Bull. Natn. Sci. Mus., Tokyo, Ser. E, 3, December 22, 1980

# On the Duwun Chondrite: The Chemical Composition, Mineralogy and Petrography

By

**Hideo YABUKI**

The Institute of Physical and Chemical Research, Wako, Saitama,

and

**Masako SHIMA**

Department of Physical Sciences, National Science Museum, Tokyo.

## I. Introduction

In 1958, the National Science Museum purchased a meteorite which weighed 2117 g, and was covered by black outer crust, as is shown in Fig. 1.

It is said that the meteorite fell on a hill called Seungdurisan, Duwun-Myoen, Kohung-gun, Choenra-Namdo, Korea, approximately 33°26′ N., 127°16′ E., with a flash of light and detonation at 15: 47 hrs on November 23, 1943. At the same time a few stones fell in an area further to the Southeast of Duwun-Myoen.

The meteorite we obtained was named Duwun after the name of the village, where it fell.

## II. Chemical Composition

The chemical composition of the Duwun chondrite was determined by a method similar to ones described in the previous papers (Murayama *et al.*, 1978; Okada *et al.*, 1979; Shima *et al.*, 1979a, 1979b).

A minor modification was applied to the fractional dissolution method, that is ammoniacal EDTA solution was used after $CuCl_2$-KCl and before $Br_2$-aqua regia treatments, for extracting phosphate mineral only (Honda & Shima, 1967, Shima & Honda, 1967, Shima 1974).

In addition to the above, for the decomposition of the Duwun chondrite, a new method (Bernas 1968) was employed for the 0.05 g pulverized sample. Detail will be described in a following paper (Shima 1980).

The determination of most of the elements were performed by atomic absorption spectrometry using Shimadzu AA–640–12, except sulphur and phosphorus which were analyzed gravimetrically and colorimetrically, respectively.

The results combined with all data obtained from four different decomposition methods are shown in Table 1. In this table, CIPW norm calculated from analytical

Table 1. Chemical composition and CIPW norm of the Duwun chondrite.

| Species | Weight percent | Species | | Weight percent |
|---|---|---|---|---|
| $SiO_2$ | 38.664 | Olivine | Fo | 30.24 |
| MgO | 24.915 | | Fa | 13.83 |
| FeO | 13.176 | Hypersthene | En | 17.14 |
| $Al_2O_2$ | 1.941 | | Fs | 5.73 |
| CaO | 1.692 | Diopside | En | 1.77 |
| $Na_2O$ | 0.936 | | Fs | 0.58 |
| $K_2O$ | 0.093 | | Wo | 2.56 |
| $Cr_2O_3$ | 0.470 | Plagioclase | Or | 0.55 |
| MnO | 0.327 | | Ab | 7.92 |
| $TiO_2$ | 0.105 | | An | 0.82 |
| $P_2O_5$ | 0.220 | Apatite | | 0.51 |
| $H_2O$ | 0.550 | Chromite | | 0.69 |
| Metal | | Ilmenite | | 0.20 |
| Fe | 8.726 | Nickel-ion | | 10.49 |
| Ni | 1.662 | Troilite | | 6.04 |
| Co | 0.100 | Water | | 0.55 |
| Sulphide | | | | |
| FeS | 6.041 | | | |
| Sum | 99.618 | | | 99.62 |
| Total Fe | 22.806 | | | |

data is also presented. The Duwun chondrite is a typical L-group chondrite whereas Ca abundance is slightly lower and Ni and Co are a little higher than average values of L-group chondrites (Mason, 1971).

Table 2. Relative elemental abundances in separated phases of the Duwun chondrite.

