Classification of stony meteorites from north-west Africa and the Dhofar desert region in Oman

Erika Ohlsson

Examensarbeten i Geologi vid
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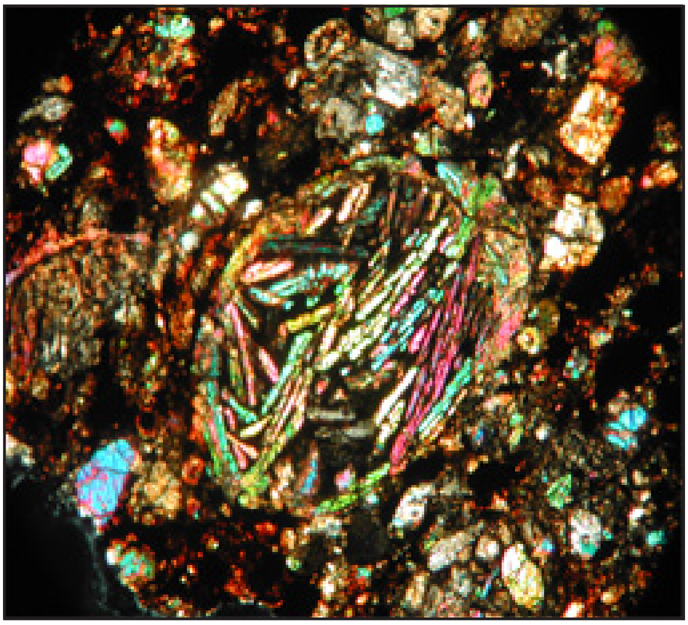

Geologiska institutionen
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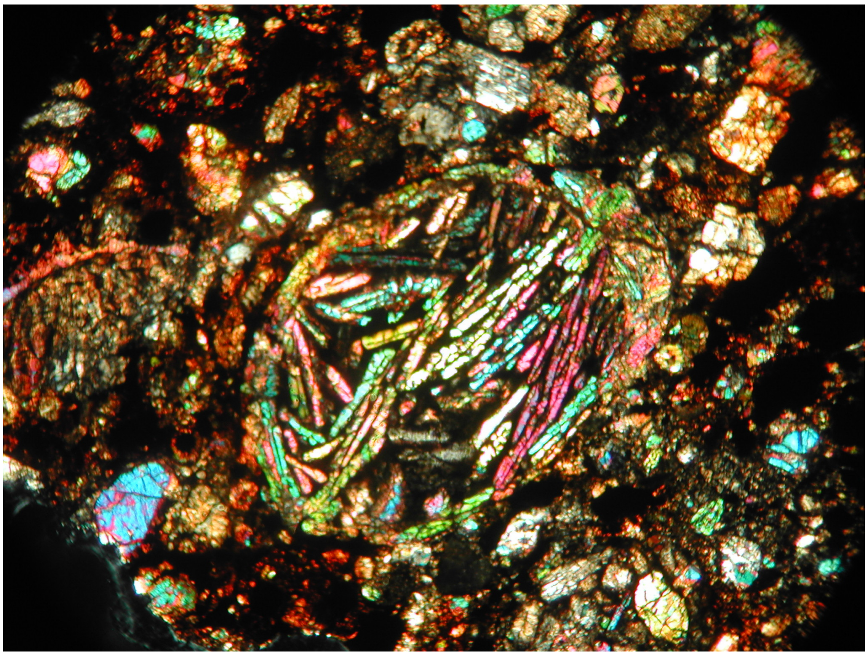

Department of Geology
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Master thesis

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Cover page photograph: The photograph shows a barred olivine chondrule about 1.5 mm in its longest dimension in the NWA-869X chondrite. The photograph is taken in crossed polarized light.

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Ohlsson, E., 2007: Classification of stony meteorites from north-west Africa and the Dhofar desert region in Oman. *Examensarbeten i geologi vid Lunds Universitet - Berggrundsgeologi*, Nr 218, 62pp

Abstract: Meteorites are divided into three basic groups, iron, stony-iron and stony meteorites. The stony meteorites are further divided into primitive achondrites and chondrites. The chondrite class is divided into different groups, enstatite chondrites, ordinary chondrites, carbonaceous chondrites and rumuruti chondrites. The enstatite chondrites are divided into EH and EL, which stands for enstatite high FeO and enstatite low FeO. This is the basis also for the ordinary chondrites where the H is high FeO, L low FeO and LL low FeO and low total iron. The carbonaceous chondrites are also further divided but their names are based on the type specimen for each group. Chondrites have an easily recognizable texture with the main feature being chondrules, spherical bodies of silicate minerals, in a matrix. The major minerals are olivine and pyroxene with metal and sulphides as complementary minerals. When a chondrite have been assigned to a specific group they are further divided into petrographic types based on among other things the homogeneity of the olivine grains. The chondrites can also be assigned to a specific shock stage and/or weathering grade. Chondrules can also be divided based on the main mineral in them and if they are high or low FeO chondrules, but the basic property on which to divide them is their texture.

The meteorites analyzed in this study are from two different areas, NWA-869X and NWA-UKW are from Morocco in north-western Africa, while 05-1A Dhofar, 06-1 Dhofar, 06-18 Dhofar and 06-26 Dhofar all are from the Dhofar desert region in Oman on the Arabic peninsula. NWA-869X has been classified before and is in this study used as a reference. It is compared with NWA-UKW from the same area, while the Dhofar meteorites are primarily compared to each other. An optical microscope and a scanning electron microscope have been used in determining the meteorites class, group, type, stage and grade. The meteorites have all been determined to be chondrites based on their major minerals and texture. NWA-869X is an L4-5 chondrite with a weathering grade of W1, NWA-UKW is an E 3-4 chondrite with a weathering grade of W4, 05-1A Dhofar is a H4, W3 chondrite, 06-1 Dhofar an H4, W4 chondrite, 06-18 Dhofar is an H4, W2-3 chondrite and 06-26 Dhofar an H4, W3 chondrite. No chondrite has been assigned a shock stage since the defining properties of shock were not observed. Based on the weathering grade the Dhofar meteorites and NWA-UKW have been on Earth around 30 000 years and NWA-869X around 10 000 years. If possible a bulk chemistry analysis would be of interest since this would give a higher degree of certainty to the results obtained in this study.

Keywords: chondrites, Dhofar NWA, chondrules, petrographic type, shock stage, weathering grade

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Klassifikation av stenmeteoriter från nordvästra Afrika och ökenregionen Dhofar i Oman

ERIKA OHLSSON

Ohlsson, E., 2007: Classification of stony meteorites from north-west Africa and the Dhofar desert region in Oman. *Examensarbeten i geologi vid Lunds Universitet - Berggrundsgeologi*, Nr 218, 62 pp

Sammanfattning: Meteoriter är indelade i tre huvudsakliga klasser, järn, sten-järn och stenmeteoriter. Stenmeteoriterna är vidare indelade i primitiva akondriter och kondriter. Kondriterna är vidare indelade i fyra grupper, enstatitkondriter, vanliga kondriter, kolrika kondriter och rumurutikondriter. Dessa grupper är i sin tur indelade i undergrupper, enstatitkondriterna är indelade i EH (hög FeO-halt) och EL (låg FeO-halt), vilket även de vanliga kondriterna är, H (hög FeO-halt), L (låg FeO-halt) och LL (låg FeO och låg total Fe halt). De kolrika kondriterna är även de indelade i undergrupper men deras namn är baserade på typexemplaret för just den gruppen. Kondriterna har en textur som lätt känns igen pga. förekomsten av kondruler (sfäriska kulor). Huvudmineralen är olivin och pyroxen med metall och sulfider som accessoriska mineral. När en kondrit blivit tilldelad en grupp indelas de vidare i petrografisk typ, som är baserat på bland annat homogeniteten av dess olivin. Kondriterna kan även delas upp i olika chockstadier och/eller vittringsgrader. Kondrulerna kan även de delas upp i olika grupper baserat på deras huvudmineral och om de har låg eller hög halt av FeO, men den huvudsakliga indelningen är baserad på deras textur.

Meteoriterna klassificerade i denna studie kommer från två områden, NWA-869X och NWA-UKW är från Marocko i nordvästra Afrika, medan 05-1A Dhofar, 06-1 Dhofar, 06-18 Dhofar och 06-26 Dhofar alla är från ökenregionen Dhofar i Oman på den Arabiska halvön. NWA-869X har klassificerats tidigare och är i denna studie med som referens. Den jämförs med NWA-UKW från samma område medan Dhofar meteoriterna framförallt jämförs med varandra. Ett optiskt mikroskop och ett svepelektronmikroskop har använts vid bestämning av klass, grupp, typ, nivå och grad. Meteoriterna har alla bestämts vara kondriter baserat på huvudmineralen och deras textur. NWA-869X är en L4-5 kondrit med en vittringsgrad på W1, NWA-UKW är en E 3-4, W4 kondrit, 05-1A Dhofar en H4, W3 kondrit, 06-1 Dhofar en H4, W4 kondrit, 06-18 Dhofar en H4, W2-3 kondrit och 06-26 Dhofar en H4, W3 kondrit. Inget chockstadium har tilldelats någon av kondriterna eftersom de utmärkande egenskaperna för chock ej observerats. Baserat på vittringsgraden för de olika kondriterna har Dhofar och NWA-UKW kondriterna varit i öknarna ungefär 30 000 år medan NWA-869X har varit i öknen ungefär 10 000 år. Om möjligt borde en bulk analys utföras då detta ökar säkerheten i klassificeringen gjord i denna studie.

Nyckelord: kondriter, Dhofar NWA, kondruler, petrografisk typ, chocknivå, vittringsgrad

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1 Introduction

Throughout history meteorites have been both feared and worshipped and even been depicted on the walls of tombs in ancient Egypt. They have been adored as Gods or thought to have been signs from the Gods. Besides this there is no better guide to the history of our Solar System than the meteorites. In extremely small grains hidden inside meteorites is part of our history, these tiny grains are the oldest parts of our Solar System, which has an age of ~4.6 Ga, and they may arguably even hold the key to the origin of life. So by analysing and studying meteorites the information we obtain may tell us how planets formed and how the universe looked long before the human race saw the light, and for hundreds of years scientists have done just this and as some questions have been answered others have been raised (Sears 1978 Norton 2002).

Meteorites, which are meteors that have reached Earth, are divided into three basic groups, iron, stony-iron and stony meteorites. These are then further subdivided into different classes. Stony meteorites are divided into primitive achondrites and chondrites, based on their mineralogy and texture and then divided into different sub-classes. After having been divided into classes they are assigned a petrographic type based on textural properties, and then allocated a shock stage and a weathering grade, which further divides the meteorites (Norton 2002).

The aim of this study is to classify stony meteorites from the Dhofar desert region in Oman, on the Arabic peninsula and a stony meteorite previously not described, NWA-UKW (north-west Africa Unknown), from Morocco (figure 1 and 2). This meteorite is compared to NWA-869X (north-west Africa, the X means that it is not the sample classified) from the same region, which has been classified earlier. The meteorites have been assigned a class, petrographic type, weathering grade and shock stage. Some may not have been fully classified when it comes to shock stage. There are also comments about the physical appearance of the meteorites as well as a mineralogical description.

Fig. 1. The map shows north-west Africa encircled with Morocco in green, from where the NWA meteorites in this study are thought to be. http://www.businessfacilities.com

Optical microscopy was utilised with both reflected and transmitted light to assign each meteorite a class, primitive achondrite or chondrites, and a subclass as well as petrographic type and to identify minerals in the thin sections. A SEM, (scanning electron microscope), equipped with an EDS detector (energy dispersion spectroscopy) was used to obtain the composition of the minerals and the images was obtained by BSE (back scatter electrons).

In this work a short introduction to the type of meteorites found in the Dhofar desert region of Oman is presented as well as those from north-west Africa. It is a brief introduction and for further information the reader is referred to the original articles cited in the reference section. The meteorite samples were provided by Erik Jonsson (SGU) and Karin Högdahl.

Fig.2. The map shows Oman on the Arabic peninsula. The Dhofar region is encircled on the map in southern Oman. http://sv.wikipedia.org/wiki/Oman

2 Meteorites

Meteorites are extraterrestrial rocks that when on collision course with Earth actually survive the journey through Earth's atmosphere. The shape of a meteorite can give the history of descent to Earth, how it travelled through the atmosphere. The shape indicates if the meteorite was rotating or not, if it broke apart high in the atmosphere or just before reaching the Earth's surface. An example of this is the stony meteorites which if they break apart get sharp angles (figure 3), but if they break apart high enough in the atmosphere they become rounded because of ablation, which is when the friction of the atmosphere heats up the surface of the meteorite and transportation of melted material takes place. These meteorites usually have a slightly undulating surface, suggesting uneven ablation; they also show flattened depressions with raised edges resembling fingerprints in clay, called regmaglypts. There are basically three different shapes a meteorite can adopt depending on the way it enters the atmosphere. A meteorite will attain a spherical shape if it experiences a random tumbling during its decent. It will become cone shaped if it rotates around the axis along the direction of motion, and finally it will take on the shape of a shield if no rotation at all takes place (Norton 2002).

Fig. 3. 06-18 Dhofar meteorite, the weathered surface and oxidized patches are easily observed in this specimen. The light bottom half has been buried in the sand while the reddish upper half has been subjected to weather and wind. Large scale in cm. Photo: Erik Jonsson.

2.1 A brief history of meteorite research

The modern studies of the meteorites began in the 18th century when Abbé Bachelay was presented with a rock claimed to have fallen from the sky in the town of Lucé in France. The Abbés description of the rock and notes of witness accounts were sent to the French Academy of Science. Lavoisier, Cadet and Fougeroux performed the first chemical analysis of a meteorite on the Academy. Their report stated that the rock was terrestrial based upon the pyrite found in it. The blackened surface of the rock was ascribed to the rock being struck by lightning. In the mid 18th century an iron rock was found in Russia; the german natural scientist Peter Pallas sent a description of this rock and a sample of it to the Academy of Science in St Petersburg (Sears 1978), Pallas was later honoured with the pallasites, a stony-iron meteorite, being named after him (Hutchison 2004).

As the scientific interest and knowledge increased it was inevitable that more advanced chemical analyses were made. Edward Howard and the French mineralogist Bournon found that it was necessary to examine the different phases within the meteorites separately. Their results showed that the rocks they examined differed from terrestrial rocks in many aspects; the meteorites contained millimetre-sized fragments of metal, curious globules of stony material and a thin black skin. In the metal, Howard identified nickel, which is rather rare on Earth. They could now link several meteorites to each other, not only in nickel content but also in the proportions of globules and the black crust (Sears 1978).

The scientists LaPlace, Biot and Poisson made the suggestion that the rocks came from the Moon, which was based on the chemical analyses of the meteorites. This hypothesis together with the idea that the rocks were accreted in the Earths atmosphere from residues of volcanic eruptions became the two most popular ideas about the origin of these rocks until around the middle of the 19th century. Proof for the extraterrestrial origin was given in the first half of the 19th century by the observation that the Leonid meteor shower did not move with the Earth as it rotated around its axis. Meteors and meteorites were at this time thought to be features of the same phenomenon (Sears 1978).

