FANTASTIC NEW CHONDRITES, ACHONDRITES, AND LUNAR METEORITES AS THE RESULT OF RECENT METEORITE SEARCH EXPEDITIONS IN HOT AND COLD DESERTS

ADDI BISCHOFF
Institut für Planetologie/ICEM, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany
E-mail: bischoa@nwz.uni-muenster.de

Abstract. In the last 25 years thousands of new meteorites were recovered in the "cold deserts" of Antarctica and in the hot deserts of Australia, New Mexico, North Africa, and Oman. Based on the findings of many spectacular samples new meteorite classes could be defined. Considering the undifferentiated chondrites, the new class of the Rumuruti (R-) chondrites was established and the carbonaceous chondrites gained three more subgroups (CR-, CH-, and CK-chondrites). Also, among the achondrites new meteorite classes were defined in recent years (angrites, brachinites, and the primitive achondrite classes of acapulcoites, winonaites, and lodranites). Certainly, the most spectacular discovery among the cold and hot desert meteorites was the recognition of the Lunar meteorites. In addition, the number of Martian meteorites has been significantly increased based on successful meteorite search.

Among the thousands of meteorite fragments mainly collected by American and Japanese expeditions in Antarctica the first lunar meteorite ALHA81005 was identified in 1982. ALHA81005 is a highland breccia like several other samples that were collected in Antarctica in the following years. The first lunar meteorite found outside Antarctica is Calcalong Creek (Australia), a small 19 g sample. In recent years several lunar meteorites were found in North Africa and Oman. The first lunar sample recovered from the northern hemisphere is Dar al Gani 262, a 513 g fragment found March 1997 in the Sahara. It was the 13th lunar meteorite. Since 1997 some more rocks from the Moon were collected: Dar al Gani 400, Yamato 981031, Dhofar 025, 026 and 071, and Northwest Africa 032 and 482. Dhofar 071 contains high abundance of once-molten fragments and interstitial fine-grained (devitrified) material.

1. Introduction

Fifteen years ago less than 1000 meteorite falls and 1706 meteorite finds were known (Graham et al., 1985). Most of these rocks were subdivided in distinct meteorite classes (different types of chondrites and achondrites), others were described as grouplets (e.g., Carlisle Lakes-type meteorites, metamorphosed carbonaceous chondrites) or unique rocks (e.g., Winona, Kakangari, Lodran, Angra dos Reis). Modern meteorite search in hot and cold deserts has increased the number of meteorites significantly as well as the number of distinct meteorite classes.

Before 1970 only 15 meteorites have been found in Antarctica. Then, 1973 systematic search of meteorites started mainly by Japanese and American exped-

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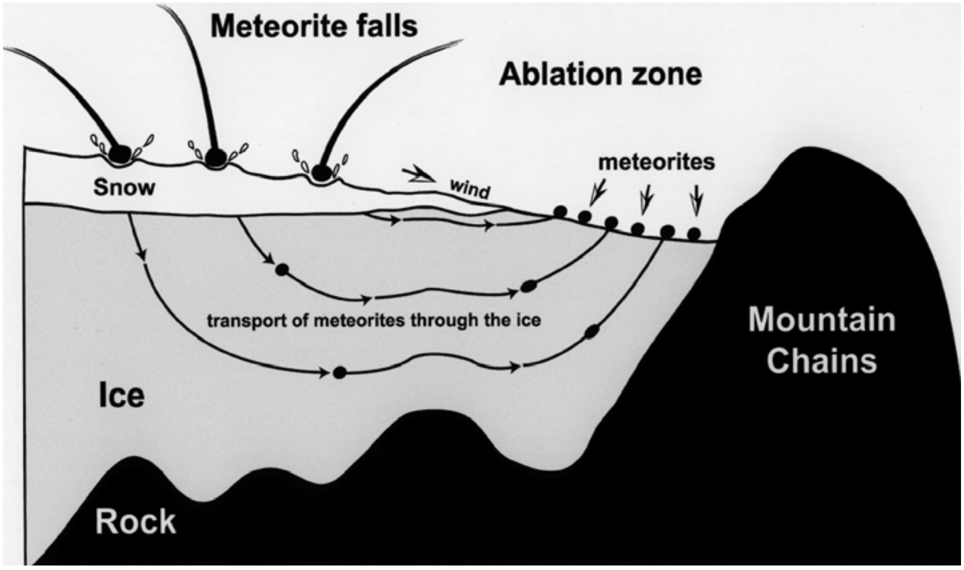