| Elements | Whole meteorite (%) | Fraction (%) | | | |
|---|---|---|---|---|---|
| | | $CuCl_2$-KCl | EDTA | $Br_2$-aqua regia | Residue |
| Si | 18.073 | | | | |
| Mg | 15.025 | 1.35 | 0.22 | 67.14 | 31.29 |
| Fe | 22.806 | 38.26 | 0.24 | 49.34 | 12.26 |
| Al | 1.027 | 0.28 | 0.61 | 2.01 | 97.10 |
| Ca | 1.209 | 2.89 | 1.06 | 13.36 | 82.69 |
| Na | 0.694 | | | | |
| K | 0.077 | | | | |
| Cr | 0.322 | ~0 | ~0 | 1.37 | 98.63 |
| Mn | 0.253 | 1.68 | 0.21 | 58.23 | 39.88 |
| Ti | 0.063 | ~0 | ~0 | ~0 | ~100 |
| P | 0.096 | ~0 | 30.10 | 69.90 | ~0 |
| Ni | 1.662 | 95.10 | 0.37 | 4.53 | ~0 |
| Co | 0.100 | 92.82 | 0.51 | 6.67 | ~0 |
| S | 2.203 | | | | |

Elemental abundances of each element and results of chemical dissolution are shown in Table 2. These data should be compared with similar data for L-group chondrites Nagai and Shibayama. Although both chondrites belong to subgroup 6, Shibayama is an example of the weathered chondrite while Nagai is not. As a result of weathering, chemical bonds of all elements examined in Shibayama are somewhat loosened and more soluble in $CuCl_2$-KCl and $Br_2$-aqua regia solutions than those in Nagai. Whereas Duwun is a rather fresh chondrite, $Mg^{++}$ indicates similar behavior to that in Shibayama, 1–1.5% of it dissolved in $CuCl_2$-KCl solution. Why does the Mg bond loosen in the Duwun? Is this the result of a heavy shock in space? If so, this may also explain the deformed crystal of pyroxene as is described in a following section. The behavior of Ni and Co indicate that the Duwun chondrite is relatively well preserved.

## III. Petrography and Mineralogy

A thin section of about 0.5 $cm^2$ and a polished thin section of about 0.3 $cm^2$ were prepared for the petrographic observation using a polarizing microscope and also for electron microprobe analyses. Unit cell parameters of olivine and orthopyroxene were determined by X-ray patterns of powdered sample mixed with a standard of pure silicon. The phase composition of transparent and opaque minerals was measured by the planimeric integration of the thin section and the polished thin section under transmitted and reflected light respectively. Refractive indices of olivine and orthopyroxene were determined by the oil-immersion method for finely pulverized sample and their HCl insoluble part respectively. Electron microprobe analyses were performed on these principal silicate minerals by using two instruments: 1) JXA-733 equipped with computer control system located at JEOL Co. Ltd., Akishima, Tokyo and 2) EMX-SM7 located at Tokyo Research and Application laboratory, Shimadzu Seisakusho Ltd., Chofu, Tokyo. The standards used for quantitative analyses of ten oxide components were pure oxides of each element for the former and analyzed kaersutite, MnO and $Cr_2O_3$ for the latter measurement. The ZAF correction was carried out in both cases.

The Duwun meteorite is an ordinary chondrite, consisting of olivine, orthopyroxene, calcic pyroxene, plagioclase, maskelynite, apatite, metallic nickel-iron, troilite, and chromite. Under the microscope, silicate phase of the meteorite is composed of a granular aggregate of various sized grains of olivine, pyroxenes with minor plagioclase (Fig. 2). The majority of silicate grains show a remarkable strain effect due to shock deformation, i.e., undulatory extinction and mosaic extinction of olivine and pyroxenes in crossed polarized light (Fig. 3), the occurrence of kink bands in several olivine and orthopyroxene grains, a few very fractured olivine grains, some recrystallized olivine grains, and advanced maskelynitization of plagioclase. Some bent crystals of orthopyroxene as seen in Fig. 4 also arrest attention in thin sections. They appear apparently to have suffered a plastic deformation by some heavy strain. Chondrules are few and range up to 1.0 mm in size. They are mainly composed of olivine, pyroxenes, and some plagioclase, occasionally associated with aggregates of fine chromite-like crystals (Fig. 5). Most of chondrules are deformed in shape, and the border between chondrules and the matrix is almost obliterated. In this meteorite, in addition to chondrules a pyroxenite-like fragment is contained (Fig. 2). It is mainly composed of an aggregate of clinopyroxene (diopside?) showing fine exsolution lamellae of clinopyroxene species and several orthopyroxene grains (Fig. 6). A fused texture is also noticed in thin sections of the Duwun chondrite. Fused droplets of troilite, metallic nickel-iron, or silicate are enclosed in other phases (Figs. 7, 8). Clouds of dust-sized particles are also recognized sporadically in the matrix and chondrules (Fig. 9). These parts are