In the early 19th century the Swedish chemist and mineralogist J.J. Berzelius analysed numerous meteorites and found that the majority of the meteorites were remarkably similar chemically, but that three meteorites stood out. These were studied in more detail by Gustav Rose, a student of Berzelius, who found that they resembled terrestrial volcanic rocks. The curious globules discovered by Bournon were named chondrules by Rose in the beginning of the later half of the 19th century. About a year after this, H.C. Sorby (geologist and petrographer) recognized the textures as similar to those from a quenched system. He also gave birth to the idea of the chondrules having been melted or at least partially molten. He based this on the shape of the chondrules; although he also stated that they came from the sun. In the later half of the 19th century the idea that meteorites originated among the asteroids became the consensus (Sears 1978).

Shepard was the first to divide meteorites into classes; at the first level there were two classes, metallic and stony, these were in turn divided into three orders each and finally into a number of sections, totalling 16 groups classified by texture in analogy with terrestrial volcanic rocks. Of course this was not the only scheme made for classification of meteorites. Rose's scheme was based on mineralogy and composition and it became the most popular. Tschermak and Brezina enlarged and modified this scheme which became the basis of the modern classification scheme and reached its final form in the beginning of the 20th century (Sears 1978, Hutchison 2004). By the mid 20th century the Rose-Tschermak-Brezina scheme was no longer used as more accurate chemical and mineralogical analyses were available. An attempt to further classify stony meteorites, chiefly chondrites, by the degree of re-crystallization was made. The most important scheme at this time was the combined (chemical-petrologic) scheme of Van Schmus and Wood (Hutchison 2004).

2.2 Asteroid parent bodies for stony meteorites; past and present

The planets in our Solar System are distanced with a remarkable symmetry from the Sun. Mercury 0.321 AU (astronomical units); Venus 0.732 AU; Earth 1.000 AU; Mars 1.500 AU, and Jupiter 5.2 AU from the sun. The location of Jupiter is twice the distance it should be if geometry were to be maintained, in other words there is a gap (Norton 2002). Johannes Kepler first noticed this gap at 2.8 AU from the Sun and insisted that an "unseen" planet had to exist at this position (figure 4).

In the early fall of the year 1800, a society with the purpose to look at the sky in an attempt to find this "unseen" planet was formed. Astronomers scattered throughout Europe was involved in this project. At the end of the year Giuseppe Piazzi in the southernmost observatory of Europe on Sicily made the discovery of a star of the 8^{th} magnitude not previously marked on any chart. He noted the position but found the following night that it had moved, he continued to follow this celestial body which he called a comet although no tail had been observed and the path of the object was almost circular, he named it Ceres. This was the first asteroid to be discovered (Norton 2002).

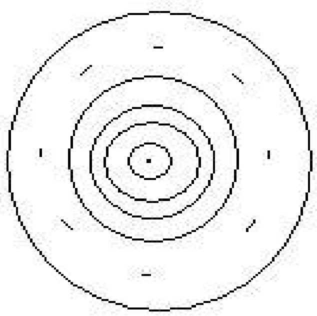


Fig. 4. The figure shows schematically the orbit of the planets (whole circles, sun represented with a dot) and where the "unseen" planet should have been with a broken circle.

The second and third asteroids were found in the next three years and toward the end of the 19^{th} century over 300 asteroids had been discovered (Norton 2002). In the beginning of the 21^{st} century more than 40,000 asteroids had been numbered (Karttunen et al. 2003), and thousands more are catalogued every year since.

Most asteroids with relatively stable orbits are found within a belt, extending from about 2 AU to 4 AU and are called main belt asteroids. In the belt there are gaps since the asteroids are not uniformly scattered throughout the belt. The theory currently accepted assumes that asteroids were formed at the same time as the planets. The asteroids today have formed through collisions and fragmentation of the primeval asteroids and are fragment of these; the primordial asteroids were never able to form a planet (Norton 2002).

The vast majority of meteorites are fragments splintered off asteroid parent bodies. There are a few rare meteorites coming from comets, Mars and the Moon. Ongoing research is to link a specific meteorite to a particular parent body. All known asteroids show signs of impact which might account for different shock stages of the meteorites, if indeed the asteroids are the parent bodies of meteorites. By using reflectance spectrophotometry the minerals comprising the asteroid can be obtained, this has led to a classification of asteroids and an attempt to link the asteroids to meteorites found on Earth (Norton 2002).

There is a connection between an asteroid's composition and its position in the asteroid belt and the distribution of the asteroids holds important information about the conditions of the early solar nebula. The inner belt contains asteroids made up of refractory minerals with a few volatiles as might be expected being closer to the Sun. The middle and outer belts contain asteroids with more volatiles, water-bearing minerals and organic compounds. These asteroids are the most common type and have been connected to the carbonaceous chondrites. The inner belt asteroids are believed to be the parent bodies of ordinary chondrites because these asteroids are the only main-belt objects whose gross mineralogy matches that of ordinary chondrites with olivine, pyroxene and metal (Norton 2002). Another suggestion as the parent bodies for the ordinary chondrites are another type of asteroids but these are themselves fragments of the inner belt asteroids and is therefore not a satisfactory solution (McSween Jr et al. 1990).

There are also Earth-crossing asteroids, which are not connected to the main belt asteroids, when one collides with Earth it will cause a global catastrophe, but this may happen once in one million years. Collision with smaller bodies, causing damage similar to a nuclear bomb may happen once per century (Karttunen et al. 2003). On the other hand it has been estimated that at least 10^5 kg of meteoritic material falls on Earth each day, most of the debris cause no visible light show. The largest meteorites reach Earth at their cosmic speeds, resulting in impact craters. Smaller bodies slow down and drop like stones (Norton 2002).

2.3 Classification of meteorites

There are several types of meteorites, and although there are some similarities there are also fundamental differences. The main types of meteorites used to be the iron meteorites, the stony-iron meteorites and the stony meteorites (Sears 1978). The iron meteorites consist almost wholly of metal, the stony-iron meteorites consist of roughly equal amounts of metal and silicates and the stony meteorites are dominated by silicate minerals (Hutchison 2004). In recent years this classification has been revised and the classification now starts with the primitive or undifferentiated and differentiated classes.

Primitive meteorites have not been subjected to temperatures high enough to cause melting since their parent bodies formed. Differentiated meteorites on the other hand show evidence of partial or complete melting of their parent bodies (Norton 2002). This new classification takes into account the origin and evolution of the rocks. All the stony meteorites and hence the chondritic meteorites, belong to the primitive or undifferentiated meteorites while stony-iron and iron meteorites belong to the differentiated meteorites. The achondrites on the other hand are divided with the primitive achondrites being recognized as undifferentiated meteorites while the other achondrites, including the Lunar and Martian meteorites belong to the differentiated meteorites (figure 5) (Norton 2002 and Hutchison 2004).

Actually, the classification begins before even looking at the meteorite itself. If the meteorite is seen falling to the Earth and is retrieved shortly thereafter, it is classified as a fall, but if it is found without it being seen to fall it is classified as a find. This difference is important because the time spent on Earth can lead to contamination of the meteorite's chemical composition and degree of oxidation of the metal grains (Norton 2002). In this study the achondrites are seen as a group on its own, and thus not belonging to either of the basic three groups, iron, stony-iron or stony meteorites (Hutchison 2004).

In the different meteorites over 275 mineral species have been identified, reflecting diverse redox environments (Rubin 1997). Minerals occuring in meteorites include phosphides and phosphates, sulphides and sulphates, carbides and carbonates and silicides and silicates. Meteorites also contain minerals formed by shock metamorphism and terrestrial weathering of the primary minerals. In some cases the presence or absence of a mineral can help classify a meteorite, so it is not only the chemistry of a meteorite that is important but also its mineralogy.

2.3.1 Iron meteorites

Iron meteorites are divided into groups by a chemical classification based on the contents of Ni, Ga, Ge and Ir. The structure of iron meteorites are subdivided into eight categories, hexahedrites, octahedrites with six subdivisions, and ataxites. Based on the Ga content the iron meteorites are divided into four basic groups then further subdivided into genetically distinct groups, A through F. Today there are twelve groups. Iron meteorites have a density of 7.5 to 7.9 g/cm^3, and it sets them apart from other meteorites even in the field (Hutchison 2004).

2.3.2 Stony-iron meteorites

Stony iron meteorites consist of roughly equal amounts of silicate and Fe-Ni metal; they are divided into pallasites and mesosiderites. The pallasites are composed of metal and olivine ($(Mg,Fe)_2SiO_4$) and the metal forms a generally unbroken mesh in which silicates are set. In the mesosiderites, which is composed of metal, olivine and various silicates, the metal is unevenly distributed as cm-sized pods, veins and smaller grains interspersed with lithic and mineral silicate clasts (Hutchison 2004).

The pallasites are divided into three subgroups, main group pallasites (MGP), pyroxene pallasites and the Eagle Station trio. Main group pallasites have olivine (Fo_{82-89}) and metal with about 10 wt% Ni. The presence of Ca-poor pyroxenes ($(Fe,Mg)SiO_3$) is diagnostic of the pyroxene pallasites. Pyroxene occurs also in other pallasites as rare µm-sized grains intergrown with olivine and/or troilite (FeS). Pyroxene pallasites contain olivine with compositions Fo_{87-90}. The Eagle Station trio exhibit less magnesian olivine, (Fo_{80}) and higher Ni content, about 15 wt% in the metal (Hutchison 2004).

Mesosiderites are brecciated mixtures of metal and silicates and clasts of olivine are present as a

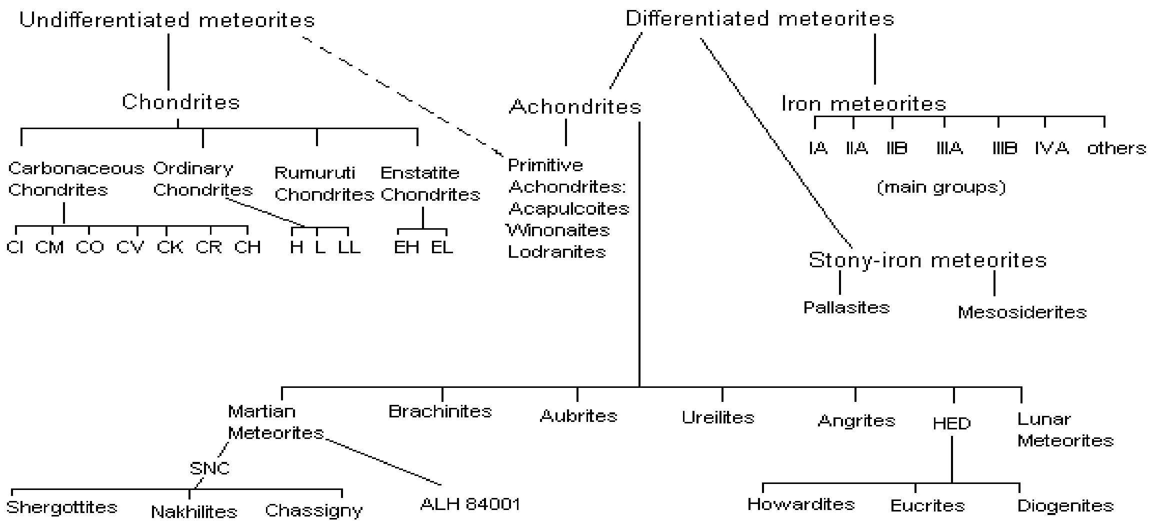


Fig. 5. The relationship between different meteorite classes and groups is easily seen in this figure from Hutchison 2004.

minor constituent. Metal occurs as mineral clasts, as a constituent of some lithic clasts and as veins in silicate clasts and matrices. The most common lithic clasts are orthopyroxenites and the most common mineral clasts are orthopyroxene; while pigeonite ($(Mg,Fe^{2+},Ca)(Mg,Fe^{2+})Si_2O_6$) clasts are less common. The silicate matrices are dominated by Ca-poor pyroxene. The minor minerals troilite, tridymite (monoclinic or triclinic SiO_2), chromite ($FeCr_2O_4$), "merrilite" ($Ca_9NaMg(PO_4)_7$) (merrilite is not approved as a mineral of its own and therefore merrilite = whitlockite ($Ca_9Mg(PO_3OH)(PO_4)_6$)), augite ($(Ca,Na)(Mg,Fe,Al)_2O_6$) and schreibersite ($(Fe,Ni)_3P$) are present in approximately decreasing order of abundance. Olivine is generally absent in matrix, even in meteorites in which it occurs as clasts. Ilmenite ($FeTiO_3$) and rutile (TiO_2) occur as trace minerals (Hutchison 2004).

2.3.3 Achondrites

Achondrites are subdivided into primitive achondrites, sometimes under stony meteorites, and differentiated achondrites. Primitive achondrites underwent minimal melting and re-crystallization and are essentially slightly modified chondritic rocks. Three groups are recognized; the acapulcoite-lodranite group; the winonaites and chondritic silicate inclusions in group IAB irons; and the olivine-rich brachinite group (Hutchison 2004).

The acapulcoites have higher abundances of Ca-poor pyroxene than of olivine. The lodranites on the other hand have variable amounts of plagioclase, metal and sulphide. In both subgroups green chromian-diopside ($CaMgSi_2O_6$) may occur. The winonaites have essentially ordinary chondritic mineralogy with additional minor schreibersite, daubréelite ($FeCr_2S_4$) and alabandite (MnS). The brachinite on the other hand has unzoned olivine, with a $Fo_{65\text{-}70}$ composition, and chromian-diopside or chromian-augite (Hutchison 2004).

The properties of the differentiated achondrites differ markedly from the chondritic and are the products of widespread melting accompanied by crystal-liquid fractionation. They are truly magmatic rocks and include solidified melts, cumulates from melts and mechanical mixtures of such components, induced by impact. The differentiated achondrites are divided into four groups; HED (howardites, eucrites and diogenites), angrites and Lunar and Martian meteorites. Howardites, eucrites and diogenites (HEDs) constitute the largest group. Howardites are polymict regolith breccias largely composed of eucrite and diogenite debris. The dominating minerals are diogenitic orthopyroxene and Ca-pyroxene and plagioclase. Other minerals occurring in lesser amounts are Fe-Ni metal, chromite, troilite, silica mineral(s) and olivine (Hutchison 2004).

Eucrites are pyroxene-plagioclase achondrites consisting of predominantly pyroxene and anorthite ($CaAl_2Si_2O_8$) with minor amounts of silica, chromite, ilmenite, Ni-poor kamacite (α-(Fe,Ni)) and troilite. Most of the eucrites are monomict breccias, others are polymict, and a few are unbrecciated (Hutchison 2004).

Diogenites are Ca-poor pyroxenites with the bulk diogenites containing >90 vol% pyroxene with accessory olivine, chromite, Ca-rich pyroxene, plagioclase, troilite, Ni-poor Fe metal and a silica phase (Hutchison 2004). .

Angrites are Ca-rich basaltic meteorites highly undersaturated in silica with a distinct mineralogy which include abundant diopside-hedenbergite pyroxene with high Ti and Al content ("fassaite"). They also have a significant Ca component in their olivine and, when present, nearly pure end-member anorthite. The ferromagnesian minerals tend to be Fe-rich. Accessory titanomagnetite, Fe,Al,Cr-spinel, "merrilite", troilite and Fe-Ni metal may also occur (Hutchison 2004).

