hours from the Costa Brava. The work was very productive and thoroughly enjoyable. Research showed that meteoritic chondrules were formed by more than one process. Some certainly were formed by impact-related processes, but many chondrules apparently had formed as a result of another process.[33] Many questions concerning the major process responsible for chondrule formation remain unanswered.[34]

In 1979, several researchers suggested that a small group of meteorites, the so-called "SNC meteorites" (for shergottites, nakhlites and Chassigny), might have originated from Mars (Photo 58).

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[33]E. A. King, "Refractory Residues, Condensates and Chondrules from Solar Furnace Experiments," *Journal of Geophysical Research* (supplement), vol. 87 (1982), A429–A434.

[34]E. A. King, ed., *Chondrules and Their Origins*, Lunar and Planetary Institute (Houston, 1983).

SNC meteorites have crystallization ages ranging from one billion to 1.3 billion years and show highly fractionated rare earth element distribution patterns indicating a probable origin on a planetary body that was internally able to generate lava flows and associated igneous rocks for a longer time span than on the Moon. Some of the SNC meteorites were found to contain trapped noble gases and nitrogen similar to analyses of the atmosphere of Mars as determined by the Viking landers. It has been generally assumed that the SNC meteorites were launched from Mars by a large impact and arrived in an Earth-crossing orbit. The same scenario was proposed for the lunar origin of tektites, yet we knew tektites did not originate from the Moon, and we had no examples of lunar meteorites.

Only a few years later, in 1982, an anorthositic highlands breccia, Allan Hills A81005 (Photo 59), was distributed to investigators in the Antarctic Meteorite Collection Program. The breccia was recog-

Photo 58. An "SNC" meteorite (EETA79001) collected in the Antarctic near Elephant Moraine. This and the other SNC meteorites probably originated from the planet Mars. (NASA photograph S80-37638)

nized immediately as a lunar meteorite. Its composition was very similar to Apollo 16 breccias, but it had slightly lower concentrations of potassium, rare-earth elements, and some other trace elements. The objections to the impact mechanism for launching rocks from a planetary surface without totally melting them were no longer realistic, especially considering that an additional five lunar breccia samples were recognized in Antarctic meteorite collections by the Japanese. Everyone had looked for pieces of the Moon in the meteorite collections before the Apollo landings, but the right samples were not collected until after Apollo. It now appears likely, however, that we have recognized pieces of Mars well in advance of a sample return from that planet.[35]

In the mid-1970s, Russian investigators recognized an impact structure in southern Siberia, the Zhamanshin crater. Located about 200 kilometers north of the Aral Sea, the crater has abundant tektites (Photos 60, 61, 62) and shows evidence of associated shock

[35]For example, see M. R. Smith, J. C. Laul, M. S. Ma, T. Huston, R. M. Verkouteren, M. E. Lipschutz, and R. A. Schmitt, "Petrogenesis of the SNC (Shergottites, Nakhlites, Chassignites) Meteorites: Implications for Their Origin from a Large Dynamic Planet, Possibly Mars," *Journal of Geophysical Research* (supplement), vol. 89 (1984), B612–B630.