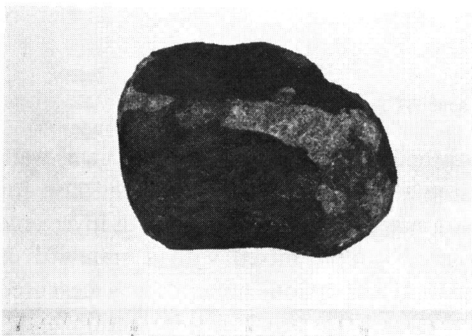

Fig. 1. The complete mass of the Duwun chondrite. 2117 g in weight.

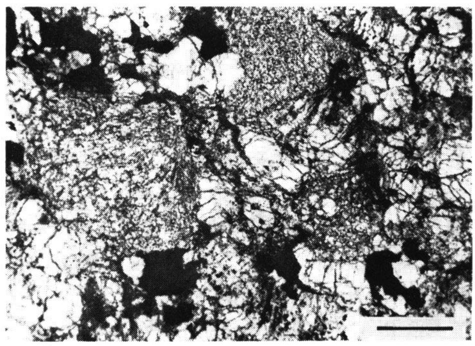

Fig. 2. A thin section of the Duwun chondrite. It is composed of granular aggregates of silicates and irregular opaque minerals, with relatively few chondrules. A pyroxenite-like fragment in fan-shape is seen at left-hand side. Plane polarized light. Scale bar is 0.5 mm long.

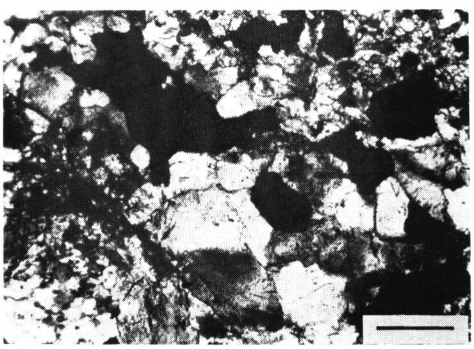

Fig. 3. Recrystallized structure and advanced mosaicism of olivine and pyroxene grains. Crossed polarized light. Scale bar is 0.1 mm long.

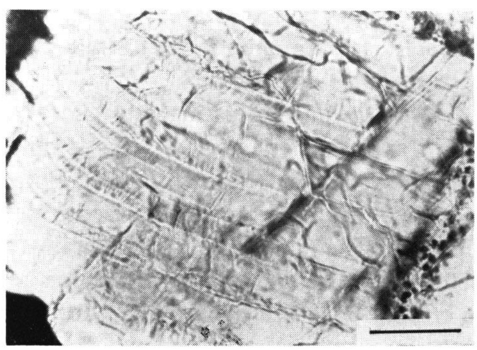

Fig. 4. Orthopyroxene crystals bent by plastic deformation. Plane polarized light. Scale bar is 0.03 mm long.

always embedded in brownish material, probably glassy object, which cannot be clearly decided by interruption of adjacent silicates.

The phase composition obtained by modal analysis is listed in Table 3. The original data in volume per cent were converted to weight per cent by multiplying by the specific gravities of each constituent. The obtained composition is very close to the CIPW norm calculated from analytical data (Table 1) and the average of L-group chondrites (Van Schmus, 1969). The only difference is in olivine, that is, the modal analysis gives 50% while CIPW norm is 44% and incidentally the average of L-group chondrite above is 45–49%. This may be caused by analysing too small an area of

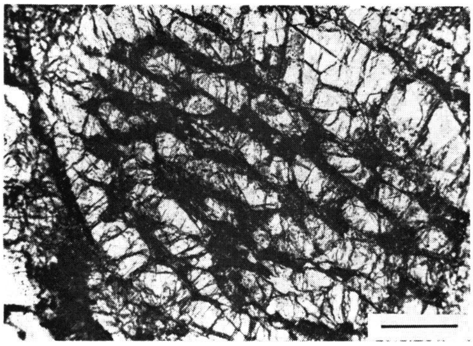

Fig. 5. A barred chondrule consisting of olivine bars, intersticial plagioclase, and aggregates of fine chromite-like crystals. Plane polarized light. Scale bar is 0.2 mm long.

