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An appreciation of Dieter Stöffler

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With this volume of *Meteoritics & Planetary Science*, we honor Dieter Stöffler (Fig. 1) on the occasion of his (obligatory) retirement from university service, for his many outstanding contributions as a teacher, researcher, and servant of the profession.

Dieter was born on May 23, 1939, in Schramberg, Kreis Rottweil, Germany. He began his studies of mineralogy and geology at the Eberhard Karls University in Tübingen, Germany in 1958 and received his doctorate in natural sciences in 1963. Until 1970, he was assistant to Professor Wolf von Engelhardt at that university (Fig. 2) and, in 1970, earned his "Habilitation" (an advanced doctorate at German universities that is a prerequisite for teaching at the university level). He was docent at Tübingen until 1974 and then moved to the Westfälische Wilhelms-University in Münster as Professor of Petrography and Mineral Deposits, a position he held until 1987. In that year, Dieter became Professor of Cosmic Mineralogy and Director of the newly founded Institute for Planetology at Münster, the only chair and institute of its kind in Germany. In 1993, Dieter moved on to Humboldt University in the then–re-united Berlin, where he served as Director of the Naturhistorisches Forschungsinstitut and the Museum für Naturkunde until 1999 and, until 2004, as Professor of Mineralogy and Petrology and Director of the Institute of Mineralogy.

In his long and distinguished career, Dieter has had a dedicated following of students and co-workers. During this time, he supervised or co-supervised some 20 master's degree candidates and 33 doctoral candidates. But most of us know Dieter because of his outstanding success and lasting contributions as a researcher and scholar, having mostly worked on four diverse celestial objects: the Earth, the Moon, asteroids, and comets (Table 1).

Dieter's terrestrial work has been pioneering and has dealt mostly with impact craters and the effects of shock waves on minerals. This work was initially stimulated by Dieter's mentor, Professor Wolf von Engelhardt (Fig. 2), who introduced him to the Ries impact crater, which became one of Dieter's life-long areas of research (Fig. 3). Of the many papers that Dieter published on the Ries, several are seminal and have influenced the entire field of terrestrial impact cratering. A number of these (e.g., Stöffler 1971b; Pohl et al.

Fig. 1. Dieter Stöffler, October 1993.

Table 1. The 147 publications of Dieter Stöffler listed by major topics.

Topic	Number of publications
Terrestrial impact craters	62
Shock wave experiments	15
Lunar rocks	29
Meteorites from the Moon	4
Meteorites from primitive asteroids	9
Meteorites from differentiated asteroids	3
General planetary geology	13
Cometary analog materials	9
Meteorites from Mars	3

Fig. 2. Dieter Stöffler with his mentor, Professor Wolf von Engelhardt, at the 1996 Meteoritical Society meeting in Berlin.

Fig. 4. Dieter Stöffler in the Ries impact crater with astronauts Edgar Mitchell (Apollo 14) and Eugene Cernan (Apollo 17).

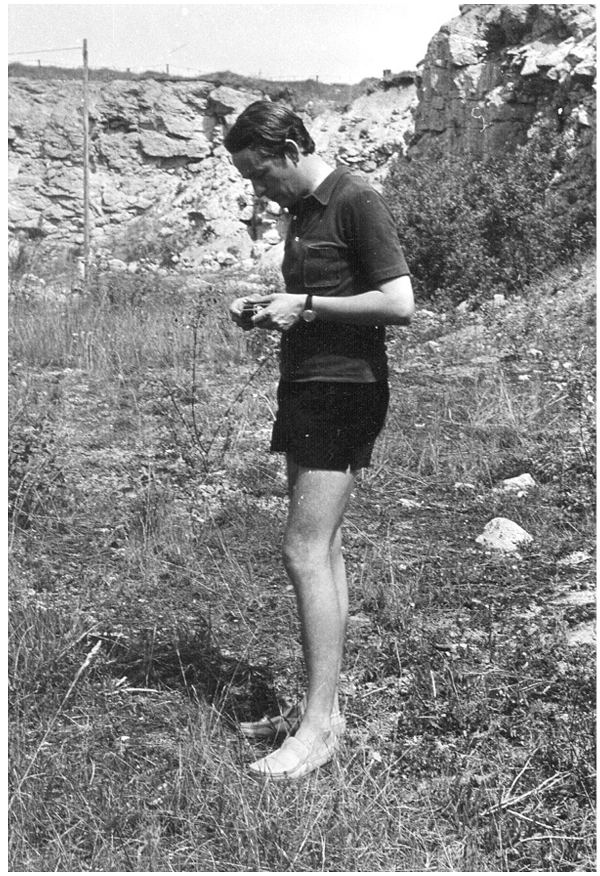

Fig. 3. Dieter Stöffler doing field work in the Otting quarry of the Ries impact crater, May 1971.