Lunar meteorites consist of highland breccias, breccias of mixed highland/mare derivation to unbrecciated mare basalts. Highland breccias are dominantly anorthosite-norite-troctolite (ANT) debris. The unbrecciated meteorites are low Ti-basalts. Most of the lithic clasts in low Ti-basalts are of mare origin. In the highland breccias the dominant mineral is plagioclase, it occurs as clasts and as mineral grains in matrix. Its composition is generally close to pure anorthite, $An_{95\text{-}98}$, but some is more sodic ($\sim An_{83}$). Pyroxene set in matrix range widely in its composition. Phosphates, phosphides, troilite, spinel ($MgAl_2O_4$) and Fe-Ni metal occur as accessory minerals. In the mare meteorites pyroxene is more abundant than plagioclase and the crystals are zoned. Trace amounts of fayalitic olivine are present and opaque phases include ilmenite, spinel and troilite (Hutchison 2004).

Martian meteorites include basalt, dunite, lherzolite, olivine clinopyroxenite and orthopyroxenite. All are richer in volatiles and have more sodic plagioclase than the HEDs (howardites, eucrites and diogenites), angrite and lunar meteorites. Some contain hydrous minerals and several contain salts. Martian basalts have been moderately shocked but not brecciated. The Martian basalt meteorites are dominated by pyroxene, the most abundant accessory phases are Fe-Ti oxides, including titanomagnetite, ilmenite and ulvöspinel (Fe_2TiO_4). Magnetite (Fe_3O_4), chromite and hercynite ($FeAl_2O_4$) occur as minor constituents. Two phosphates are present in the Martian basalts; "merrilite" and chlorapatite ($Ca_5(PO_4)_3Cl$) (Hutchison 2004).

The Martian meteorites called shergottites has olivine ($Fo_{75\text{-}64}$) as the dominating mineral. Ca-poor pyroxene and augite are also present, as well as ilmenite, chromite and pyrrhotite ($Fe_{1-x}S$) as trace minerals (Hutchison 2004).

Nakhlites, another Martian meteorite type, is an olivine clinopyroxenite consisting of augite and olivine set within a finer grained mesostasis (last formed interstitial material between larger mineral grains). The nakhlites are almost unshocked and their large pyroxene crystals have homogeneous cores, with a sharp transition to Fe-enriched rims. The olivine has Fo_{35-32} cores, but zoning or a second generation of olivine extends the range to Fo_{23}. Fibrous crystals of plagioclase, K-feldspar, chlorapatite, Ti-rich magnetite, ilmenite, troilite and pyrite occur in minor amounts. Salts include halite, carbonates, sulphates and chlorapatite, that have been interpreted as evaporates (Hutchison 2004).

Martian dunite, chassigny, consists of olivine enclosed poikilitically by Ca-pyroxene. Trace phases are feldspar, chromite and melt inclusions in olivine. Interstitial trace minerals are chlorapatite, troilite, marcasite (FeS_2), ilmenite, rutile and baddeleyite (ZrO_2) (Hutchison 2004).

2.3.4 Stony meteorites

Stony meteorites are divided into chondrites and to some extent primitive achondrites. Achondrites have been reported on above and will therefore not be included here.

Chondrites are divided into four classes, enstatite chondrites (E chondrites), ordinary chondrites (OC), rumuruti chondrites (R chondrites) and carbonaceous chondrites (C chondrites), these classes are further divided into different groups. The four classes are composed mainly of silicates, primarily olivine and pyroxene; they also contain variable amounts of metal and sulphide minerals. The most important textural property is the presence of chondrules, small rounded globules composed of silicate minerals in different shapes and sizes (Norton 2002).

3 Chondrites

The chondrites are thought to be the most primitive rocks of the Solar System, which is based on the fact that their chemical composition is similar to that of the Sun (Zanda et al. 2006). CAIs (calcium-aluminum-rich inclusions) that occur in chondrites are thought to be the oldest objects known so far, they are interpreted as both refractory condensates and evaporation residues. Chondrite groups are also known to have specific oxygen, copper, zinc and chromium isotopic signatures. There are four elements, Fe, Mg, Si and O, that comprises nearly 90 % of most chondrites (Larimer 1968), and the dominant mineral assemblages are in addition to olivine and pyroxene also Fe-Ni metals.

Chondrites, irrespective of class, have a basic structure although there are differences separating the classes. All, except CI (Carbonaceous Ivuna), have relatively large spherical chondrules which have intricate internal structure. The chondrites also have opaque minerals, metal or sulphide, usually outside the chondrules. These opaque minerals and the chondrules are set in a fine-grained matrix (Sears 1978).

Most of the volatiles such as In, Tl, Bi, and Pb seem to be located in the matrix, and as the matrix decreases so does these elements (Sears 2004).

Olivine is the dominant mineral in most chondrites and it shows a wide range of composition which is related to the FeO/MgO ratio in the individual meteorite. Because of this it provides an excellent criterion for the classification of chondrites (Mason 1963). Reverse zoning, where the MgO amount increases towards the edges instead of decreasing, in olivine and orthopyroxene is an indication of *in situ* reduction (Kallemeyn & Wasson 1985). In addition equilibrated chondrites are characterized by olivine grains with a narrow range in composition (Kallemeyn et al. 1989).

3.1 Chondrite classes

Chondrites are divided into classes based on physical and compositional properties; E chondrites (enstatite chondrites), OC (ordinary chondrites), C chondrites (carbonaceous chondrites) and the newest group R chondrites (rumuruti chondrites). The first three classes are further divided into EH, EL for the E-chondrites, H, L, LL for the ordinary chondrites and CK, CV, CO, CH, CR, CM and CI for the C-chondrites, these being regarded as the most primitive chondrites and the ones resembling the Sun the most (Sears 2004). It is also important to note that ordinary chondrites are only termed ordinary because they are abundant on Earth, but this is probably not the case in space (Sears 2004).

When the chondrites have been sorted into a class they are further divided into different petrographic types which is based on physical and chemical properties as well (section 3.2).

3.1.1 Enstatite chondrites

The dominant silicate in this group is the pyroxene enstatite ($MgSiO_3$), which is iron-free (Sears 1978) the iron is instead present in its metallic form or in sulphides (Norton 2002). The metal in these chondrites is entirely kamacite, with the remainder of the Fe situated in sulphides, primarily troilite. Enstatite chondrites contain excess of silica in the form of tridymite and/or quartz together with which olivine cannot coexist in equilibrium (Mason 1963); it is the only meteorite in which quartz can exist at all (Norton 2002). Olivine can occur as forsterite (Mg_2SiO_4) only if there is a deficiency of silica.

Some elements exists in different phases than they do in other meteorites, for instance Cr, Mn, and Ca which in E chondrites forms sulphides (daubreelite; alabandite; CaS, oldhamite) and two minerals that are unique for E chondrites, sinoite (Si_2N_2O) and osbornite (TiO) (Sears 1978). The chondrules in these chondrites are generally quite small, around 0.2 mm on average, and they are usually poor in olivine and the dominating mineral in the chondrules are orthopyroxene (Norton 2002). The EH chondrites are minichondrule-bearing while the

Table 1. The table shows the properties of the different chondrite groups which are used when determining what group a chondrite belongs to (Sears 2004).

	EH	EL	H	L	LL	R	CK	CV	CO	CH	CR	CM	CI
Physical Properties													
Chondrule diameter	0.2-0.6	0.8	0.3	0.7	0.9	0.4	0.7	1	0.2-0.3	<0.1	0.8	0.3	
Metal grain size			0.2	0.18	0.14					6			
Chondrule abundance	20-40	20-40	65-75	65-75	65-75	≥40	15	35-45	35-40	~70	52	~15	0
Metal abundance	22	18	16	6	2	0.1	<0.01	0-7	0-5	20	6.3	0	0
Matrix abundance	<5	<5	5-10	5-10	5-10	35	75	40-50	30-40	5	44	~60	100
Compositional Properties													
Carbon	0.42	0.32	0.11	0.12	0.22		0.1	0.43	0.38		1.97	1.82	2.8
Water	1.9	1.6	0.22	0.46	0.71		1.6	0.25	3.3		7.11	10.4	16.9
Fe_m/Fe_t	0.76	0.83	0.58	0.29	0.11	~0	~0	0-0.3	0-0.2	0.95	0.22	0	0
Fe/Si	0.95	0.62	0.81	0.57	0.52		0.83	0.76	0.77	2.2	0.81	0.8	0.86
Mg/Si	0.77	0.83	0.96	0.93	0.94		1.13	1.07	1.05	1.02	1.06	1.05	1.05
Ca/Si	0.035	0.038	0.05	0.046	0.049		0.068	0.084	0.067	0.017	0.06	0.068	0.064
δ17 O	3	2.7	2.9	3.5	3.9	5.27	-5	~-4.0	~-5.1	~-1.3	~-0.7	~4.0	~8.8
δ18 O	5.6	5.3	4.1	4.6	4.9	4.74	-1	~0	~-1.1	~0	~2	~12.2	~16.4

Units: chondrule diameter and metal grain size, mm; chondrule and matrix abundance, vol%; metal, carbon, water abundance wt%; Fe_m/

EL chondrites have moderately sized chondrules (Rubin 1997).

The E chondrites are subdivided into two groups EH and EL. EH is a high-Fe, high siderophiles group while the EL is the low-Fe and low siderophiles group (Sears et al. 1982). The enstatite chondrites are unique in their bulk chemistry, they are among the most reduced class of meteorites; their silicates are almost Fe-free and they contain Si in the metal (Hutchison 2004). These chondrites also have the lowest Mg/Si and refractory/Si ratios of the chondrites (Sears et al. 1982). The volatile siderophiles Ga and Ge are two times higher in the high-Fe than in the low-Fe groups. Scandium and particularly Mg tend to have higher values in EL than in EH. Enstatite chondrites that have suffered the highest degree of metamorphism contain well crystallized orthopyroxene while in the least metamorphosed cases most pyroxene is clinopyroxene. The pyroxene composition of the enstatite chondrites varies with petrologic type 1-6: MnO, Na_2O and FeO are lowest in type 6 and CaO is highest (Rubin 1997).

3.1.2 Ordinary chondrites

Ordinary chondrites are stony meteorites where the main components are olivine and pyroxene, the ratios vary from class to class, as do the amount of iron, which already in hand specimen can indicate whether it is H, L, or LL chondrite. H stands for high total iron (both as metal and as oxides); L stands for low total iron and LL for low total iron and low metal. LL chondrites also tend to be brecciated to a higher degree (Sears 1978). Olivine and "hypersthene" ($(Fe,Mg)SiO_3$) constitute about two-thirds of the bulk of ordinary chondrites, with metal and sulphide (troilite) making up the remainder (McSween et al. 1990). Other normative minerals are diopside, apatite, chromite, ilmenite, orthoclase ($KAlSi_3O_8$) , albite ($NaAlSi_3O_8$) and anorthite. Normative olivine abundances decrease with increasing metal and "hypersthene".

One of the main characteristic features of ordinary chondrites is the depletion of volatiles (Norton 2002). Another important feature is that chondrule size, whole-rock oxidation state and $\delta^{17}O$ content increase from H to L to LL chondrites (Rubin 2005). On the other hand the metal grain size and metal abundance decreases from H to L to LL (Sears 2004). The most useful criterion to tell the groups apart is the ratio between metallic and total iron, since these values do not overlap, but this too can be misleading. It has been found that most of the plagioclase in equilibrated ordinary chondrites is a product of devitrification of glass and re-crystallization of microcrystalline material (Dodd Jr. et al. 1966). This does not mean that primary feldspar is entirely absent. All three groups of ordinary chondrites (H, L, and LL), were distinct already at the earliest stages of metamorphism, which means metamorphism is not the cause for differentiating the groups.

The major metallic phases are kamacite and taenite (γ-(Fe,Ni)); tetrataenite is rare and awaruite

(Ni_3Fe) is very rare (Rubin 1997), according to Mason (1963) the nickel-iron metal tends to cement the silicate phases and give the meteorite a greater mechanical strength. The major sulphide phase is troilite; pentlandite ($(Fe,Ni)_9S_8$) occurs as an accessory phase in some oxidized LL otherwise the dominant oxide is chromite; ilmenite and rutile occur as rare phases.

The mean Ni values of equilibrated OCs decrease from H (69.2 wt‰) to L (65.4 wt‰) to LL (49.8 wt‰). Olivine and kamacite compositions are valuable in the classification of the vast majority of the OCs independent of their bulk compositional data. The martensite (metal with ≥77 wt‰ Ni) proportions vary with chondrite group as do their Ni/Mg ratios (table 2). When going through the H-L-LL sequence, kamacite becomes systematically richer in Co and poorer in Ni; the grain size also decreases (Rubin 1990).

In the field it can be useful to assess the weight of the meteorite specimen as the ordinary chondrites have a density between 3.5 and 3.8 g/cm^3. It differs from carbonaceous chondrites and iron meteorites and can therefore act as a first approximation of the class to which the meteorite belongs (Norton 2004).

Table 2. The table shows the variation in chemical composition between the groups of ordinary chondrites (Rubin 1990, 1997, Norton 2002, Sears 2004).

	H	L	LL
Mean Fayalite composition	18.8 mol%	24.7 mol%	29.4 mol%
Mean Ferrosilite composition	17.2 mol%	21.3 mol%	24.1 mol%
Mean Chromite (FeO)	31.2 wt%	33 wt%	34.5 wt%
Mean Chromite (MgO)	2.7 wt%	2 wt%	1.6 wt%
Mean Chromite (MnO)	0.94 wt%	0.74 wt%	0.63 wt%
Mean Chromite (TiO_2)	2.3 wt%	2.8 wt%	3.2 wt%
Mean Kamacite (Co)	0.47 wt%	0.8 wt%	7.7 wt%
Mean Kamacite (Ni)	6.9 wt%	6.5 wt%	5 wt%
Fayalite ranges	17.3-20.2mol%	23.0-25.8mol%	26.6-32.4mol%
Kamacite Co ranges	4.4-5.1 mol‰	6.7-9.5 mol‰	14.2-370 mol‰
Mean Ni in equilibrated OC	69.2 wt‰	65.4 wt‰	49.8 wt‰
Kamacite Ni ranges	57.5-74.8 wt‰	51.6-75.4 wt‰	33.1-72.1 wt‰
Ni/Mg ratios	0.114 wt‰	0.081 wt‰	0.067 wt‰
Martensite propro-tion	14 %	35 %	22 %
Type I chondrule material	45 %	28 %	22 %
Tyoe II chondrule material	36 %	58 %	61 %
Co in kamacite	3.3-4.8 wt‰	6.7-8.2 wt‰	15-110 wt‰

3.1.3 Carbonaceous chondrites

Carbonaceous chondrites visually resemble charcoal briquettes and are quite rare. One reason that they are so rare is that they are friable, porous and loaded with soluble minerals, which causes the meteorites to disintegrate within a few months in a wet climate, they are quite rare even as falls. Hydrous minerals are present in all the carbonaceous chondrites and in some the water content is as high as 17-22 wt% and in others as low as <1 wt% (Norton 2002). Throughout carbonaceous chondrites it is common with metal inclusions in the chondrules, which is not the case for ordinary chondrites (Dodd Jr. et al. 1966). Olivine is a minor constituent 10-30 % usually as small scattered grains and chondrules (Mason 1963). C chondrites are the only meteorites containing organic compounds that may be considered precursors of life (Norton 2002). The average density of a carbonaceous chondrite varies between 2.2 and 2.9 g/cm^3. The C chondrites are subdivided into several groups;

CK chondrites (named after the type specimen Karoonda) are the only carbonaceous chondrite that shows petrographic type above 3, (section 3.2), the majority being 5. They appear dull and sooty on cut surfaces, which is due to what is called silicate-darkening. This is when fine (0.3-10 µm) particles of pentlandite and magnetite have permeated the interiors of the normally clear silicate minerals of the matrix. The cause of this is still unknown (Norton 2002). Small shock veins up to several millimetres in length are common, and all known specimen show shock stages between S2 and S5, (section 3.4). Most of the chondrules are porphyritic olivine although some are barred olivine (for details about chondrule properties see below) and the average diameter of chondrules is 0.7 mm (Sears 2004). Pyroxene is on the other hand relatively rare and only one radial pyroxene has been reported. The matrix is black and opaque. Within the matrix there is an abundance of small isolated olivine grains that have diameters between 0.025 and 1 mm and metal is very rare (Rubin 1997).