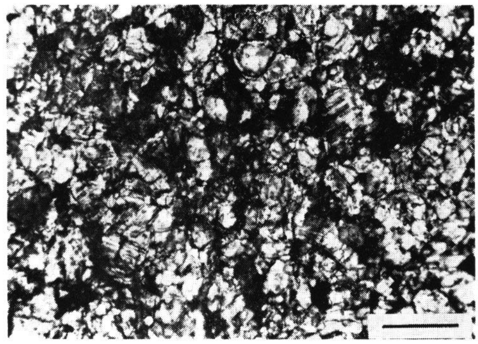

Fig. 6. Magnification of a part of pyroxenite-like fragment. It consists mainly of clinopyroxene with fine lamellae of clinopyroxene and some orthopyroxene grains. Crossed polarized light. Scale bar is 0.2 mm long.

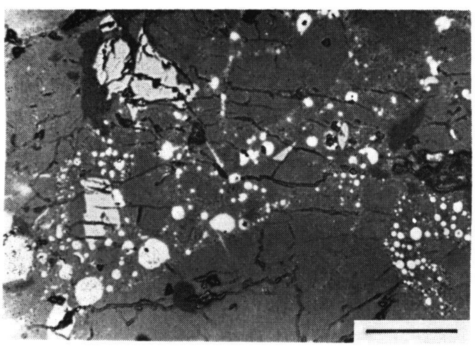

Fig. 7. Fused texture is sporadically seen. Globules of troilite and metal are spread in silicates. Surrounding silicates are changed into brownish, probably glassy material, whose surface appears rough. Reflected light, Scale bar is 0.03 mm long.

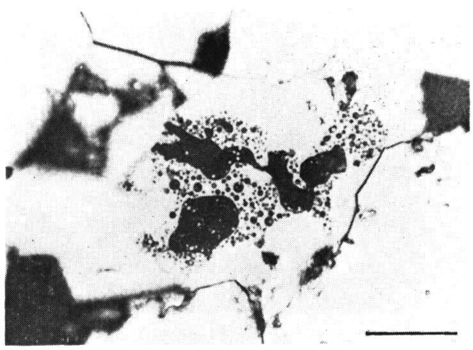

Fig. 8. Reversed relation of Fig. 7. Tiny globules of silicates (black) are included in a coarse grain of troilite (white). Reflected light. Scale bar is 0.03 mm long

about 0.8 $cm^2$ which is insufficient to represent this meteorite.

*Olivine*; Olivine is the commonest constituent both in the matrix and in chondrules. It is usually xenomorphic except in some parts where the internal structure of porphyritic chondrules are still recognized as a relict (Fig. 10). Interstices of these parts are filled with plagioclase and aggregates of elongated crystals, some of which appear to be olivine and others clinopyroxene (Fig. 10). The grain size of olivine in the matrix ranges from 0.01 to 0.7 mm. Most grains show heavily deformed feature as described before and well-developed (010) cleavage can be seen in many of them. The refractive

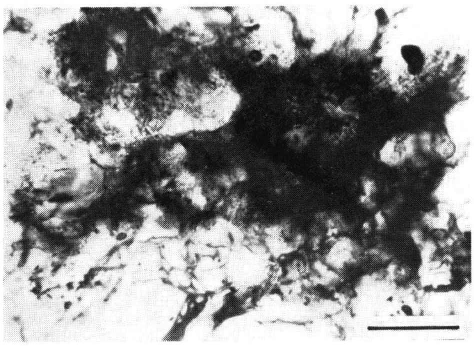

Fig. 9. Cloud of dust-sized particles in silicates (now brownish material). Local fusion? Plane polarized light. Scale bar is 0.03 mm long.