1977) deal with progressive metamorphism and classification of impact formations and include estimates of the shock pressures experienced by them (Table 2). The field work at the Ries crater, which included training sessions with some of the Apollo astronauts (Fig. 4), culminated in papers on the results from the research drilling of the crater in 1973 (Stöffler 1977; Stöffler et al. 1977) and with a summary paper by Stöffler and Ostertag (1983). Over the years, Dieter expanded his work on terrestrial impact craters to many others besides the Ries, particularly those on the Canadian shield and in Scandinavia. This includes, for example, studies of the West Clearwater Lake (Engelhardt et al. 1968), the Haughton (Redeker and Stöffler 1988), and the Sudbury (Grieve et al. 1991; Stöffler et al. 1994) impact craters. He also worked on the Lappajärvi, Finland, crater (Bischoff and Stöffler 1984) and, more recently, has been one of the leaders in the study of the drill core obtained at the Cretaceous-Tertiary boundary Chicxulub crater (e.g., Claeys et al. 2003; Dressler et al. 2003; Stöffler et al. 2004; Hecht et al. 2004).

Many of Dieter's classical papers deal with the effects of shock deformation on minerals in terrestrial impact craters (e.g., Stöffler 1966, 1967, 1971a, 1984). Others are devoted to studies of the experimental deformation of minerals by shock under controlled conditions, which led to the calibration of the shock pressures experienced by minerals in natural impact craters (e.g., Stöffler 1972, 1974; Stöffler and Hornemann 1972; Stöffler et al. 1975; Stöffler and Langenhorst 1994; Grieve et al. 1996).

Dieter's outstanding contributions to the petrography and petrogenesis of the Moon began with his role as a co-investigator under P. I. Professor von Engelhardt and, after leaving Tübingen, as a P. I. in the Apollo program. He and his collaborators made important contributions to the fields of shock metamorphism and petrography of lunar highlands rocks (e.g., Stöffler et al. 1981, 1985; Ostertag et al. 1987). This research benefited greatly from Dieter's and his team's experience with field work in, and shocked rocks from, terrestrial impact craters (e.g., Stöffler et al. 1974, 1979). His Apollo lunar sample research culminated in a classical paper that proposed a classification and nomenclature scheme for lunar highlands rocks that is universally accepted in the field (Table 3) (Stöffler et al. 1980).

Table 2. Impact formations at the Ries crater. From Pohl et al. (1977); stages of shock metamorphism after Stöffler (1971b).

Impact formation	Particle size (m)	Stratigraphic provenance	Shock metamorphism	Geological setting	Texture
Impact melt	As inclusions <0.2–0.5 m	Crystalline rocks	Stage IV 550–1000 kbar	As inclusions in suevite or as larger coherent bodies	Polymict (mixed with rock and mineral clasts)
Suevite	<0.2–0.5 m	Crystalline rocks > sedimentary rocks	Stages 0–IV <~1000 kbar	Central crater cavity, megablock zone, and Vorries zone	Polymict
Dike breccias	<0.2–0.5 m	Crystalline rocks > sedimentary rocks	Stages 0–II <~350 kbar	Crater basement megablocks, surface megablocks	Polymict
Crystalline breccia	<0.5–1 m	Crystalline rocks	Stages 0–II <~350 kbar	As irregular bodies within or on top of Bunte breccia, central crater cavity	Polymict
Bunte breccia	<25 m	Sedimentary rocks > crystalline rocks	Stages 0–II <~350 kbar	Megablock zone and Vorries zone	Polymict
Megablocks	~25–1000 m	All stratigraphic units	Stages 0–I <~50–100 kbar	Crater basement, inner ring, megablock zone, and Vorries	Monomict
Brecciated and fractured autochthonous rocks	–	All stratigraphic units	Stage 0 <~50 kbar	At the tectonic rim, undisplaced crater basement	Monomict

Table 3. Classification and nomenclature of lunar highland rocks (modified from Stöffler et al. 1980).

1. Igneous rocks
    - 1.1. Volcanic rocks
        - 1.1.1. Basalts
    - 1.2. Plutonic rocks
        - 1.2.1. Anorthosites (anorthosite, noritic anorthosite, gabbroic anorthosite, troctolitic anorthosite)
        - 1.2.2. Norites (anorthositic norite, norite, gabbroic norite, olivine norite)
        - 1.2.3. Gabbros (anorthositic gabbro, gabbro, noritic gabbro, olivine gabbro)
        - 1.2.4. Troctolites (anorthositic troctolite, troctolite)
        - 1.2.5. Ultramafics (pyroxenite, peridotite, dunite)
2. Metamorphic (recrystallized) rocks
3. Breccias
    - 3.1. Monomict breccias
        - 3.1.1. Cataclastic rocks
        - 3.1.2. Metamorphic (recrystallized) cataclastic rocks
    - 3.2. Dimict breccias
    - 3.3. Polymict breccias
        - 3.3.1. Regolith (soil) breccias
        - 3.3.2. Fragmental breccias
        - 3.3.3. Crystalline melt breccias (impact melt breccias)
        - 3.3.4. Glassy melt breccias (impact glass)
        - 3.3.5. Granulitic breccias