Figure 1. Meteorite accumulation in Antarctica. Figure redrawn after drawing of L. Schultz, Max-Planck-Institute für Chemie (Mainz).

itions. Until today more than 20000 meteorite fragments were recovered (number uncorrected for pairing). Very successful was the meteorite search on so-called blue ice fields. In Antarctica, meteorites that fell on a huge ice area will be transported through the ice and will be concentrated in distinct ablation zones near mountain chains (Figure 1). Because of the cold environment and the lack of liquid water meteorites will survive in the ice for a very long time. A huge advantage for meteorite search is given through the fact that very small samples can be collected due to the lack of vegetation.

Since all individual fragments in Antarctica reveal their own separate number, the number of meteorite fragments is very large. An about similar number of meteorite fragments has been recently collected in hot deserts, where the situation is greatly different. The meteorites are on average much younger than the Antarctic samples caused by extreme weathering (strong temperature changes, rain and atmospheric water, wind erosion, etc.). Meteorites will not be transported over tens of kilometers as it is the case in Antarctica. Therefore, fragments lying together in a limited area receive the same collection name and number. In recent years several thousands of new meteorite numbers were approved by the Nomenclature Committee of the Meteoritical Society. In the Sahara of North Africa most meteorites were recovered from large, flat, and almost featureless desert areas (Regs), which are typically covered with cm-sized rounded rocks (pebbles) and a small amount of sand. All these sediments are light-coloured, yellow to grey (Figures 2 and 3; compare Bischoff and Geiger, 1995; Bischoff, 2001). Otto (1992) described these rocks as "fine-grained breccias of angular to slightly rounded fragments of quartz,

Figure 2. Meteorite find in the Ilafegh region of Algeria. The Ilafegh 001 H4 chondrite weighing 713 g was found in September 1989.

plagioclase, and microcline embedded in a matrix consisting of clay minerals, calcite, and some white mica".

At the moment the number of collected meteorites from the main meteorite search fields in hot deserts can only be roughly estimated with about 7000–8000 (numbers uncorrected for pairing) including several 10 000 fragments (Bischoff, 2001).

2. Classification of Meteorites

To sort extraterrestrial rocks into broadly similar types of objects and to better understand the origin of these rocks and their relationships, meteorites have been classified for a long time. An old classification system is simply distinguishing between stony, stony-iron, and iron meteorites. This kind of classification considers just the modal abundance of metal in a rock, but does not contain any information on its formation process. Thus, considerable diversity exists within the group of stony meteorites. This group includes primitive, unequilibrated chondrites as well as differentiated rocks from asteroids and also stones from the Moon and Mars (Lunar and Martian meteorites). Therefore, meteorites are much better broadly subdivided into the two main divisions "differentiated" and "undifferentiated" meteorites (Figure 4). Such a classification considers the origin and evolution of the