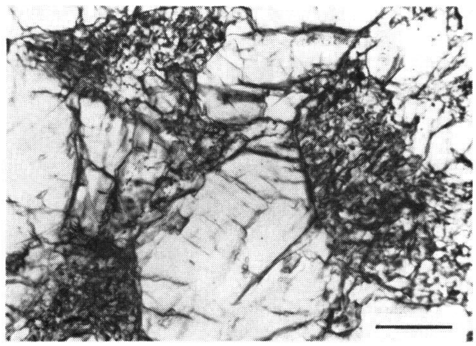

Fig. 10. Magnification of a relict part of porphyritic chondrule. Phenocrysts are nearly idiomorphic but fairly corroded. Intersticial plagioclase are filled with elongated crystals of olivine or pyroxenes. Plane polarized light. Scale bar is 0.05 mm long.

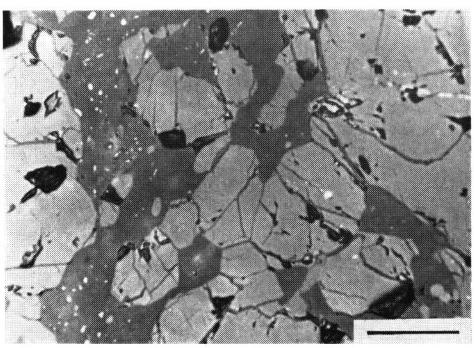

Fig. 11. Plagioclase and maskelinite (dark gray) occurs xenomorphic filling interstices among other silicates (gray). Fine chromite-like crystals and minute granular olivine or pyroxene are often included in them. Reflected light. Scale bar is 0.03 mm long.

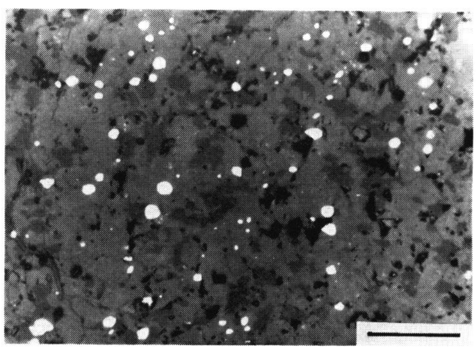

Fig. 12. Finely disseminated nickel-iron (white) in silicates. Reflected light. Scale bar is 0.03 mm long.

Table 3. Modal composition of the Duwun chondrite.

| Constituents | Composition in weight per cent |
|---|---|
| Olivine | 50 |
| Orthopyroxene | 21 |
| Calcic pyroxene | 6 |
| Plagioclase* | 7 |
| Apatite | <0.5 |
| Metallic nickel-iron | 9 |
| Troilite | 6 |
| Chromite | 1 |
| Sum | 100 |

* Maskelynite is included.

indices, $\alpha=1.678$ and $\gamma=1.720$, indicate 24 mole per cent of $FeSiO_3$ component, according to the determinating curve of Deer *et al.* (1962). This value is in good agreement with the result from interplaner spacing $d_{130}$ and the determination curve of Yoder and Sahama (1957). The unit cell parameters of olivine are a=4.773Å, b=10.273Å, and c=6.014Å. The chemical composition of olivine determined by electron probe microanalysis is shown in Table 4. It indicates the average molar composition of $Fo_{77}Fa_{23}$. These data as well as CIPW norm in Table 1, suggest that olivine composition in the Duwun chondrite is quite uniform through whole stone.

Table 4. Chemical composition of olivine in the Duwun chondrite.

| | 1 | 2 | 3 | 4 | 5* | Aver. |
|---|---|---|---|---|---|---|
| $SiO_2$ | 37.99 | 38.91 | 39.03 | 38.99 | 36.61 | 38.31 |
| $TiO_2$ | 0.02 | 0.00 | 0.01 | 0.00 | 0.02 | 0.01 |
| $Al_2O_3$ | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| FeO | 21.57 | 20.15 | 20.60 | 20.98 | 23.62 | 21.38 |
| MnO | 0.47 | 0.45 | 0.39 | 0.40 | 0.59 | 0.46 |
| MgO | 39.19 | 40.12 | 40.58 | 39.34 | 37.81 | 39.41 |
| CaO | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| $Na_2O$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 |
| $K_2O$ | 0.00 | 0.00 | 0.03 | 0.01 | 0.00 | 0.01 |
| $Cr_2O_3$ | 0.00 | 0.00 | 0.01 | 0.02 | 0.01 | 0.01 |
| Sum | 99.34 | 99.65 | 100.65 | 99.64 | 99.68 | 99.59 |
| Fa mole % | 23.6 | 22.0 | 22.2 | 23.0 | 26.0 | 23.4 |

* Grains 1–4 and 5 were analyzed by JXA–733 and EMX–SM7 electron probe microanalyzer respectively.