His work on asteroids, as well as asteroidal meteorites, concerns modeling of the effects of impacts on asteroid-sized bodies and the petrography and petrogenesis of meteorites from differentiated as well as primitive asteroids. He and his co-workers concluded that, on relatively small asteroids, impact cannot have been the heat source for their melting and thus the differentiated meteorites (e.g., the ureilites, aubrites, mesosiderites, the Eagle Station pallasites, acapulcoites, lodranites, IAB, IIICD, and IIE irons) must have had heat sources other than impact (Keil et al. 1997). His research team's vast experience with terrestrial and lunar impact breccias served them well in their studies of the shock effects on asteroidal meteorites (Stöffler et al. 1988; Bischoff and Stöffler 1992) and, in particular, the brecciated howardite, eucrite, and diogenite (HED) meteorites and the interpretation of their textures and compositions for deciphering the role of thermal and impact metamorphism of their parent body, most likely asteroid 4 Vesta (Metzler et al. 1995). Dieter and his co-workers also contributed extensively to the understanding of impact breccia formation on chondrite parent bodies (Bunch and Stöffler 1974) and the lithification of gas-rich ordinary chondrite regolith breccias by impact-derived, local,

Table 4. Progressive stages of shock metamorphism of ordinary chondrites. Only shock effects in olivine and plagioclase are used for classification (the prime shock criteria are underscored). The post-shock temperature refers to the temperature increase upon pressure release relative to the ambient pre-shock temperature (after Stöffler et al. 1991).

Shock stage	Effects resulting from equilibrium peak shock pressure		Effects resulting from local P-T excursions	Shock pressure (GPa)	Post-shock temperature increase (°C)	Estimated minimum temp. increase (°C)
	Olivine	Plagioclase				
Unshocked S1	Sharp optical extinction, irregular fractures		None	<4–5	10–20	10
Very weakly shocked S2	Undulatory extinction, irregular fractures		None	5–10	20–50	20
Weakly shocked S3	Planar fractures, undulatory extinction, irregular fractures	Undulatory extinction	Opaque shock veins, incipient formation of melt pockets, sometimes interconnected	15–20	100–150	100
Moderately shocked S4	Mosaicism (weak), planar fractures	Undulatory extinction, partially isotropic, planar deformation features	Melt pockets interconnecting melt veins, opaque shock veins	30–35	250–350	300
Strongly shocked S5	Mosaicism (strong), planar fractures + planar deformation features	Maskelynite	Pervasive formation of melt pockets, veins and dikes; opaque shock veins	45–55	600–850	600
Very strongly shocked S6	Restricted to local regions in or near melt zones					
	Solid state recrystallization and straining, ringwoodite, melting	Shocked melted (normal glass)	As in stage S5	75–90	1500–1750	1500
Shock melted	Whole rock melting (impact melt rocks and melt breccias)					

intergranular melting (Bischoff et al. 1983). One of the most widely cited papers in meteoritics deals with the classification of shock in ordinary chondrites into six stages, from unshocked (S1) to very strongly shocked (S6) (and shock melted) (Table 4), based on microscopically-determined shock effects in constituent olivine and plagioclase (Stöffler et al. 1991).

Finally, in a series of papers, Dieter and collaborators have studied cometary analog materials (e.g., Stöffler 1991; Stöffler and Düren 1992). This work was carried out in preparation for the anticipated return of cometary samples to Earth by the Rosetta Mission, and curation and study of these materials in terrestrial laboratories.

Dieter has been much honored for his research by many different organizations. The Meteoritical Society elected him as a fellow in 1986, honored him with the Barringer Medal in 1993, and chose him as its president for 1997–1998. In 1989, Dieter received the prestigious Leibniz Preis of the Deutsche Forschungsgemeinschaft, a total of about $1.8 million for five years of discretionary research funding. In 1991, the International Astronomical Union named asteroid 4283 “Asteroid Stöffler” in his honor. Dieter’s work on the Ries impact crater and his dedication to help start the Ries Museum in Nördlingen earned him the “Ehrenbrief” (Letter of Honor) of the town of Nördlingen (1991), and the “Rieser Kulturpreis” (Culture Award of the Ries) (2003). Finally, Dieter was elected member of the Berlin-Brandenburgische Akademie der Wissenschaften (1995) and of the Deutsche Akademie der Naturforscher Leopoldina (1999).

The many former students, co-workers, and colleagues from across the world wish Dieter Stöffler continued productivity and much health in the years to come.

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