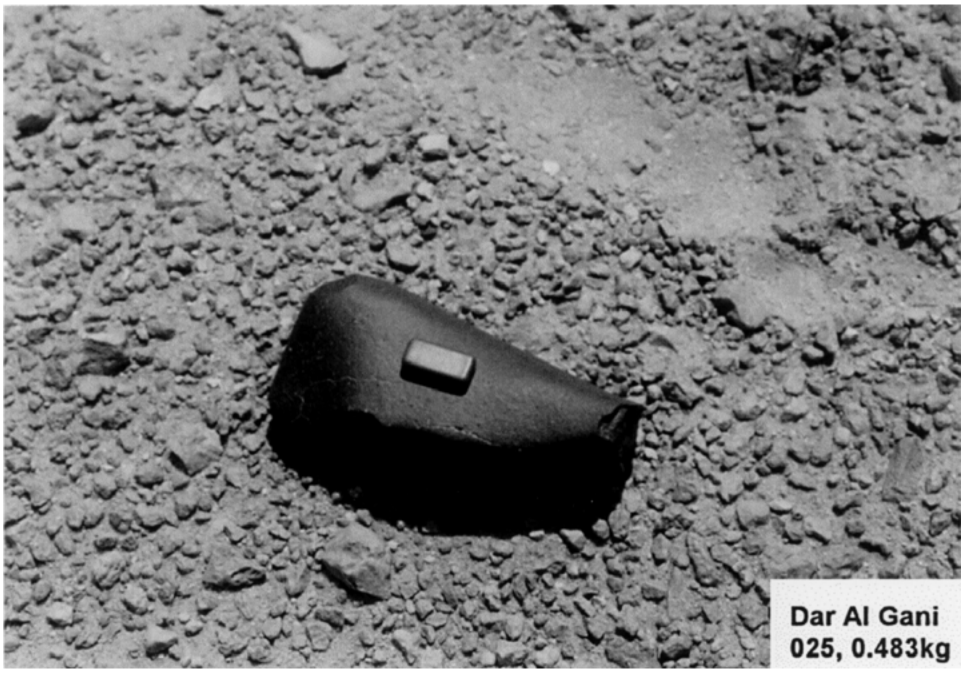

Figure 3. Meteorite find in the Dar al Gani area of Libya. The CO3 chondrite Dar al Gani 025 was found as a 483 g piece in May 1995.

rocks: All the chondritic rocks belong to the undifferentiated meteorites, whereas the differentiated meteorites include the (metal-poor) achondrites (plus the Lunar and Martian meteorites) as well as the stony-iron and iron meteorites.

In the past, five similar meteorites were necessary to define a new meteorite class (as done for the CI chondrites). The successful meteorite search in hot and cold deserts resulting in the finding of several ten thousand new samples has significantly increased the number of distinct new meteorite classes.

Actually, four distinct chondritic classes with 12 groups are well-defined: (a) Carbonaceous chondrites (with the groups: CI, CM, CO, CV, CK, CR, CH), (b) Ordinary chondrites (with the groups: H, L, LL), (c) Enstatite chondrites (with the groups: EH, EL), and (d) Rumuruti chondrites (R-chondrites). The R chondrites and three groups of carbonaceous chondrites (CK, CR, CH) have been established in recent years (e.g., Kallemeyn, 1988; Geiger and Bischoff, 1990; Weisberg et al., 1991, 1993; Bischoff et al., 1993a, b, 1994; Schulze et al., 1994; Rubin and Kallemeyn, 1994; Kallemeyn et al., 1991, 1994, 1996; Clayton and Mayeda, 1999; Bischoff, 2000).

Besides the diverse groups of iron meteorites and the two classes of stony-irons (pallasites and mesosiderites) the following main achondrite groups can be named among the differentiated meteorites: The primitive achondrites (acapulcoites, winonaites, and lodranites), the HED-meteorites (*H*owardites, *E*ucrites,