*Pyroxene*; Orthopyroxene is mostly 0.1–0.3 mm and rarely reaches up to 0.8 mm in size and occurs as xenomorphic crystals being commonly elongated in parallel to c-axis. Orthopyroxene grains often have thin lamellae of clinopyroxene, which is parallel to the (100) plane of the host. A few chondrules consisting of a bundle of orthopyroxene and clinopyroxene laths are seen in thin sections. The refractive indices of orthopyroxene are $\alpha=1.678$, $\gamma=1,690$, which give about 21–22 mole per cent of $Fe_2SiO_4$ component according to the determinative curve of Kuno (1954). Microprobe data shown in Table 3, on the other hand, indicate that the average molar composition of orthopyroxene is $Wo_2En_{78}Fs_{20}$ which agrees well with the data by chemical analyses. Unit cell parameters of orthopyroxene are a=18.296Å, b=8.873Å and c=5.199Å. Calcium-rich pyroxene, probably diopside, occurs in irregular or granular shape aggregating with orthopyroxene and/or plagioclase. They commonly include thin exsolution lamellae as seen in Fig. 6. Clinopyroxene is also present as a reaction rim around orthopyroxene grains. No grains of clinobronzite were found in studied sections.

*Plagioclase and Maskelynite*; Plagioclase usually occurs as irregular shapes filling the interstices among other silicates both in the matrix and in chondrules (Fig. 11). It commonly includes fine, granular grains of olivine or pyroxenes, or aggregates of minute translucent crystals like chromite, many of which are idiomorphic and often arranged in some preferred orientation. Approximately half of the plagioclase grains have been changed into clear, isotropic material, maskelynite.

*Apatite*; Apatite, or possibly whitlockite, is a very minor mineral constituent in this meteorite, and occurs as xenomorphic crystals up to 0.3 mm in size. It is not uniaxial as is the usual case but shows small negative optic axial angle. A few minute olivine grains are rarely included in apatite.

*Opaque minerals*; Metallic nickel-iron (kamacite and taenite), troilite, and chromite are the opaque phase of this meteorite. They are present usually in irregular shaped grains occupying interstices of silicate grains and also in minute individual grains in silicates (Fig. 12). Intimate intergrowth with each other phases is very common. Fine fragments of troilite in irregular shape are occasionally embraced by coarser grains of nickel-ion.

## IV. Discussion

There was a considerable difference between the data obtained by JXA-733 and EMX-SM7 electron probe microanalyzer (see Tables 4, 5). The results by the latter tend to be rich in FeO comparing with the former, and data obtained from both instruments shifted somewhat in both direction compared with the data obtained by wet-chemical analyses. The difference is due to neither the compositional dispersion among grains nor to heterogenity in the composition, because chemical composition of olivine and orthopyroxene determined by fractional dissolution method, EPMA, X-ray and optics show very good agreement with each other, while samples for chemical analyses and the studies of petrography and mineralogy were taken from completely defferent positions in the original stone. The discrepancies appear to arise from the use of different instruments with inadequate correction coefficients. Further, the possibility cannot be excluded that the standards used in each analysis were of completely different form. The cause of these discrepancies must be studied in detail for

Table 5. Chemical composition of orthopyroxene in the Duwun chondrite.