CV chondrites (named after the type specimen Vigarano) consist of large chondrules ~1 mm in a fine-grained matrix which essentially consist of olivine with the most common type of chondrules being porphyritic olivine (Sears 1978, 2004). The olivine matrix is more iron-rich than in ordinary chondrites and it is quite common to find large (~2 mm) refractory whitish minerals with a high Ca, Al and Ti content (CAIs), such as spinel and melilite. The matrix is much more compact than in the CI and CM chondrites and there is less pore space (Norton 2002). The matrix is also more grey than black and contain large, well-defined chondrules giving the CV chondrite petrographic type 3; i.e. CV3. Contributing to the opacity of the matrix is evenly distributed carbon-based material that thinly coats much of the olivine. In the chondrules opaque grains of metal, iron sulphide and magnetite can be identified. Larger crystals of olivine within the chondrules frequently show zoning with increasing iron content towards the rims. In these chondrites anorthite-forsterite-spinel chondrules can be found which are extremely rare in other chondrite groups. Troilite and Co-bearing pentlandite are the major sulphide phases in CV chondrites and phyllosilicates occur in the matrices, chondrules and refractory inclusions (Rubin 1997).

CO chondrites (named after the type specimen Ornans) are very poor in volatiles and contain metal and sulphide (Sears 1978). The chondrules are well defined and most of them are porphyritic olivine chondrules. The average size of the chondrules is 0.2-0.3 mm (Sears 2004) and they are closely packed (Kallemeyn & Wasson 1981). The minor amount of interstitial matrix consists mainly of olivine.

CH chondrites (so called because of their high metal amount) are the most metal-rich chondrites of all the chondrite groups, including the enstatite chondrites. It is also the newest recognized group of the carbonaceous chondrites. They contain about three times as much Fe as CR chondrites and large metal fragments are not uncommon in the matrix. Chondrules are sparse and small, averaging <0.1 mm in diameter (Norton 2002). The smallest chondrules are cryptocrystalline in texture. No petrographic types have been assigned this group so far.

CR chondrites (named after the type specimen Renazzo) are constituting a relatively new group with an abundance of metal. Metallic Fe-Ni accounts for 5-8 vol% with the sulphides (pyrrhotite and pentlandite) comprising an additional 1-4 vol%. The chondrules have an average diameter of 0.7 mm and the majority are low-FeO porphyritic olivine chondrules. The matrix is opaque with the major constituents being magnetite and phyllosilicates (Norton 2002).

CM chondrites (named after the type specimen Mighei are now being classified as CM2); have well defined but sparsely distributed small chondrules in the matrix. The chondrules, chondrule fragments, crystal aggregates and individual crystal grains constitutes ~50 wt% of the CM chondrite. The chondrules are small averaging 0.5 mm in diameter, where the smallest are nearly spherical in shape with a granular texture, and the larger ones are irregular in shape without rims and are composed of large euhedral to subhedral olivine crystals. Individual olivine crystals make up about 20 vol% or more of the CM chondrites. In the chondrules and the aggregates metallic iron grains can frequently be seen as well as highly refractory CAI minerals in the aggregates. The matrix is black and opaque, with composition resembling that of the CI chondrites, but with less magnetite. The major constituents of the matrix are phyllosilicates (Norton 2002).

CI chondrites (named after the type specimen Ivuna) have hydrated minerals and the major silicate component is serpentine ($Mg_3Si_2O_5(OH)_4$) and all iron present is concentrated in magnetite solely. The most important factor in classifying a CI-chondrite is the fact that they contain no chondrules at all, but the chemistry matches that of chondrites which places them in the chondrite class (Norton 2002). They also contain isolated olivine and pyroxene grains and intergrowths of olivine/pyroxene; these are believed to be fragments of chondrules. Essentially the CIs have fine-grained matrix, which in thin section is black and opaque. They contain characteristic forms of magnetite, such as framboids (microscopic aggregates of spherical grains), spherulites, and platelets. There are usually microscopic veins running through the matrix, and these appear to be lined with epsomite ($MgSO_4.7H_2O$).

3.1.4. Rumuruti chondrites

R chondrites or rumuruti chondrites are the newest group in the chondrite class, unrecognized until 1993 (Norton 2002). All of these chondrites are brecciated with light clasts in a dark matrix, the light clasts are of petrographic type 5-6 while the matrix is of type 3-4 which means they are genomict breccias. The R chondrites have the highest iron oxidation of any chondritic meteorite but almost no free iron metal at all. Most of the iron is situated in pyrrhotite, pentlandite and in olivine. All of these meteorites show weak to moderate shock metamorphism (S3-S4), (table 6). Metal is very rare, chromian spinel is the

Table 3. The table shows the distribution of petrographic types in chondrites. Where a column does not add up to 100 % some of the chondrites have been placed outside the common petrographic types. A zero means that specimens have been identified but they are extremely rare and constitutes less than half a percent of the total. Numbers calculated from Hutchison 2004.

Chondrite class / Petrographic type	EH	EL	H	L	LL	R	CK	CV	CO	CH	CR	CM	CI
1			0	0	0						6	6	100
2			0	0	0			3		100	78	94	
3	46	19	13	17	22	42	11	97	97		6		
4	26	3	24	11	15	11	50						
5	15	6	38	20	23		25						
6	5	61	21	49	36		4						

dominant oxide phase; magnetite and ilmenite are rare (Rubin1997).

3.2 The petrographic classification scheme

There are two different classification schemes for the petrographic types, the first are applicable on all chondrites and the second on the ordinary chondrites, there has not yet been any ordinary chondrite found that has a lower petrographic type than 3.0. Both schemes are based on the same properties of the chondrites but have fundamental differences when it comes to how to divide the groups, in the first there is type 1 through 6, in the second there are type 3 through 6. In this the properties of type 3 chondrites have been further divided into subtypes 3.0-3.1, 3.2-3.3, 3.4-3.5, 3.6-3.7 and 3.8-3.9 based on among other things the heterogeneity of the metal and the texture of the matrix (tables 4 and 5).

The minerals that occur in a chondrite can reveal the petrographic type, as example type 3.0-3.5 chondrites can be mentioned where the dominant silicate phases are olivine and low-Ca pyroxene. In the chondrules, olivine and low-Ca pyroxene and in some cases calcic plagioclase occur together with siliceous igneous glassy mesostasis and minor pigeonite and augite whereas type 5 and 6 chondrites contain diopside and sodic plagioclase instead of chondrule glass. The hydrated clay mineral smectite occurs in the matrices of some LL3 chondrites in association with calcite and magnetite, which is indicative of minor-to-moderate aqueous alteration (Rubin 1997).

Petrologic type is a primary classification tool for meteorites that relies on several characteristics. Weathering processes, that primarily alters metals and sulphide inclusions, make many of the characteristics indistinct and difficult to recognize. Only rarely are silicates altered, however, oxide stains often develop which overlay any silicate component (Marsh and Lauretta 2006).

3.3 Metal and sulphide in chondrites

The Co content in the kamacite phase in chondrites can be used to determine the ordinary chondrite class (Afiattalab and Wasson 1980), since the Co content show restricted non-overlapping ranges in the three groups.

During heating sulphur is lost from the sulphide minerals and accreted on metal grains as rims. These rims have two distinct layers that incorporate nearby silicate grains. In experimental studies it has been shown that sulphide forms in pore spaces penetrating the interior of metal grains and that the main mechanism for moving sulphur through the sample is vapour transport. As sulphur is lost the sulphide grain becomes successively smaller and more iron rich (Lauretta et al. 1997).

The fraction of metal-bearing chondrules decreases from type 3 to type 6 as well as the amount of metal in the interiors of the chondrules. From the lower to the higher types the fraction of fine-grained metal undergoes a rapid decrease, whereas the fraction of coarse-grained metal increases. Metal and troilite often form mixed assemblages (and sometimes spheroidal opaque “chondrules”) in the lower petrographic types; in the higher types these compounds generally occur as separate grains. Kamacite and less often taenite are often polycrystalline in type 3 chondrites. The typical grain shape in all petrologic types is irregularly equant. However in type 3 small spheroidal grains inside chondrules are fairly common, decreasing to rare in type 5 chondrites, and angular grain borders tend to become rounded with increasing petrologic type (Norton 2002).

Nickel, Ni, and cobolt, Co, are both highly siderophile elements and are mainly found in the metal phases of chondrites. In contrast to the trends in the H and L groups the average Co content in the taenite increases with increasing Ni concentration in the LL chondrites. Kamacite grains near the surfaces of chondrules are often associated with troilite (Afiattalab and Wasson 1980).

During cooling Ni is rejected from troilite and enters adjacent taenite, with continued cooling this reaction eventually forms tetrataenite (Rubin et al. 1999). Fe from the metal replaces Ni in the troilite while primary troilite was inherited from the chondrule precursors.

3.4 The Stöffler-Keil-Scott shock classification system

The shock classification system designed by Stöffler, Keil and Scott in 1991 is based on shock effects in olivine and plagioclase (oligoclase), and they have divided these effects into six different stages. Their work is based on the fact that shock metamorphism and brecciation resulting from hypervelocity collisions between the parent bodies of the meteorites is the most common feature in meteorites reaching Earth. By studying these features information about the collisional and geological history of the meteorites asteroidal parent bodies can be obtained. Their paper focuses mainly on ordinary chondrites and it relies on olivine which occurs in all chondrite groups. Planar fractures and planar deformation in olivine is introduced as critical shock indicators (Stöffler et al.1991). They studied all petrologic types from 3 to 6 as defined by Van Schmus and Wood in 1967 (table 4). Mechanical deformation and phase transformation can be detected primarily in the olivine grains. The mechanical deformation include a) undulatory extinction in olivine, pyroxene, and plagioclase; b) planar fractures and planar deformation features in olivine and planar deformation features in plagioclase; c) mechanical twinning in pyroxene; and d) mosaicism in olivine, pyroxene, and plagioclase. Phase transitions include a) trans-

Table 4. Petrographic types by Van Schmus and Wood 1967. Arrow means that the property is the same as for the previous type (Sears 2004).

Petrographic type/ Property	1	2	3	4	5	6
Homogeneity of olivine and pyroxene composition		Mean deviation px≥5 %, ol≥5 %	→	<5 % mean deviation to uniform	Uniform ferromagnesian minerals	→
Structural state of low-Ca pyroxene		Predominantly monoclinic crystals	→	Monoclinic crystals >20 %	Monoclinic crystals <20 %	Orthorombic crystals
Degree of development of secondary feldspar		Absent	→	<2 μm grains	<50 μm grains	Clear interstitial glass;>50 μm grains
Igneous glass in chondrules		Clear and isotropic primary glass; variable abundance		Turbid if present	Absent	→
Metallic minerals (maximum wt% Ni)		Taenite absent or very minor (Ni<200 mg/g)	Kamacite and Taenite present (>20 %)	→	→	→
Sulphide minerals (average Ni content)		>5 mg/g	<0.5 %	→	→	→
Chondrule texture	No chondrules	Very sharply defined chondrules	→	Well-defined chondrules	Chondrules readily distinguished	Chondrules poorly defined
Matrix texture	All fine-grained opaque	Much opaque matrix	Opaque matrix	Transparent microcrystalline matrix	Re-crystallized matrix	→
Bulk carbon (wt%)	3-5 %	1.5-2.8 %	0.1-1.1 %	<0.2 %	→	→
Bulk water content (wt%)	18-22 %	3-11 %	<2 %	→	→	→

Table 5. Modified petrographic table after Sears 2002 and Hasan 1988. Petrographic type 3 is further divided compared to table 4. Arrow means that the property is the same as for the previous type (Sears 2004).

Petrographic type/ Property	3.0-3.1	3.2-3.3	3.4-3.5	3.6-3.7	3.8-3.9	4	5	6
Homogeneity of olivine*	50		40-50	20-40	5-20	<5	uniform	→
Structural state of low-Ca pyroxene	Predominantly monoclinic					Monoclinic crystals >20 %	<20 %	Orthorombic
Feldspar	Absent	→	→	Rare or Absent		<2 μm grains	<50 μm grains	>50 μm grains
Primary glass	Clear isotropic	→	→	Turbid	→	Turbid if present	Absent	→
Thermoluminescence sensitivity (Dhjala=1)	<0.01	0.010-0.046	0.046-0.22	0.22-1.0	1.0-4.6	1-10	>5	→
Heterogeneity of metal**	>17	10-17	6.0-10	2.5-6.0	<2.5	→	Uniform	→
Average Ni content of sulphide minerals	>0.5 %	<0,5 %	→	→	→	→	→	→
Chondrule delineation	Very sharply defined		→	→	→	Well-defined	Readily defined	Poorly defined
Matrix texture (% transparent microcrystalline)	≤20	10-20	~20-~50	>60	→	100	Re-crystallized matrix	→
Matrix (FeO/ (FeO+MgO)) ***	>1.7	1.5-1.7	1.3-1.5	1.1-1.3	>1.1	→	→	→

* standard deviation of the mole% fayalite in the olivine divided by the mean fayalite expressed as a percentage
** standard deviation of the nickel content in the kamacite (wt%) divided by the mean nickel content expressed as a percentage
*** divided by the same quantity for the bulk meteorite

formation of plagioclase into diaplectic glass called maskelynite (shock-disordered plagioclase glass); b) melting of plagioclase and formation of (normal) glass; c) solid state re-crystallization of olivine; d) melting of olivine and formation of fine-grained polycrystalline olivine and; e) transformation of olivine and pyroxene into ringwoodite and majorite respectively, and/or dissociation of olivine into several crystalline or glassy phases (Stöffler et al.1991).

What follows is a summary of the criteria of shock stages taken from Cambridge Encyclopedia of Meteorites (Norton 2002).