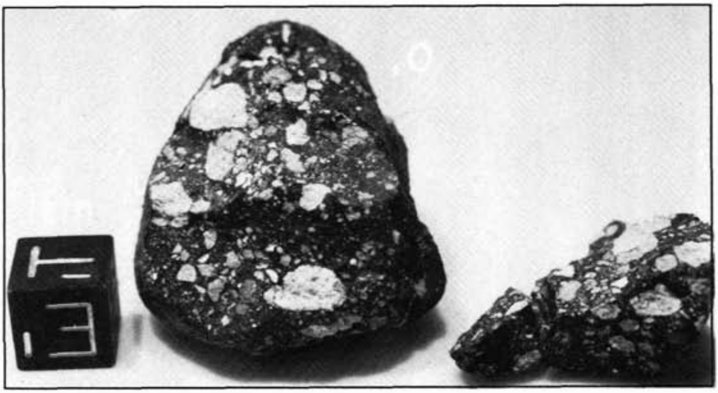


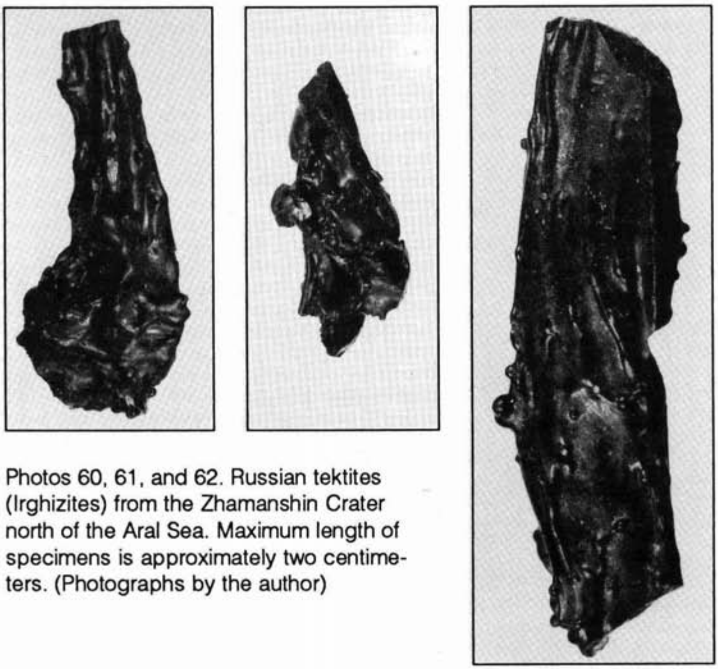
Photo 59. Antarctic meteorite collected near Allan Hills (ALHA81005) that is a fragment of the regolith from the highlands of the Moon. Several such lunar meteorites have now been recognized in the Antarctic meteorite collections. (NASA photograph S82-35867).

metamorphism.[36] Zhamanshin is a small crater, only about 10 kilometers in diameter. The tektites formed by the impact event do not possess all the properties of previously known tektites. Although some are identical to other tektites under the microscope, they contain more water, intermediate between other tektite glass and obsidian, and have a lower ferrous to ferric iron ratio.[37] In summary, the Russian tektites (Irghizites) are a beautiful link between the impact products of small and large impact craters. Had the Irghizites been one of the first groups of tektites studied, the whole argument about the origin of tektites probably never would have occurred.

Before, during, and after the Apollo program, unmanned plane-

[36] P. V. Florensky, "The Zhamanshin Meteorite Crater (the Northern Near-Aral) and Its Tektites and Impactites," Izvestiya of the Academy of Sciences of the U.S.S.R., Geologic Series, no. 10 (1975), 75–86.

[37] E. A. King and J. Arndt, "Water Content of Russian Tektites," Nature, vol. 269, no. 5623 (1977), 48–49.



Photos 60, 61, and 62. Russian tektites (Irghizites) from the Zhamanshin Crater north of the Aral Sea. Maximum length of specimens is approximately two centimeters. (Photographs by the author) tary missions were launched to various planets. These launches occurred at irregular intervals and included fly-bys, orbiters, and landers. I began to look at the data from these missions, particularly the images. An early Mars fly-by mission, Mariner 4, obtained a limited set of poor-quality images from the planet. These images indicated the body was cratered terrain, much like the lunar highlands. The evidence was disappointing because we had hoped to find a more active planet. Mariner 6 and Mariner 7 broadened our view of the surface considerably, but it was not until the Mariner 9 Mars orbiter and Viking orbiters that we realized the full range of geological processes that has shaped the exceedingly varied surface features. The chief differences between the Moon and Mars derive from the larger size of Mars—large enough to remain internally active for much longer than the Moon—and the presence of abundant volatile elements and compounds such as water. Surface analyses from the Viking landers indicate a soil that is very different from lunar soil, probably due to interaction with the atmosphere and other volatiles. Chemical weathering of Mar's surface rocks has played a very important part. The variety of terrains and surface features is tremendous, ranging from huge canyons to giant inactive volcanoes, icy polar caps to desert dunes, relatively recent low flat desert to ancient densely cratered uplands. Involved in a Mars geologic mapping project, I produced a photogeologic map of a Mars quadrangle at the scale of 1:5,000,000[38] on a base made from Mariner 9 imagery. When I joined the Mars Geologic Mapping Program, I discovered that a former schoolmate, Carroll Ann Hodges, who had attended high school and college with me, had applied for the program, too.[39] Later, another high school and college friend, Joachim Meyer, who was on the Tulane University faculty, joined the program. Still another old classmate from the Uni-

[38]E. A. King, "Geologic Map of the Mare Tyrrhenum Quadrangle of Mars," USGS Map I-1073 (MC-22) (1978), with text.