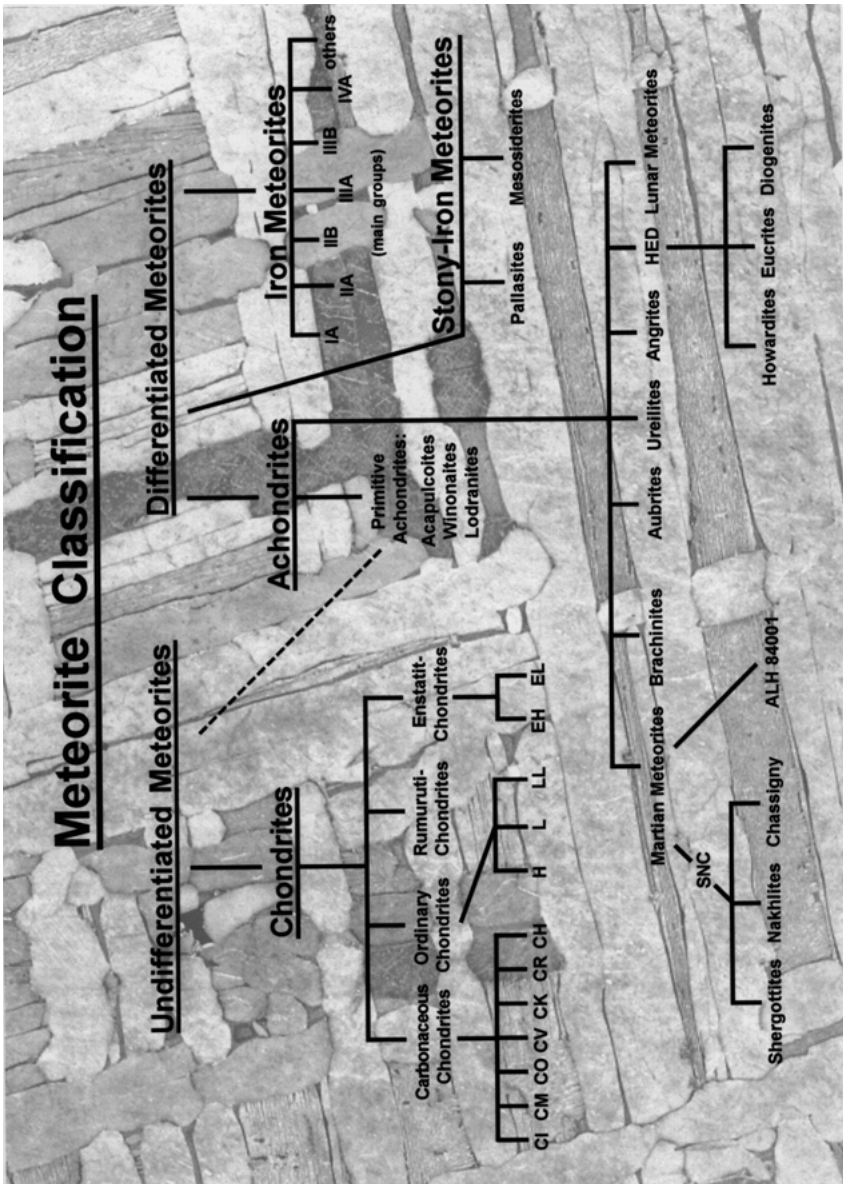

Figure 4. Classification of meteorites: Based on their origin meteorites can best be subdivided into differentiated and undifferentiated rocks.

*D*iogenites), aubrites, brachinites, ureilites, and angrites. In addition, the Martian meteorites (SNCs (*S*hergottites, *N*akhlites, *C*hassigny) and ALH84001) and the Lunar meteorites have to be included in the achondrite group. Among the achondrites the new meteorite classes defined in recent years include angrites, brachinites, and the primitive achondrite classes of acapulcoites, winonaites, and lodranites (e.g., Nehru et al., 1992; Kimura et al., 1992; Takeda et al., 1994; McCoy et al., 1993, 1996, 1997; Zipfel et al., 1995; Mittlefehldt et al., 1996, 1998; Clayton and Mayeda, 1996; Benedix et al., 1998).

3. The Lunar Meteorites

Among the thousands of meteorite fragments mainly collected by American and Japanese expeditions in Antarctica the first lunar meteorite ALHA81005 was identified in 1982 (Score and Mason, 1982). ALHA81005 is a highland breccia like several other samples that were collected in Antarctica in the following years. The first lunar meteorite found outside Antarctica is Calcalong Creek (Australia), a small 19 g sample (Hill et al., 1991). In recent years several lunar meteorites were found in North Africa and Oman. The first lunar sample recovered from the northern hemisphere is Dar al Gani 262, a 513 g fragment found March 1997 in the Sahara (Bischoff and Weber, 1997; Bischoff et al., 1998). It was the 13th lunar meteorite. Dar al Gani 262 is a mature, anorthitic regolith breccia with highland affinities. About 52 vol% of the studied thin sections of Dar al Gani 262 consist of fine-grained (smaller than approximately 100 μm) components, and 48 vol% is mineral and lithic clasts and impact melt veins. The most abundant clast types are feldspathic fine-grained to microporphyritic crystalline melt breccias (50.2 vol%; Bischoff et al., 1998), whereas mafic crystalline melt breccias are extremely rare (1.4 vol%). Granulitic lithologies are 12.8 vol%, cataclastic anorthosites and intragranularly recrystallized anorthosites are 8.2 and 8.8 vol%, respectively, and (devitrified) glasses are 2.7 vol% (Bischoff et al., 1998). Impact melt veins cutting across the entire thin section were probably formed subsequent to the lithification process of the bulk rock at pressures below 20 GPa. The bulk rock never experienced a higher peak shock pressure (Bischoff et al., 1998).