S1-unshocked: Rotation of the thin section shows sharp optical extinction in the olivine and plagioclase. As in terrestrial rocks olivine and plagioclase grains may have irregular fractures in them. Formed at pressures below 5 GPa.

S2-very weakly shocked: Undulose extinction in both olivine and plagioclase and irregular fractures are common. Formed at P = 5-10 GPa.

S3-weakly shocked: Set of planar fractures, shock lamellae appear in olivine, in each set there are three or more parallel fractures, some of the sets are intersecting each other. At this stage the shock lamellae are the most important shock indicators. Undulose extinction in both the olivine and the feldspar are clearly visible, although no planar fractures occur in the latter. Pockets of melted material and opaque melt veins begin to appear. Formed at P = 15-20 GPa.

S4-moderately shocked: The most important criteria for the S4 stage is a weak mosaic pattern that forms on the olivine crystals. The plagioclase crystals show undulose extinction but also begin to show partially isotropic planar deformation structures. The beginning of a phase change is taking place, plagioclase are turning into "maskelynite", an in situ-formed plagioclase composition glass. At this stage the melt pockets with interconnecting veins also become more prevalent. Formed at P = 30-35 GPa.

S5-strongly shocked: Mosaic texture in olivine crystals together with the planar fractures and planar deformation features appear very strong. The S5 stage is distinguished by the fact that oligoclase has completely transformed into maskelynite. The melt veins and melt pockets spread throughout the meteorite. A mix of crystalline material formed by melting and intergrowth of various silicate minerals, troilite and metal, comprise opaque shock veins which increase with increasing shock stage, and also enlarge into melt pockets. Formed at 45-55 GPa.

S6-very strongly shocked: Re-crystallization of olivine and plagioclase in the solid state occurs, and melting of olivine and pyroxene along the crystal edges takes place. Some olivine grains change into ringwoodite. Maskelynite melts and turns into normal glass in the melt pockets and the pressure required is 75-90 GPa.

Stöffler et al. (1991) concluded that petrologic type 3 chondrites were deficient in shock stages S4 to S6 and with increasing petrologic type the frequency of these stages increases. They noticed that stage S3 was the most abundant of the stages in the petrologic types and that the degree of shock metamorphism correlated with the loss of noble gases in the meteorites. They also noted that in shock stages S1 and S2 there seem to be no loss of noble gases. No shock stage has been assigned completely shock-melted ordinary chondrites because these rocks will be termed impact-melt rock or impact-melt breccia. The

Table 6. Shock grade criteria and the pressure to which the criteria is associated with (Stöffler, Keil and Scott 1991).

Shock stage	**Effects resulting from equilibration peak shock pressure**		**Effects resulting from local P-T-excursions**	**Shock pressure GPa**
	Olivine	*Plagioclase*		
Unshocked S1	Sharp optical extinction, irregular fractures		None	<4-5
Very weakly shocked S2	Undulatory extinction, irregular fractures		None	5-10
Weakly shocked S3	Planar fractures, undulatory extinction, irregular fractures	Undulatory extinction	Opaque shock veins, incipient formation of melt pockets, sometimes interconnected	15-20
Moderately shocked S4	Mosaicism (weak), planar fractures	Undulatory extinction, partially isotropic, planar deformation features	Melt pockets, interconnecting melt veins, opaque shock veins	30-35
Strongly shocked S5	Mosaicism (strong), planar fractures + planar deformation features	Maskelynite	Pervasive formation of melt pockets, veins and dikes; opaque shock veins	45-55
Very strongly shocked S6	Restricted to local regions in or near melt zones:		As in stage S5	75-90
	Solid state recrystallization and staining, ringwoodite, melting	Shock melted (normal glass)		
Shock melt	Whole rock melting (impact melt rocks and melt breccias)			

presence of relict chondrules and of mineral and lithic clasts in an igneous matrix indicates that the rock is an impact-melt breccia, while an igneous texture of the whole rock, indicating crystallization from a liquid establishes the rock as an impact-melt rock.

Another feature worth mentioning is shock veins, or opaque melt veins, which forms at relatively low equilibration shock levels and as the pressure rises becomes more complex and abundant. The veins are essentially formed by frictional melting, which is proved by the smearing of molten metal or troilite into a thin string along the veins. Important to note is that it is *in situ* melting, the melt veins and pockets surround unmolten chondritic constituents (Stöffler et al. 1991). Within the veins of highly shocked ordinary chondrites the spinel form of olivine, ringwoodite ($(Mg,Fe)_2SiO_4$), is formed as well as a polymorph of pyroxene, majorite ($Mg_3(Fe)_2(SiO_4)_3$) (Rubin 1997).

There are three fundamental scenarios for the formation of shocked chondrites, fragmentation and escape; cratering, spallation and escape; cratering, ejecta deposition and regolith formation. They are all a function of size. The relative size of the colliding bodies is also of importance for the temperature experienced by the shocked rocks immediately after shock pressure release. It was early recognized that impact processes in general are prime factors affecting very fundamental properties of meteorites, including the loss of noble gases as mentioned above (Norton 2002). Shock effects involving mineral transformations occur in metallic FeNi, elemental C, olivine, orthopyroxene, plagioclase and zircon (Rubin 1997). The resulting minerals are baddelyite, chaoite (C), diamond (C), lonsdaleite (C), magnesiowüstite ((Mg,Fe)O), majorite, martensite (alloy of iron and carbon), ringwoodite and suessite ($(Fe,Ni)_3Si$).

3.5 Weathering grade

A scale of the weathering effects caused by the terrestrial climate and observed in thin sections has been proposed by Wlotzka (1993), the weathering grade is divided into seven levels. The weathering effects are important since it can give an estimation of the time spent on Earth by the meteorite since a correlation can be found between the time spent on Earth and the grade of weathering. Weathering first affects the metal grains then the troilite and finally the silicates. Ordinary chondrites are porous rocks that when exposed to the arid climate of deserts starts to weather. The oxidation of the metal leads to volume expansion which may reduce porosity, and by doing so reduce the ability of water to penetrate the sample (Bland et al. 2006).

W0: no visible oxidation of metal or sulphide. A yellow brown limonitic staining may already be noticeable in transmitted light. Fresh falls are usually of this grade, although some are already W1.

W1: minor oxide rims around metal and troilite, minor oxide veins

W2: moderate oxidation of metal about 20-60 % being affected

W3: heavy oxidation of metal and troilite, 60-95 % being replaced

W4: complete (>95 %) oxidation of metal and troilite, but no alteration of silicates

W5: beginning alteration of mafic silicates, mainly along cracks

W6: massive replacement of silicates by clay minerals and oxides

In stage W2 massive veining with iron oxides can be found. The veins develop independently from weathering grade, apparently in cracks that form through mechanical forces. Carbonates usually fill up the broader cracks. W5 and W6 are rare. Silicate alteration affects the olivine grains first starting at the centre of the grain (Wlotzka 1993).

For meteorites found in Roosevelt County, New Mexico correlation of weathering grade to terrestrial ages was suggested, the ages were similar for chondrites found in Libyan and Algerian deserts: W2, 5,000-15,000 yr; W3, 15,000 to 30,000 yr; W4, 20,000 to 35,000 yr; W5 and W6, 30,000 to >45,000 yr. These ages are not true for all meteorites; a meteorite named ALHA77278 found in Antarctic had a terrestrial age of 320,000 years but only a weathering grade of W1 (Wlotzka 1993).

The most important minerals formed by terrestrial weathering of meteorites are goethite (FeO(OH)) and magnetite (Rubin 1997). A few other minerals formed by terrestrial weathering are akaganéite (β-$Fe^{3+}_8(OH,O,Cl)_{17}$), apatite, bassanite ($CaSO_4 \cdot 0.5H_2O$), bunsenite (NiO), cassidyite ($Ca_2(Ni,Mg)(PO_4)_2 \cdot 2H_2O$), collinsite ($Ca_2(Mg,Fe)(PO_4)_2 \cdot 2H_2O$) and epsomite ($MgSO_4 \cdot 7H_2O$), among others (Rubin 1997).

4 Chondrules

Chondrules are spherical "balls" that make up ~75 vol% of chondrites; they have a ferromagnesian composition and their abundant appearance in chondrites have given the chondrites their name (Norton 2002). Because the chondrules are so common in the chondrites their composition and texture are very important for the chondrite as a whole (Sears 1978). Chondrules include fragmented as well as complete spherules, all melted, partially or totally.

Chondrules consists mainly of olivine and low-Ca pyroxene with feldspar and glass in the mesostasis (Bridges et al. 1998) and their size varies among the different chondrite groups, both within and in between the groups (Norton 2002). As example the average size of the chondrules in carbonaceous chondrites ranges from <100 µm to 1000 µm (table 1) and the chondrule density which also varies between the groups is at most 65-75 vol% in the ordinary chondrites.

There is usually no open pore space between the chondrules but rather a fine-grained matrix, with similar mineralogy as the chondrules themselves (Norton 2002). Sharply defined chondrules are found in type 3 ordinary and carbonaceous chondrites. The chondrules are also densely packed and seem to have escaped any form of secondary processes including severe thermal metamorphism that is characteristic for ordinary chondrites of type 4-6. Type 2 shows far fewer chondrules and also alteration due to the presence of water. In general larger chondrules have higher refractory/volatile ratios, and the mesostasis tend to be crystalline in the larger ones and glassy in the smaller chondrules (Bridges et al. 1998).

Ordinary chondrites of petrographic type 4-6 are considered to be equilibrated in which the chondrule mesostasis are devitrified or crystalline. As the groundmass progressively coarsens with increasing petrographic type, intergrowth with chondrules increases and their outlines becomes blurred. Small chondrules tend to disappear as they integrate with the groundmass and so the average size of the surviving chondrules increases (Hutchison 2004).

4.1 Classification of chondrules

Since the chondrules textures tend to be similar in several meteorites, they have been divided into two categories labelled porphyritic and non-porphyritic chondrules (table 7). These two groups were then further divided based on their primary mineral (Norton 2002).

There are some features that are common to all chondrules among others the mesostasis which are quartz-, albite-, and anorthite-normative. With increasing petrologic type, the proportion of quartz- and anorthite-rich chondrule mesostasis decreases. The diversity of the chondrule population increased due to metamorphism as some respond faster to metamorphism than others (Sears et al. 1992).

4.1.1 Porphyritic chondrules

In the ordinary chondrites the porphyritic chondrules comprise 81% of all chondrules. They are thought to have been only partially melted during formation and there are two main types, Type I which is FeO-poor and Type II which is FeO-rich; these can be distinguished by their fayalite and ferrosilite contents. The Type II varieties are more commonly seen in ordinary chondrites (Norton 2002). The porphyritic chondrules are further divided into basic groups based on the dominating mineral composition, porphyritic olivine (PO), porphyritic pyroxene (PP), porphyritic olivine-pyroxene (POP), and granular olivine-pyroxene (GOP).

Porphyritic olivine (PO) chondrules contain olivine crystals with visible crystal faces (Norton 2002). The crystal shapes ranges from euhedral to anhedral. Olivine crystals are easily recognized with their fine random cracks and their birefringent second to third order colours. Along the cracks alteration can often be seen and sometimes a rim around the grains and zoning occurs where the chemical composition changes towards a more FeO-rich composition at the rims. The olivine grains are surrounded by a matrix of clear glass which in most cases has an oligoclase composition.

Porphyritic pyroxene (PP) chondrules consists normally of low-Ca pyroxene or clinoenstatite in type 3 chondrites. They usually have low birefringent colours, and polysynthetic twinning planes often transect the crystals (Norton 2002). Type I and type II PP chondrules differ in their appearance, where type I have tiny colourful olivine grains enclosed within the pyroxene grains, type II have very large pyroxene crystals closely packed compared to the pyroxene crystals of type I.

Porphyritic olivine-pyroxene (POP) chondrules are the most common type and they contain mixtures of both olivine and clinoenstatite (Norton 2002). The rim of larger pyroxene grains typically encloses smaller olivine grains in the interior of the chondrule.

Granular olivine-pyroxene chondrules (GOP) are the rarest of all chondrules and they generally have small anhedral grains of olivine and pyroxene tightly packed in a glassy mesostasis. These small grains are usually surrounded by a rim of coarser grains of the same mineral (Norton 2002). They are sometimes placed in a group by itself and not under porphyritic chondrules depending on the author (authors comment).

4.1.2 Non-porphyritic chondrules

Non-porphyritic or droplet chondrules are thought to once have been fully molten. They include radial pyroxene (RP), barred olivine (BO), cryptocrystalline (C) and glassy chondrules of which all are easily recognized (Norton 2002).

Radial pyroxene (RP) chondrules are the most spherical and consist of extremely thin laths of orthopyroxene (bronzite) or low-Ca pyroxene. The laths are arranged in a fan-like pattern and extend from one or more nucleation points. In petrographic type 4 and 5 chondrites the shape is not spherical but

Table 7. The table shows the different types of chondrules and their abundance in chondrites (Norton 2002).

	Type	Texture	Abundance (%)
Group 1 porphyritic	PO	Porphyritic Olivine	23
	PP	Porphyritic Pyroxene	10
	POP	Porphyritic Olivine-Pyroxene	48
Group 2 non-porphyritic	RP	Radial Pyroxene	7
	BO	Barred Olivine	4
	C	Cryptocrystalline	5
Group 3	GOP	Granular Olivine-Pyroxene	3

rather scalloped like a shell which is a result from corrosive chemical alteration (Norton 2002).

Barred olivine (BO) chondrules have a distinctive texture with plates of olivine forming parallel bars set in glass (Norton 2002). The olivine bars usually go to extinction simultaneously and have the same interference colours, which indicate that they are all oriented identically. The bars are surrounded by a rim of the same mineral which has the same interference colours and extinction direction as the crystals in the interior. Sometimes small opaque mineral grains often consisting of troilite can be seen in the rim. Occasionally the bars are situated at angles towards another and have then different extinction angles, and interference colours (Norton 2002). Barred olivine chondrules are rare but their bulk compositions span the range of almost all observed compositions of olivine (Connolly Jr et al. 1998).

Cryptocrystalline (C) chondrules consist of microcrystalline orthopyroxene grains, which have a patchy extinction.

Glassy chondrules are relatively rare and are more or less featureless, except for when feathery needles of olivine or pyroxene have crystallized out of the glass. Glass chondrules are only found in chondrites of type 2 and 3 (Norton 2002).

In ordinary chondrites the non-porphyritic chondrules have generally lower concentrations of refractory elements than porphyritic chondrules (Scott et al. 1994).

4.1.3 Other chondrules

Most chondrules have bulk compositions similar to those of the bulk chondrite, but there are a few rare classes that deviate significantly (Krot et al. 1993). Two of these classes are the Al-rich chondrules and the "chromite" chondrules. Chromite chondrules are usually 100-300μm in apparent diameter, and their morphology is distinct from the irregular shapes of chromatic inclusions of similar mineralogy in the same meteorite. Chromite-bearing silicate (CBS) chondrules are generally larger than the chromite chondrules; they consist of 85-95 vol% silicate and 5-15 % chromite. Matrix spinel is always chromite.