[39]Caroll Ann Hodges had worked for the U.S. Geological Survey, Branch of Astrogeology, Menlo Park, Calfornia. She worked on many aspects of lunar and martian geology, particularly image interpretation, and later went into administration.

versity of Texas, Jim Underwood, who had joined the Kansas State University faculty, was selected to participate in the planetary mapping. He is now serving a term at NASA Headquarters as program scientist for the mapping program. The geologic mapping project forced me to examine the imagery seriously so I could compare features of the Moon and Mars.

Mariner 10 managed to fly by Venus and collect some data, but its chief accomplishment was imaging approximately half the surface of Mercury. Mercury proved to be relatively dull, with a cratered surface revealing little evidence of a geologically active history. Like the Moon, Mercury lacks an atmosphere and appears to be barren of volatiles. I collaborated with a colleague to produce a photogeologic map of a portion of the surface of the planet.

Venus has been the target of a long series of Soviet spacecraft. The Soviets have been very successful in landing probes on the hot surface (approximately 450 degrees Centigrade) and making measurements and taking images. The first image from the surface of the planet was taken by the Venera 9 lander in 1975. During December 1978, however, 10 separate unmanned spacecraft were hurled at Venus, including both U.S. and Soviet efforts. Seven of these craft entered the dense atmosphere (approximately 92 times the pressure of the Earth's atmosphere at the surface) and took various measurements. Venera 11 and Venera 12 landed instrument packages on the surface. The U.S. Pioneer Venus Orbiter contained a radar experiment which permitted low-resolution topographic mapping of about 90 percent of the surface through the dense cloud cover that permanently surrounds the planet. Later, Venera 13 and Venera 14 obtained surface imagery, surficial analyses by X-ray fluorescence indicating two different types of basalt. Later missions obtained orbital radar imagery of a large portion of the Venusian surface. Based on radar image interpretations, both impact craters and large volcanic features have been identified. Although Venus is nearly the Earth's twin planet in size and density, Venus apparently has not experienced active plate tectonics. It seems the relatively rigid Venusian lithosphere is too thin for plate tectonics, and something more like "scum tectonics" has occurred. Although an interesting and dynamic planet, the tough temperature and pressure environment on the surface indicates Venus will remain in the realm of unmanned spacecraft and robots for a long time. Even an automated sample return from Venus appears extremely difficult with current technology.

The Soviet Union continued automated sample returns from the Moon with the Luna 24 Mission in August 1976, which returned a core 160 centimeters long from Mare Crisium on the Moon's eastern limb. Under a joint agreement with NASA, the Soviet Academy of Sciences provided U.S. scientists with three grams of soil for scientific study, which resulted in a substantial volume.[40] The basalts from Mare Crisium were found to be derived from two potassium and titanium depleted magmas, one of which has twice the magnesium oxide content of the other.

The clouds of Jupiter and the surfaces of the four Galilean Satellites were beautifully imaged by Voyager I and Voyager II. Io, with its orange, sulfur-rich surface, lack of impact craters, and more than 10 active volcanoes, is unique. Europa also lacks impact craters and has a surface probably composed of dusty ices. Ganymede's surface shows the effects of many impacts and relative movements of large segments of icy crust. Callisto is covered with small- to intermediate-sized impact craters. Four adjacent satellites—each different from the other! For these planetary bodies we have a few images, but little other information.

Voyager I continued on to the Saturnian System, with Voyager II close behind. The chief data of geologic interest were the images of the 15 moons of Saturn. The moons proved to be mostly water ice with varying numbers and sizes of craters and some dull surface differences in albedo, probably due to dust or silicate rocks. Although the images are dramatic, few other data exist.

The European Space Agency (ESA) accomplished a beautiful

[40] R. B. Merrill, ed., "Mare Crisium: The View from Luna 24," *Geochimica et Cosmochimica Acta* (supplement 9, 1977).