Since 1997 some more rocks from the Moon were collected: Dar al Gani 400, Yamato 981031, Dhofar 025, 026, 081, and Northwest Africa 032 and 482 (Zipfel et al., 1998; Grossman, 2000, 2001; Kojima and Imae, 2000). The first observations and chemical analyses of the lunar meteorite find Dhofar 081 will be briefly presented below.

Dhofar 081. This rock was found 1999 in the desert of Oman as a stone weighing 174 g. Hand specimen inspection revealed typical features of a lunar highland breccia: Abundant light-coloured clasts are embedded in a fine-grained matrix (Figure 5). The prepared thin section shows that Dhofar 081 contains a higher abundance of

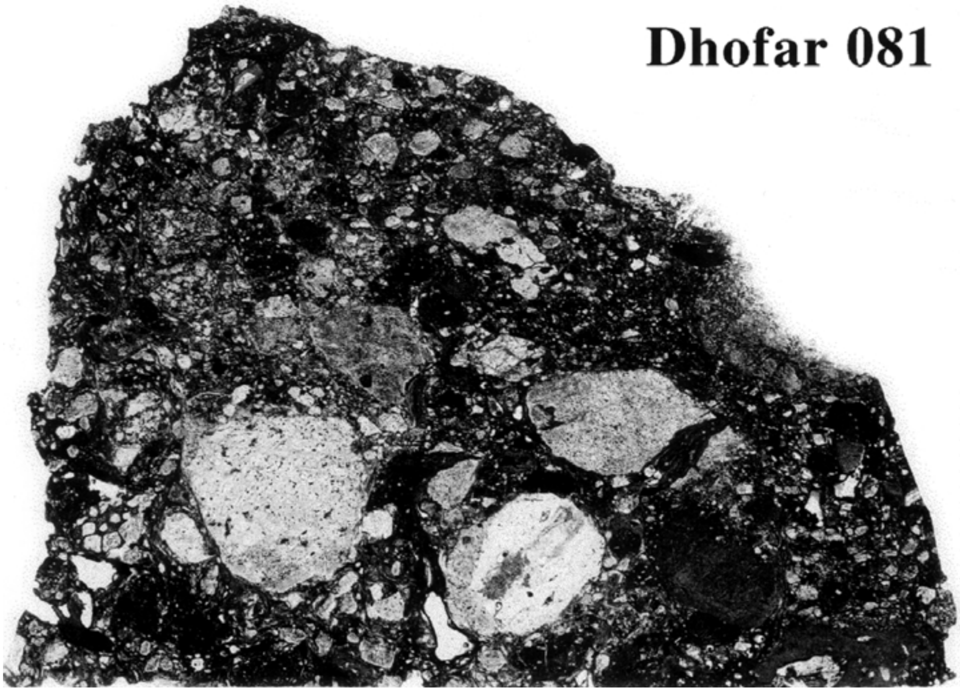

Figure 5. Transmitted light photograph of a thin section from Dhofar 081 showing huge light fragments of cataclastic anorthosites, recrystallized anothosites, and "devitrified" plagioclase glass. Fragments of crystalline impact melt breccias are mostly grey to dark grey. All fragments are embedded in a fine-grained (basically devitrified) matrix. Size: 1.5 cm in largest dimension.

once-molten material interstitial to the lithic fragments than any other lunar meteorite studied by the author (MAC88104/5, ALHA81005, Y-82192/3, Y-791197, Y-86032, QUE93069, and Dar al Gani 262). Most (if not all) of this interstitial material is crystalline (fine-grained devitrified). Flow structures "schlieren" are easy to recognize (Figure 6). Vesicles within this interstitial material are very abundant and their abundance is the highest in all lunar meteorites studied by the author. The breccia contains various kinds of fragments typical also for other lunar highland breccias (e.g., Bischoff et al., 1987, 1998; Bischoff, 1996). The largest fragments include cataclastic anorthosites, intragranularly recrystallized anorthosites, and crystalline fine-grained impact melt rocks and breccias. While many other types of different lithic clasts and mineral fragments have been observed, round impact melt spherules, a typical component of the lunar regolith, which occurs in most other lunar meteorites, were not detected in the thin section studied.