| | 1 | 2 | 3 | 0 | 5* | Aver. |
|---|---|---|---|---|---|---|
| $SiO_2$ | 55.38 | 56.15 | 55.27 | 56.10 | 54.89 | 55.56 |
| $TiO_2$ | 0.18 | 0.18 | 0.15 | 0.23 | 0.17 | 0.18 |
| $Al_2O_3$ | 0.15 | 0.17 | 0.11 | 0.26 | 0.02 | 0.14 |
| FeO | 13.93 | 13.31 | 12.43 | 13.08 | 16.08 | 13.77 |
| MnO | 0.52 | 0.45 | 0.39 | 0.48 | 0.64 | 0.50 |
| MgO | 28.83 | 29.49 | 29.45 | 29.04 | 29.18 | 29.20 |
| CaO | 0.60 | 0.87 | 0.67 | 0.75 | 0.65 | 0.71 |
| $Na_2O$ | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.01 |
| $K_2O$ | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| $Cr_2O_3$ | 0.05 | 0.08 | 0.01 | 0.15 | 0.15 | 0.09 |
| Sum | 99.64 | 100.70 | 98.63 | 100.11 | 101.36 | 100.16 |
| Fs mole % | 21.1 | 19.9 | 18.9 | 18.9 | 23.3 | 20.4 |

* Grains 1–4 and 5 were analyzed by JXA–733 and EMX–SM7 electron microprobe analyzer respectively.

Table 6. Identification of chemical group.*

| | Duwun | H | L | LL |
|---|---|---|---|---|
| $Fe_{total}/SiO_2$ | 0.590 | 0.77±0.07 | 0.55±0.05 | 0.49±0.03 |
| $Fe_{metal}/Fe_{total}$ | 0.383 | 0.63±0.07 | 0.33±0.07 | 0.08±0.07 |
| Fayalite ratio | 24.0<br>24.0**<br>23.4*** | 18±2 | 24±2 | 29±2 |
| $SiO_2/MgO$ | 1.551 | 1.55±0.05 | 1.59±0.05 | 1.58±0.05 |

* Classification: After Van Schmus and Wood (1967).
** Obtained by optics.
*** Obtained by EPMA.

each case, and this presents a subject for further work.

Petrographically this chondrite exhibits considerable evidence of a history of heavy strain. According to the dynamic experiments by Carter *et al.* (1968), well-developed mosaicism and incipient recrystallization of olivine or pyroxenes indicate heavy to very heavy shock of 0.5–1.0 Mb. Advanced maskelynitization of plagioclase crystals also indicates an intense stress experienced by this chondrite (Van Schmus and Ribbe, 1968). Such deformational features in silicates due to preterrestrial collision are comparatively more common in L-group chondrites than in chondrites of other types (Van Schmus and Ribbe, 1968).

The fused texture sporadically recognized in studied thin sections is also a point of great interest. Though such a feature is not so rare in ordinary chondrites, the cause of the local fusion is not yet apparently proved (Ramdohl, 1973). Dodd and Jarosevich recently reported "melt pocket", i.e., brown glassy part including xenocrysts of ferromagnesiam silicates and droplets or irregular masses of metal and troilite. Existence of melt pockets is closely related to the loss of $^{40}Ar$ in L-group chondrites.

Though it is not obvious whether the fused part observed in the Duwun chondrite is of the same character as melt pockets, it seems also to be due to the effect of heat developed on impact, by analogy with melt pockets. Similar fused grobules were also observed in heavily shocked L 6 chondrites, Yamato-74362 (Yabuki, 1978) and Nagai (Murayama *et al.*, 1978).

## V. Conclusion

The chondrite Duwun fell in Duwun-Myoen, Kohung-gun, Choenra-Namdo, Korea at 15: 47 hrs on November 23, 1943.

From the chemical analysis data, especially the value of total Fe (22.81%) and ratios of $Fe_{total}/SiO_2$ (0.590), $Fe_{metal}/Fe_{total}$ (0.383) and $SiO_2/MgO$ (1.55) and molar compositions of olivine ($Fa_{24}$) and pyroxene ($Fs_{20}$), it is concluded that the chondrite Duwun is typical L-group chondrite.

Petrographical and mineralogical investigations support above conclusion. The well-developed chondritic texture, homogeneous olivine and pyroxene compositions, good development of plagioclase, the presence of maskelynite, absence of igneous glass and deformed chondrules with indistinct and obliterated chondrule-matrix boundary suggest that the Duwun chondrite belongs to the petrologic subgroup 6 of Van Schmus and Wood's classification.

Mosaic texture, kink bands, undulatory extinction of olivine and pyroxene grains, maskelynitization of plagioclase, and some deformed pyroxene crystal indicate that the Duwun chondrite suffered from a heavy shock effect, as is seen in most other L-group chondrites.