4.1.4 Metal and sulphide in chondrules

Almost all chondrules in ordinary and carbonaceous chondrites contain minor or trace amounts of metal and/or sulphide minerals together with the silicate minerals and glass. The metal and the sulphide occur as either spherules in chondrule mesostasis or within silicate minerals or as irregular masses between the silicates. Metal and sulphide also occur as rims around chondrules (figure 6) and it is common that they are associated with each other in the same spherule or assemblage (Grossman & Wasson 1985). Equilibrium condensation in a gas of solar composition produces metallic Fe-Ni at relatively high temperatures. Metal could only have been a chondrule

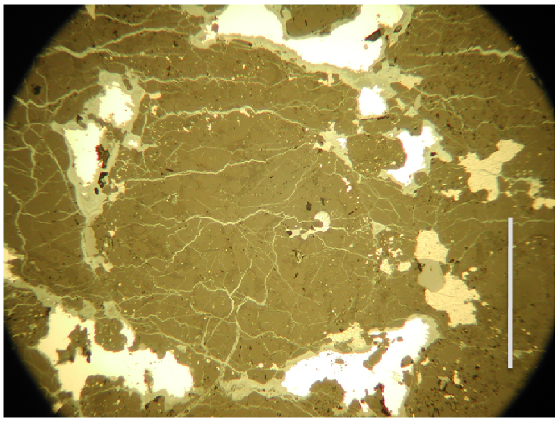


Fig. 6. A metal and sulphide rim around a porphyritic chondrule in 06-18 Dhofar meteorite. Photograph taken in reflected light, scale bar on the right 0.5 mm long.

precursor material if it was unable to react with the gas. Grossman and Wasson (1985) suggest that the entry of Co and Ni into silicates may have occurred while metal and silicates were in contact inside the molten chondrule, they also believe that the metal-loss during melting was not the dominant fractionation mechanism.

Most metal and sulphide in chondrules were probably present in the solar nebula before chondrule formation (Grossman & Wasson 1985) and the amount of metal formed by reduction during chondrule melting was subordinate. Chondrules are depleted in metal chiefly because they sample metal-poor precursor assemblages.

4.1.5 Refractory inclusions and Ca-Al-Ti-rich inclusions (CAIs)

Refractory inclusions are subdivided on the basis of mineralogy and texture; type A inclusions are fine-grained and have suffered secondary alteration. Type B inclusions are larger, coarse-grained with little or no alteration. Type C inclusions are believed to be solidified melts (Sears 2004).

Other types of inclusions are identified by descriptive names such as amoeboid-olivine aggregates and spinel-pyroxene aggregates (Sears 2004). The rare earth elements, Yt to Lu, are refractory elements and are therefore abundant in these inclusions. The refractory inclusions are believed to be the first solids that formed in the Solar System (Rubin 2000).

CAIs are refractory, high-temperature minerals with high amounts of Ca, Al and Ti (Bischoff & Keil 1984), which is indicative of formation early in the history of the Solar System and they are thought to hold information about the formation of planets and planetisimals. In most chondrite classes trace amounts of CAIs can be observed, but they are abundant in CV chondrites (Sears 2004). Al-rich objects are common constituents in all types 3 and 4 ordinary chondrites but they are widespread, although rare, in carbonaceous chondrites. This provides evidence that ordinary and carbonaceous chondrites and their constituents share a common origin (Bischoff & Keil 1984).

Refractory inclusions in chondrules are rare and there is a difference in amounts between type I and type II chondrules, in the H, L and LL chondrites (Zanda et al. 2006).

4.2 Formation of chondrules

The abundance of chondrules suggests widespread melting in the protoplanetary disk (Hewins 1997) and that it was a common phenomenon in the early Solar System. Although the mechanisms for forming chondrules have not yet been fully understood, there are a few models that are consistent with the high constraints demanded for the formation of chondrules; nebular lightning, magnetic reconnection flares, gas dynamic shock waves and radiative heating by among others ^{26}Al (Rubin 1999). Even though not fully understood chondrules represent a unique insight into the processes that occurred in the dusty, turbulent nebula in which the Sun and the planets formed (Sears et al. 1992).

The properties of the chondrules are in them selves evidence that they formed in the nebula from a melt and that their precursors were incompletely melted (Rubin 2000). A spherule requires at least 30-40 % melting to form and the fine-grained porphyritic textures described above can only be produced by incomplete melting (Connolly and Hewins 1995). Another source of evidence for partial melting is that relict grains are found in more than 15 % of all chondrules in type 3 ordinary chondrites. There are several types of relict grains: "dusty" mafic silicates, magnesia relict grains and large relict grains.

Large relict grains are much bigger than the phenocrysts in its host chondrule, sometimes one relict grain can constitute more than 90 vol% of the chondrule. The relict grain can also be a refractory inclusion.

It seems plausible and highly likely that most relict grains were derived from phenocrysts of pre-existing, collisionally disrupted chondrules. The free phenocrysts became trapped within porous dust clumps and subsequently melted. Free phenocrysts are not the only material being trapped within chondrules, other chondrules also became trapped, and these are called compound chondrules. Independent enveloping compound chondrules are objects in which a secondary chondrule encloses an unrelated primary one (Rubin 2000).

The duration under which the individual chondrule formed may have been very short, but the process may have been ongoing for a few million years, with different intensities. The oxygen isotopic composition and the chondrules mean sizes, which differ between and within groups, suggests that the chondrules were neither formed at one place nor at one time. The mechanisms responsible for the formation of the chondrules persisted during the time it took the nebula to cool down from above ~625 ˚C to below ~325 ˚C (Rubin 2000).

The chondrules remained hot for relatively short periods of time and they cooled rapidly, many of them were heated more than once. Zoning profiles in minerals is only one of the properties indicating that the cooling was rapid or the chondrules only melted to a low degree (Rubin 2000).

There are currently two main hypotheses of the formation environment of the chondrules, nebular setting and planetary setting (Bridges et al. 1998). The favoured hypothesis is the nebular setting. The main argument is the compositions of the chondrules that show no evidence for igneous fractionation.

In the meteorites studied by Dodd (1976) the size distributions of silicate and metal particles are narrow which suggest that chondritic material was sorted before or during its accumulation in parent bodies. With few exceptions the median diameter of silicate particles and the size ratio of silicate to metal particles decrease from LL- to L- to H-group material. Adding to the complexity of understanding the pre-accumulation history is the shock and weathering experienced by the meteorite, which complicate the interpretation of the origin of the chondrules (Sears et al. 1992).

Studying chondrules may give suggestions of physical and chemical processes that occurred within the nebula. As almost all of the chondrules are porphyritic, this suggests that (1) typical chondrule melts contained many nuclei after melting and (2) that most chondrules were melted at temperatures below their liquidi. There are some evidence that chondrules interacted with dust grains and other chondrules before accretion. The evidence are (1) fine-grained accretionary rims, interpreted to indicate that solid chondrules encountered dust during or after chondrule formation, (2) compound chondrules that indicate collisions between partially molten chondrules and other chondrules, (3) relict grains may have been incorporated into molten chondrules. Chondrules excluding dust during the cooling cycle form glass suggesting that dust grains acts as nucleation sites for crystal growth (Connolly Jr. & Hewins 1995). Pore space within chondrules would permit their interiors to interact with nebular gases and/or dust or to permit the re-condensation of sulphur into the interior of chondrules**.**

When melting is relatively limited, more nuclei or embryos survive producing coarse textures as in porphyritic olivine, PO chondrules. The greater the melting, the smaller the nuclei or embryos which survive and hence the greater the degree of undercooling needed to induce crystal growth, producing textures such as barred crystals. The finer the material, the more nuclei remain in the melt after melting. Fewer nuclei present after melting promote the formation of fewer but larger crystals. Barred textures represent a borderline between complete and incomplete melting; they are interpreted as an indicator of the maximum melting temperatures experienced by chondrules (Connolly Jr et al. 1998).

Radial and barred textures indicate rapid crystal growth within totally molten droplets after some undercooling (Hewins 1997). Apart from olivine and pyroxenes, the important phases in chondrules are glass, Fe-Ni metal, and troilite. It is plausible that some chondrules experienced a second heating with low enough intensity not to completely destroy previous crystals, others might have experienced a more thorough heating including melting which left no evidence of the primary chondrule. Both graphite and organic compound have been found in chondrules and thought of as precursor material, it has been suggested that solid carbon was present in chondrule precursors and acted as a reducing agent on the Fe-silicate component. The precursors of type I and II chondrules appear to have been similar and near-chondritic. Type II chondrules are more oxidized by nature, but both types lost volatile elements during melting and both partially reacquired volatiles later by re-condensation and related processes. The early nebular fractionation processes and evaporative loss during melting influenced chondrule compositions. Heating and cooling were probably rapid as indicated by the relict grains not dissolved in the melt.

5 Meteorites from north-west Africa and the Dhofar desert region in Oman

In desert environments, like north-west Africa and Dhofar in Oman, meteorite finds are not uncommon. Many meteorites are found close together and may or may not be from the same fall. In humid environments it is rather probable that meteorites found together are from the same fall. In deserts, on the other hand, this may not be the case since the arid climate of deserts preserve meteorites better than do a humid climate as weathering do not disintegrate the meteorites as fast. This means that there is somewhat of an accumulation of meteorites in these environments and meteorites found close together may therefore be from different falls at different times (Russel et al. 2002, Connolly Jr 2006).

5.1 Meteorites from north-west Africa

Meteorites found in north-west Africa are numerous and consist of a wide variety of types. In this study NWA-869X have been examined, the X is a remainder that this is not the sample classified but thought to be from the same fall. However, in this area several different meteorites have been found, ordinary chondrites, carbonaceous chondrites, achondrites, Lunar and Martian meteorites. They show a wide range of petrographic types as well as weathering grades and shock stages. The most common meteorites found are chondrites. The two NWA meteorites in this study are thought to be from the same fall (Russel et al. 2002, Connolly Jr 2006).

The meteorite finds from north-western Africa usually have an unknown find-location or unreported location. Geographical factors are important for the terrestrial alteration effects and since this information usually is lacking these effects cannot be studied (Devouard et al. 2006).

5.2 Meteorites from the Dhofar desert region in Oman

In recent years several meteorites have been found in the deserts of Oman. Deserts preserve meteorites better than a humid environment; this means that meteorites found in arid environments can be of much greater ages than meteorites found elsewhere and they might also represent an accumulation**.** It also means that meteorites found in deserts have to a larger degree preserved the original minerals and phases occurring in meteorites. The diversity of meteorites found in this area is great, several Lunar and Martian meteorites have been found recently (Russel et al. 2002, Connolly Jr 2006).

In a study by Gnos et al. (2006) ordinary chondrites were studied in relation to their weathering and terrestrial ages. The data indicated that the ordinary chondrites from Oman disintegrate completely after ~50 000 years. It has been interpreted as the combined result of volume increase due to oxidation of metal and sulphide, diurnal thermal cycling, and infiltration of soil material into cracks due to wind and water.

6 Analytical methods and material

Four meteorites from the Dhofar region in Oman and two meteorites from north-west Africa (NWA), presumably Morocco were studied in order to classify them based on their optical characteristics, chemical composition of the constituent minerals, and the grades of weathering and shock. The thin sections were prepared by Minoprep and from each meteorite one polished and one glass-covered thin section were made. In most cases the thin sections covers the rims of the meteorites. The thin sections were studied with optical microscopy (Nikon Eclipse E400 POL) in both transmitted and reflected light. In addition to determine mineral assemblage the diameter of the chondrules and opaque minerals, if present, were measured. In reflected light opaque phases and silicates were point counted, 600 points 1 mm steps, for each thin section to characterise the proportions of these components as accurately as possible. When uncertain transmitted light was used to determine if it was a non-opaque mineral.

Following optical microscopy an SEM (scanning electron microscope, Hitachi S-3400N), with an EDS-detector (electron dispersion detector) was utilised to obtain the compositions of the pyroxene, the olivine and the opaque minerals, and minerals not previous identified. The settings for SEM was 15 kV, emission current around 63 μA, BSE (back scatter electron) imaging, working distance ~10 mm.

For reference one of the meteorites from Morocco (NWA-869X) was reclassified as an exercise. The unclassified NWA stony meteorite from the same area was studied and compared to the NWA-869X.

The results from the EDS analysis are presented in appendix II and a list of minerals are provided in appendix I.

Determining accurately the actual mineral abundances in chondrites by petrographic point counting is highly problematic, because of difficulties in obtaining thin sections of representative size and of identifying some silicate phases by optical properties alone (McSween Jr et al. 1990).

7 Petrographic and EDS results

7.1 NWA-869X

NWA 869X previously classified as L 4-6; W1, S3 (Connolly Jr. et al. 2006) is relatively dark in colour, a brownish grey with lighter "spots" more or less rounded. There are a number of chondrules all with different appearances and shapes. In general many of the chondrules appear fragmented or porphyritic.

There is a large barred olivine (BO), where the olivine seems to form plates in rows with one main direction, a secondary direction is observed, (cover page photograph). The olivine plates are whitish in plane polarized light and in crossed polarized light they have a distinct high interference colour of the 2nd order. The rim of this chondrule is sharp although it differs in its thickness around the chondrule, it too consists of olivine grains and the chondrule has a diameter of 1.5 mm in its longest dimension.

There is also a chondrule that has a drop-like shape, the chondrule contains olivine grains both as large crystals and small. The smaller grains are angular and have crystal faces at high angles towards each other.

The diameter of 35 chondrules were measured, but only on chondrules which are readily defined, i.e. excluding blurry rims. The mean diameter of the chondrules observed in the thin section is 0.70 mm. The chondrules were classified by type in order to further aid characterization of the chondrules. The result showed that the PO (10), PP (10) and POP (8) chondrules are the most common. The chondrule types described under section 4.1 are only the "end members", and there might be chondrules in between these extremes. The type of chondrule described here is therefore an interpretation open for re-evaluations.

Point counting gave 63 % silicates, 7 % sulphide, 3 % metal, 17 % matrix (primarily glass) and a total of 10 % unknown grains.

Olivine occurs in the majority of the chondrules and there is a rather high degree of olivine in the matrix. The mean composition of the olivine is $Fa_{23\pm2}$ and the homogeneity of the olivine grains is 0.08 %. Olivine also appear as skeletal grains of which a few grains situated close together resemble a rose (figure 7A and B).

The mean composition of the low-Ca pyroxene is $Fs_{17\pm2}$ (see figure 10A for compositions). The pyroxene grains appear similar to the olivine grains except in their interference colours. They occur both in chondrules and as individual grains, but in lesser amounts than olivine.

There are also abundant opaque minerals of which those interpreted to be metal have a mean diameter of 0.2 mm. Optical microscopy showed that the opaque minerals were metallic Fe,Ni confirmed by the EDS analysis. Some of the sulphide minerals are troilite while others only show a weak anisotropy or are isotropic and the EDS analysis showed that they consist of iron sulphide intergrown with iron oxide. Sulphide also occur in rims around chondrules (figure 7D) more frequently than metal does.

Other minerals found in the sample are chlorapatite in rather high amounts, plagioclase as interstitial material in chondrules and pleonaste ($(Mg,Fe)Al_2O_4$) or hercynite ($(Fe,Mg)Al_2O_4$).