A small number of the main minerals were analyzed. The data reveal that anorthite has basically >95 mol% An-content. The olivine compositions are highly variable ranging from 25–46 mol% Fa. Different pyroxenes (Fs_{15-44};Wo_{4-41}) have been analyzed, partly showing exsolution textures.

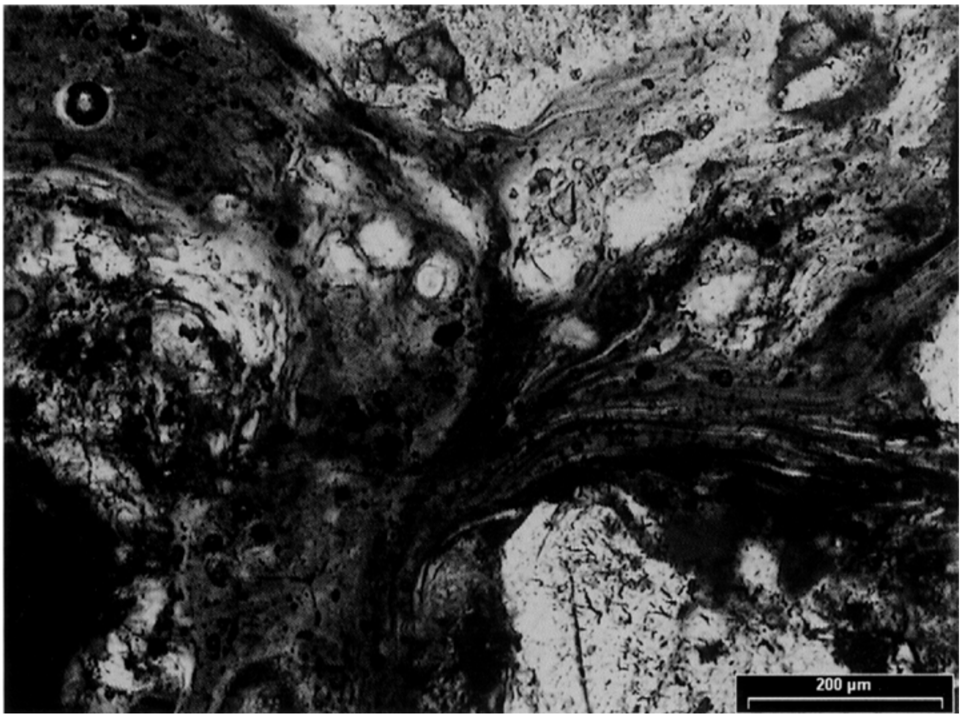

Figure 6. Transmitted light photograph of a typical area showing flow structures (schlieren) within the interstitial material between large lithic clasts.

4. Final Remarks

Based on the huge success in meteorite search our knowledge about the formation and evolution of various bodies in our solar system has been significantly increased. This is the case considering the primitive undifferentiated chondrites and their parent bodies as well as the achondritic rocks and their parent planetesimals and planets. Especially the finding of many new rocks from the Moon and (perhaps) from Mars has fruitful stimulated planetary sciences. All these fundamental studies on meteorites will be accompanied by increased space mission activities in the upcoming years. There might be many successful years in meteorite research and planetology to come.

Official meteorite search in Antarctica and unofficial search by meteorite hunters in hot deserts will certainly be continued. New unique samples will be recovered and the increasing number of rare finds will significantly increase the number of definable meteorite classes. Considering five meteorites as the minimum number of samples for a new group, only some more meteorites are necessary to define the K-chondrites (Kakangari, LEW87232, Lea Co. 002; Weisberg et al., 1996) and B-chondrites (Bencubbin, Weatherford, GRO95551; Weisberg et al., 1998).

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