Characteristic features of the Duwun chondrite are presences of droplets of metal, troilite and silicate melt. This may result from locally occurring heavy shock effects.

## VI. Acknowledgement

The Authors are indebted to Mr. S. Murayama, the National Science Museum, for providing them with the Duwun chondrite. The electron probe microanalyses were performed with the assistance of Mr. Y. Tanaka, Shimadzu Seisakusho Ltd., and of Mr. Y. Ono, JEOL Ltd. The authors express their sincere gratitude to them.

## References

BERNAS, B., 1968. A new method for decomposition and comprehensive analysis of silicates by atomic absorption spectrometry. *Anal. Chem.*, **40**: 1682–1686.

CARTER, N. R., C. R. RALEIGH and P. S. DECARLI, 1968. Deformation of olivine in stony meteorites. *J. Geophys. Res.*, **73**: 5439–5461.

DEER, W. D., R. A. HOWIE and J. ZUSSMAN, 1962. In "Rockforming Minerals" Vol. 1, Longmans, London: 20–24.

HONDA, M. and Masako SHIMA, 1967. Distribution of rare earths among component minerals of Bruderheim chondrite. *Earth Plant. Sci. Letts.*, **2**: 344–348.

KUNO, H., 1954. Study of orthopyroxene from volcanic rocks. *Amer. Mineral.*, **39**: 30–46.

MASON, B. ed. 1971. "Handbook of elemental abundances in meteorites." Gordon and Breach, New York.

MURAYAMA, S., Masako SHIMA and A. OKADA, 1978. The chemical composition, petrography and mineralogy of the Japanese chondrite Nagai. *Bull. Nat. Sci. Mus. Ser. E.*, **1**: 19–29.

OKADA, A., Masako SHIMA and S. MURAYAMA, 1979. Mineralogy, petrography and chemistry of the chondrite, Kamiomi, Sashima-gun, Ibaraki-ken, Japan. *Meteoritics*, **14**: 177–191.

RAMDOHL, P., 1973. In "The opaque minerals in stony meteorites." Akadimie-Verlag, Berlin, pp. 57–64.

SHIMA, Masako, 1974. The chemical compositions of the stone meteorites Yamato (a), (b), (c) and (d), and Numakai. *Meteoritics*, **9**: 123–135.

SHIMA, Masako, 1980. Analysis of the Elemental Composition of chondrites. *Bull. Nat. Sci. Mus. Ser. E.*, **3**: 13–20.

SHIMA, Masako and M. HONDA, 1967. Distribution of alkali, alkaline earth and rare earth elements in component minerals of chondrites. *Geochim. Cosmochim. Acta*, **31**: 1995–2006.

SHIMA, Masako, S. MURAYAMA and A. OKADA, 1979a. Chemical composition, petrography and mineralogy of the Shibayama chondrite found in Shibayama-machi, Sanbu-gun, Chiba-ken, Japan. *Meteoritics*, **14**: 317–330.

SHIMA, Masako, A. OKADA and S. MURAYAMA, 1979b. The chemical composition, petrography and mineralogy of the Japanese chondrite Fukutomi. *Bull. Nat. Sci. Mus. Ser. E.*, **2**: 17–28.

VAN SCHMUS, W. R., 1969. Mineralogy and petrology of chondritic meteorites. *Earth Sci. Rev.*, **5**: 145–185.

VAN SCHMUS, W. R. and P. H. RIBBE, 1968. The composition and structural state of feldspar from chondritic meteorites. *Geochim. Cosmochim. Acta*, **32**: 1327–1342.

VAN SCHMUS, W. R. and J. A. WOOD, 1967. A chemical-petrologic classification for the chondritic meteorites. *Geochim. Cosmochim. Acta*, **31**: 747–765.

YABUKI, H., 1978. Petrological studies on Yamato-74 meteorites. *Sci. Papers Inst. Phys. Chem. Res.*, **72**: 14–40.

YODER, H. S. and T. G. SAHAMA, 1957. Olivine X-ray determinative curve. *Am. Mineral.*, **42**: 475–491.