The matrix as a whole consists to a large portion of fragments (figure 7C) and crystals, and most of the fragments consist of olivine grains. The matrix is patchy with some parts looking re-crystallized while others do not.

7.2 NWA-UKW

NWA-UKW has not previously been classified and differs greatly from NWA 869X. The initial examination showed the coloration to be strongly reddish brown and the thin section appeared to lack chondrules (figure 8A). Also the optical study showed no chondrules, there appear only to be a matrix with grains evenly distributed throughout the sample. However, there are indications that chondrules might have been present, that mechanical forces have obliterated this texture by oxidation-related alteration and associated expansion increase in volume. This is based on cracks running in a fan-like pattern in some areas of the thin section (figure 8B and D). The areas that are suspected to once have been chondrules are around 2-2.5 mm in size, but where the actual chondrule begins and ends is not possible to determine.

Point counting gave 53 % silicates, 6 % sulphides, 1 % metal and 32 % veins which were distinguished from the 7 % unknown material.

An interesting feature is the lack of olivine, as no olivine grains can be found, the most abundant silicate is low-Fe pyroxene. The pyroxene is very pale in colour some grains showing a weak pleochroism in transmitted light. The interference colour is low 1st order, ranging between grey and purple brown. The grains also have an extinction angle at ~20° at

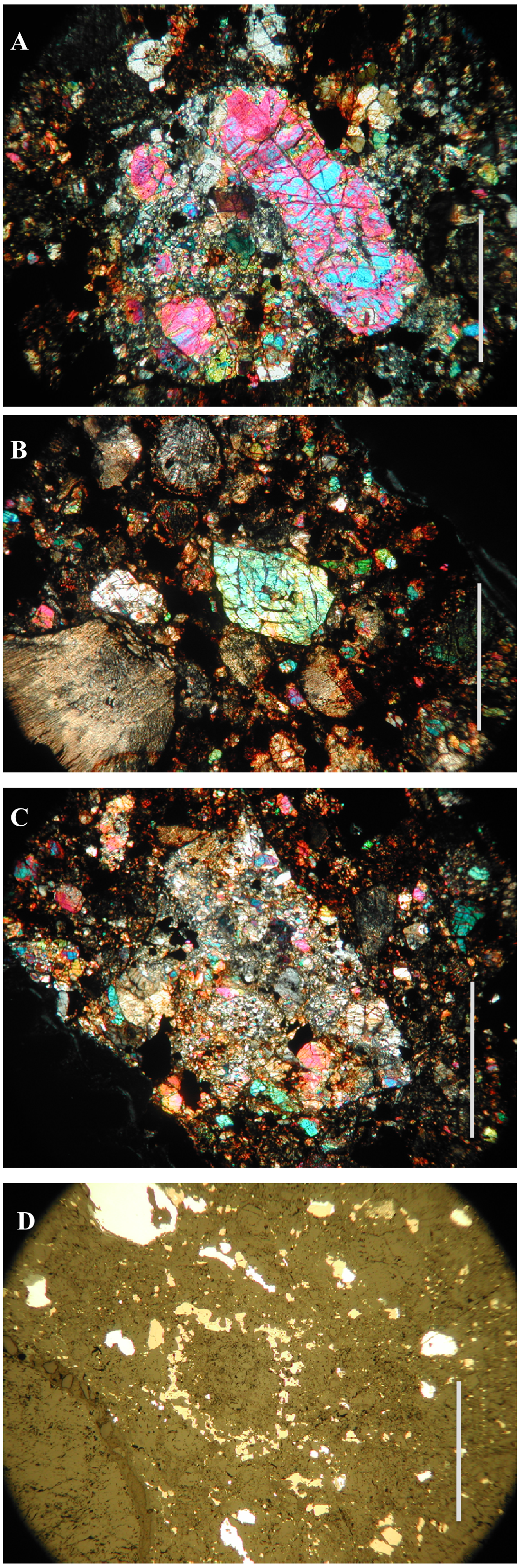


Fig. 7. Photographs of NWA-869X A) a skeletal olivine grain at the edge of a chondrule in crossed polarized light, scale bar on the right is 0.5 mm. B) skeletal olivine in the shape of a rose in crossed polarized light, scale bar on the right is 1 mm long. C) a fragment embedded at the edge of the chondrite in crossed polarized light, scale bar on the right is 1 mm long. D) sulphide rims which are common around chondrules and the border between fragments on the lower left hand, scale bar is 0.5 mm long.

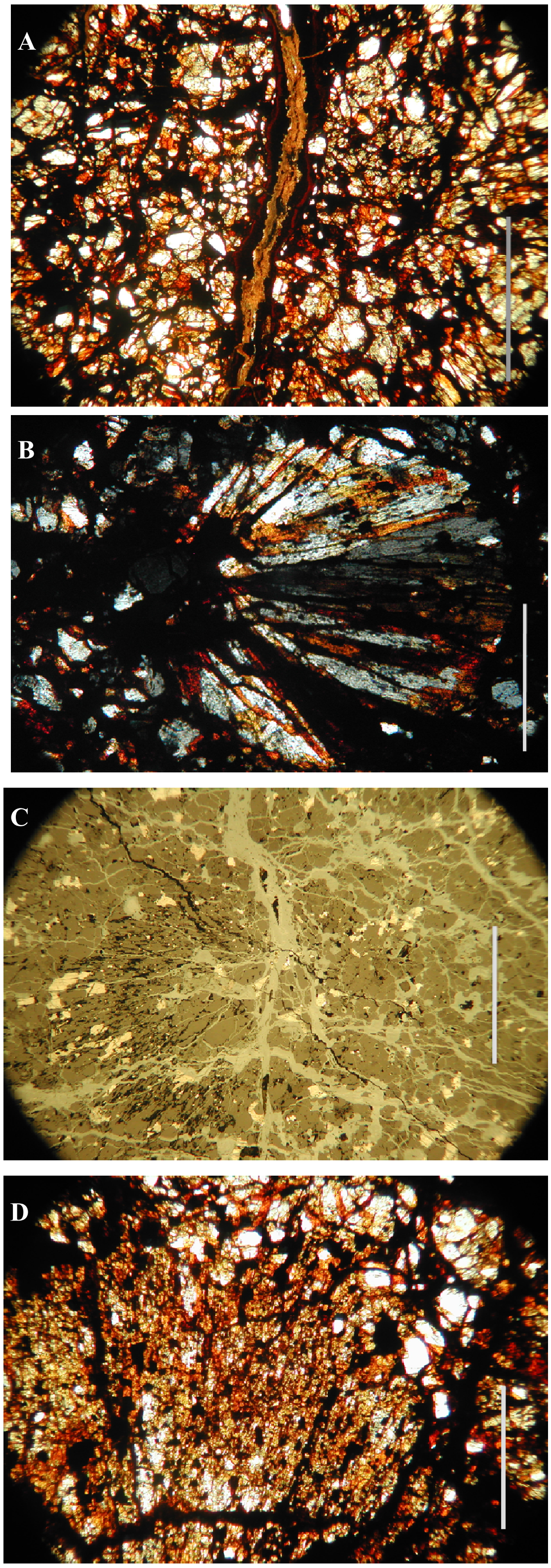


Fig. 8. Photographs of NWA-UKW A) altered material in a vein and surrounding grains in plane polarized light with the scale bar on the right being 1 mm. B) a possible chondrule in crossed polarized light , the scale bar on the right is 1 mm. C) a portion of the NWA-UKW in reflected light with the scale bar on the right being 0.5 mm long. D) a possible chondrule fragment in plane polarized light the scale bar on the right is 0.5 mm.

which point it shows a dark purple brown colour. The pyroxene when subjected to chemical analysis show rather low values of FeO and CaO; (figure 9 and 10 B). Although not all silicates measured were pure enstatite, they were still in the enstatite range.

In most of the light coloured grains there are impurities in yellow, brown and red. They do not appear to be a different mineral, but rather pyroxenes that have been contaminated or discoloured. The extinction angle for these grains are the same as for the pyroxene grains above. The reddish discolouration of the minerals has a tendency to occur in contact with matrix, not at boundaries between two grains.

Almost all the sulphides contain Ti and Cr in trace amounts and all of the metal grains contain Si in small amounts. The mean diameter of the metal grains is 0.08 mm.

Plagioclase occurs as individual grains. Phosphides were also found during chemical analysis as well as daubreelite ($FeCr_2S_4$).

The dark matrix is opaque. In some veins, the material varies from black to red to yellowish beige, and in some areas a wave pattern can be seen with the highest magnification (x500). There seem to be no specific extinction angle, the coloured matrix only becomes darker. The bright red mineral making up part of the vein crossing through the thin section (figure 8A) may be iddingsite, which is a göthite dominated fine-grained product of weathered olivine. Another indication of weathering is the many veins filled with altered material running through the thin section in all directions (figure 8C).

7.3 05-1A Dhofar

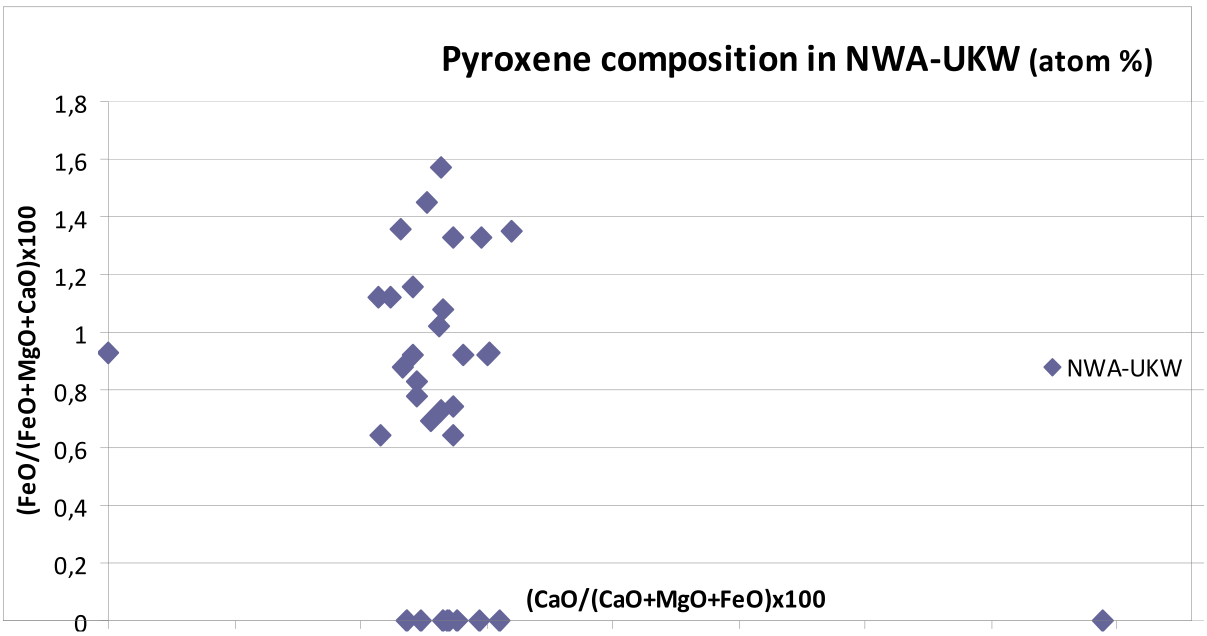
05-1A is a heavily weathered find from the Dhofar desert region in Oman (figure 11A). The sample contains many chondrules, readily defined (figure 11B and D), although some have blurred or indefinable rims and were not measured (11C). Both the metal content and the amount of sulphides are low.

The dominating chondrule textures are porphyritic, POP (12) and PO (6), although there are some chondrules that are not designated to any textural group but to an unknown group. The chondrules are easily recognized when examining the sample megascopically, but under the microscope they are often difficult to define; the rims are not easily detected and therefore measurements were not possible to make on every chondrule. There are a few beautiful RP chondrules (figure 11B), which contain small metal inclusions and in other chondrules the matrix appeared to be composed of pyroxene. In barred chondrules the bars were not only composed of olivine but also of pyroxene. Some chondrules and aggregates of mineral grains appear to be extremely fine-grained and the individual grains can not be distinguished even with the highest magnification (x50 (and x10) = x500). The chondrules were measured and the mean diameter of the chondrules is 0.71 mm in transmitted light. The chondrule diameters were also measured in reflective light, the mean diameter was here 0.59 mm, which is a little smaller than the diameters above.

Point counting gave 62 % silicates, 24% veins with unknown grey grains and altered material, metal and sulphide constitute <1 % together. A total of 14 % were unknown material.

There are two silicate phases in this chondrite; olivine and pyroxene. The mean composition of the olivine is $Fa_{18\pm2}$ and the homogeneity of the olivine grains is 3.2 %. Several of the larger olivine grains have straight extinction and what appears to be altered streaks. In the olivine, no undulose extinction

Fig. 9. The figure show the composition of the pyroxene grains in NWA-UKW. It also illustrates the narrow range of composition since only two values really stands out from the grouping of the others.



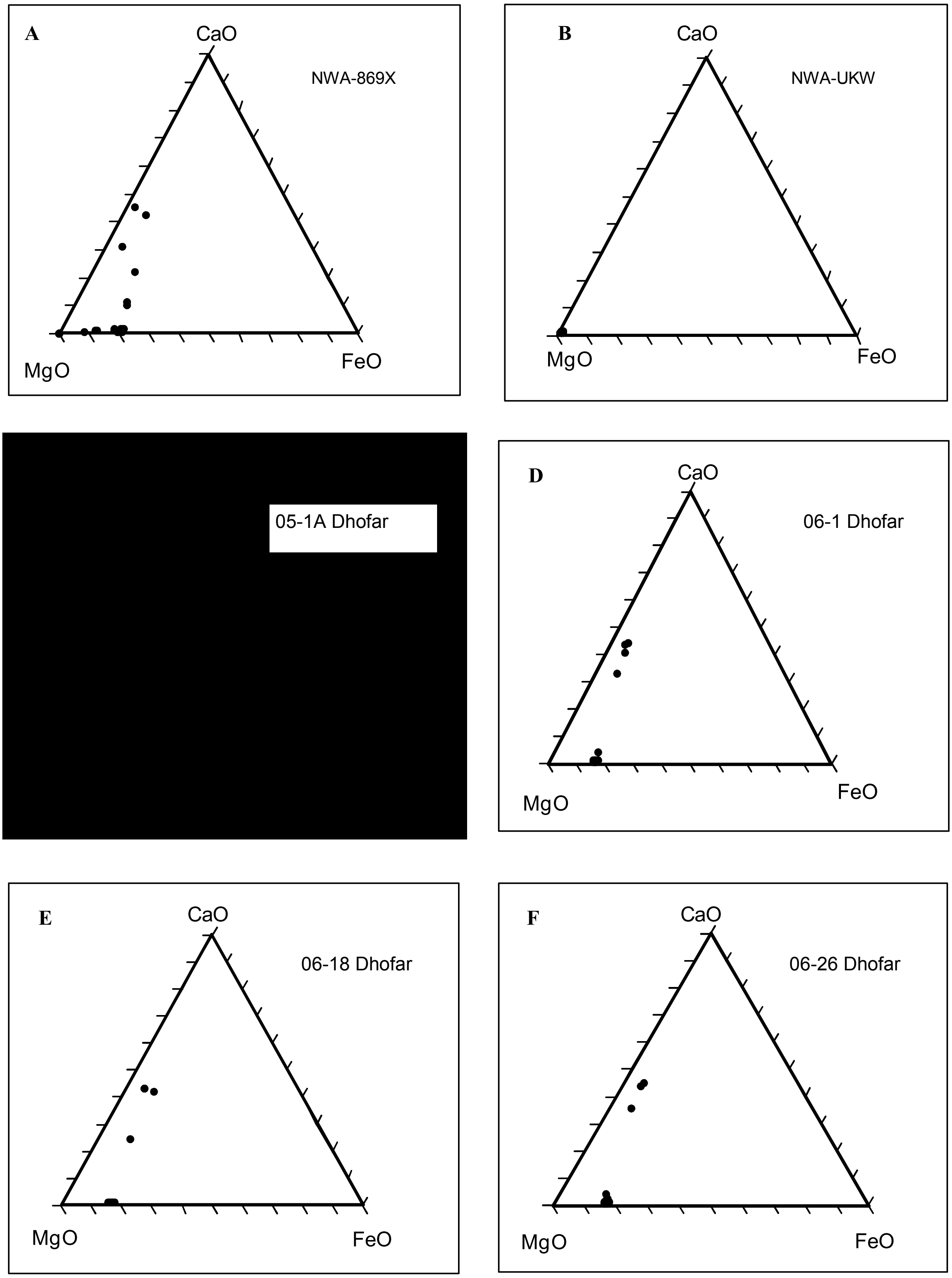


Fig. 10. The figure shows the pyroxene composition of each chondrite in a triangular plot system. The plots are calculated on atom %. It is clear that there are differences between the NWA-869X, NWA-UKW and the Dhofar meteorites. A) NWA-869X, B) NWA-UKW, C) 05-1A Dhofar, D) 06-1 Dhofar, E) 06-18 Dhofar, F) 06-26 Dhofar.

was observed.

The mean composition of low-Ca pyroxenes is $Fs_{17\pm2}$. There is however one pyroxene grain found that is very CaO-rich and FeO-poor (figure 10C). The grain is situated within a chondrule.

Many grains are difficult to identify due to the high degree of alteration, which has caused discoloration in red and yellow that sometimes obliterates the interference colour completely. A few grains are zoned, some with a dark core of pyroxene and lighter edges of olivine. In this one area it appears as if the olivine has grown out from the pyroxene grains and met in between these and not only attached themselves to the surface of the pyroxene.

The metal grains were measured both in the shortest and the longest dimension, the mean diameter is 0.021 mm. The grains are few and extremely small, the latter making them very difficult to measure. For classification purposes they are thus of no use. Most of the metal grains, or rather oxides, seem to be concentrated along the edges of the meteorite which also defines the edge of the thin section except where they are enclosed within chondrules. The sulphide grains (probably troilite) are larger than and far outnumber the metal grains, although some are comparable of size. In reflected light the sulphides show a weak anisotropy if any at all. Others contain small amounts of nickel but are otherwise pure iron sulphides. The metal grains on the other hand are isotropic although some appear to be less black in some positions, the chemical analysis show that they are free of impurities only iron and nickel in different amounts.

The matrix dominates and is difficult to distinguish from the fine-grained altered material showing opacity. Cracks, or veins, with altered material occur throughout the whole thin section. The matrix is black and opaque and not isotropic.

7.4 06-1 Dhofar

06-1 is also a find from the Dhofar desert and as the previous chondrite it has experienced severe weathering. As can be seen in figure 12A this meteorite ap-

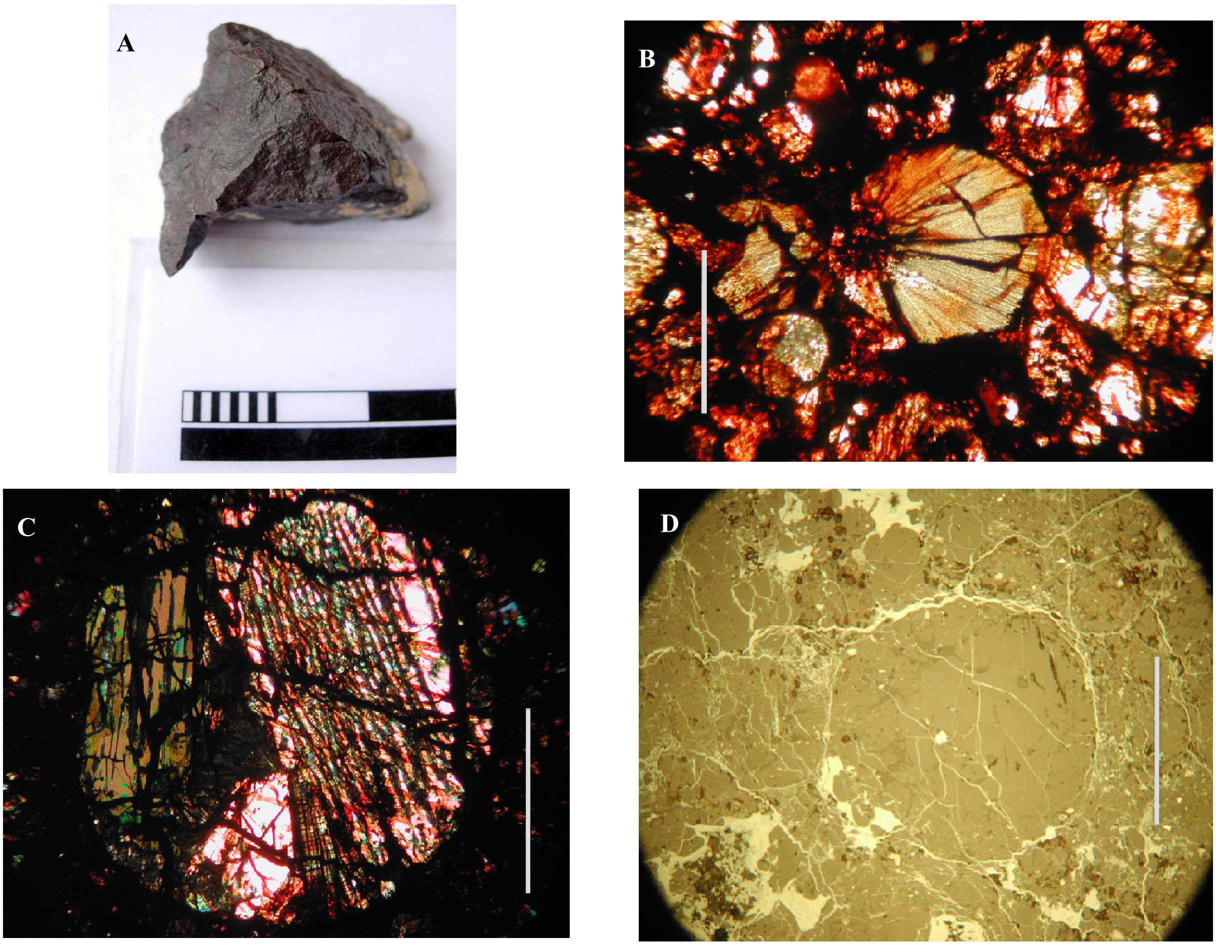


Fig. 11. Photographs of 05-1A Dhofar, A) the meteorite itself as it was found, large scale bottom is in cm. The yellow part of the chondrite (right) is the part that has been buried in the sand the other part has been subjected to the desert climate. Photograph by Erik Jonsson B) a radial pyroxene chondrule. The photograph is taken in plane polarized light. The scale bar on the left is 0.5 mm long. C) a chondrule showing the complicated texture making the chondrule difficult to classify, scale bar on the right is 1 mm long. D) a large chondrule with veins appearing to run around the chondrule as opposed to running through it. The scale bar on the right is 0.5 mm long.

pears black which may be the thin skin created by ablation during ascent to Earth. The thin section contains mainly olivine, pyroxene, metal and sulphide minerals.

The thin section in itself is very dark; it is black in the centre with a red-brown colour at the edges, which could be due to weathering.

The chondrules were measured in both thin sections, the mean diameter of chondrules altogether in transmitted light is 0.54 mm. The chondrule diameter was also measured in reflected light which gave a mean diameter of 0.49 mm which is comparable to the diameter measured in transmitted light in the same thin section. Some chondrules were difficult to classify (figure 12B) others were not (figure 12C and D)

Point counting gave 69 % silicates, 10% sulphide and 0% metal. Metal is present as mentioned above, but during the point counting the metal grains were missed, altered material constitutes 19 %.

Many of the silicate grains have acquired a reddish, yellowish colour (figure 12D). In some grains this colour is very strong and obscures the interference colour effectively and appear much lower than they actually are.

The olivine grains have a straight extinction angle. Only a few olivine grains appear to show what might be undulose extinction. The homogeneity of the olivine grains is 2.4 % and the mean composition is $Fa_{18\pm2}$.

Some pyroxene extinguishes at different angles, but it is not undulose, it appears rather to be different grains. A mineral that appears to be plagioclase is observed, but it could be pyroxene with polysynthetic twinning. The mean composition of the low-Ca pyroxenes is $Fs_{16\pm2}$ (figure 10D). Most of the pyroxene values are within a small range of composition, but there are a few that have greater CaO content, these few grains are inclusions within olivine grains or form the edge of a zoned pyroxene.

Some of the sulphide grains are isotropic but others have a strong anisotropy with a dark red brown to black colouration in reflected light. They are pure iron sulphides. There are also "spotty" sulphides which through EDS analysis were proven to be iron sulphide and iron oxide intergrowths. There is also small amounts of nickel within these grains.

The amount of metal is low, much lower than the

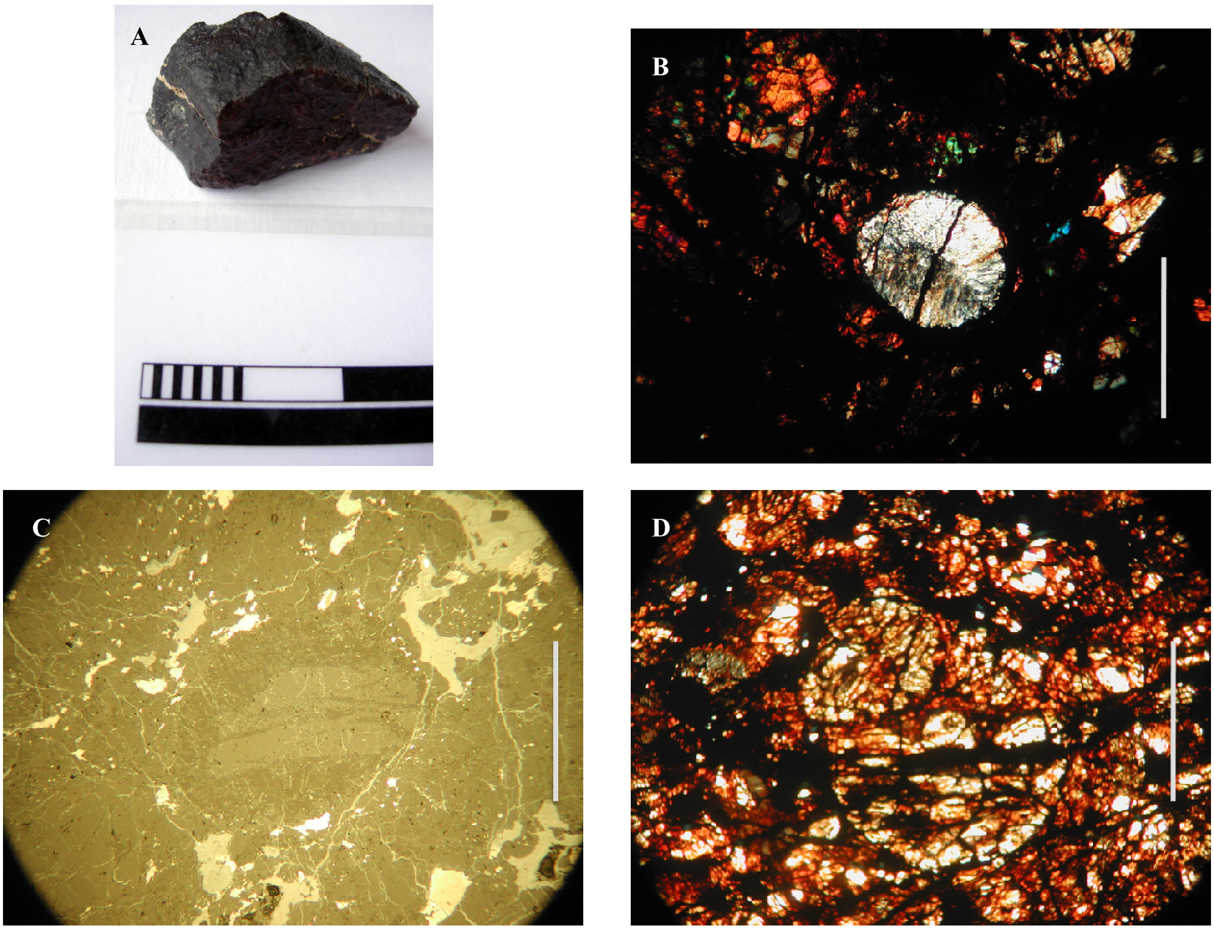


Fig. 12. Photographs of 06-1 Dhofar, A) shows the chondrite as a whole, it appears black with lighter veins see left hand side of the chondrite. Large scale in cm. Photograph by Erik Jonsson. B) shows a pyroxene chondrule not further classified in crossed polarized light, scale bar on the right is 0.5 mm long. C) shows a chondrule with rather large bars at the centre in reflected light, scale bar on the right is 0.5 mm. D) shows two chondrules of which one is severely deformed, bottom centre, plane polarized light, scale bar on the right is 0.5 mm long.

amount of sulphides and most of the metal or rather oxides are distributed around the edges of the meteorite and >95% are affected by the weathering. In reflected light the metal grains show a weak anisotropy from dark steel grey to black. The metal grains have a mean diameter of 0.06 mm and some metal grains have high Ni contents around 12 wt% while others have around 4 wt%.

Chromite is fairly common, and some pyroxenes contain trace amounts of Na, Al, Ca and Mn. The altered material is for the most part oxygen rich compounds, some with a high level of iron others with calcium. Other minerals found through chemical analysis is anhydrite ($CaSO_4$) and chlorapatite ($Ca_5(PO_4)_3Cl$). Plagioclase occurs as interstitial material in chondrules.

7.5 06-18 Dhofar

This meteorite is a find with the main minerals being olivine and pyroxene, metal and sulphide minerals. It is a heavily weathered stony meteorite (figure 13A) with many chondrules and what is interpreted to be fragments of chondrules. The chondrules are embedded in an opaque matrix, probably glass. Individual grains that seem to be “dirty”; the surfaces of some of these grains have a grainy appearance. Small cracks go through both chondrules and individual grains.

The sample is dark but seems redder around the edges which can be caused by weathering. The larger veins in the sample appears to have a main direction although the smaller ones go in all directions.

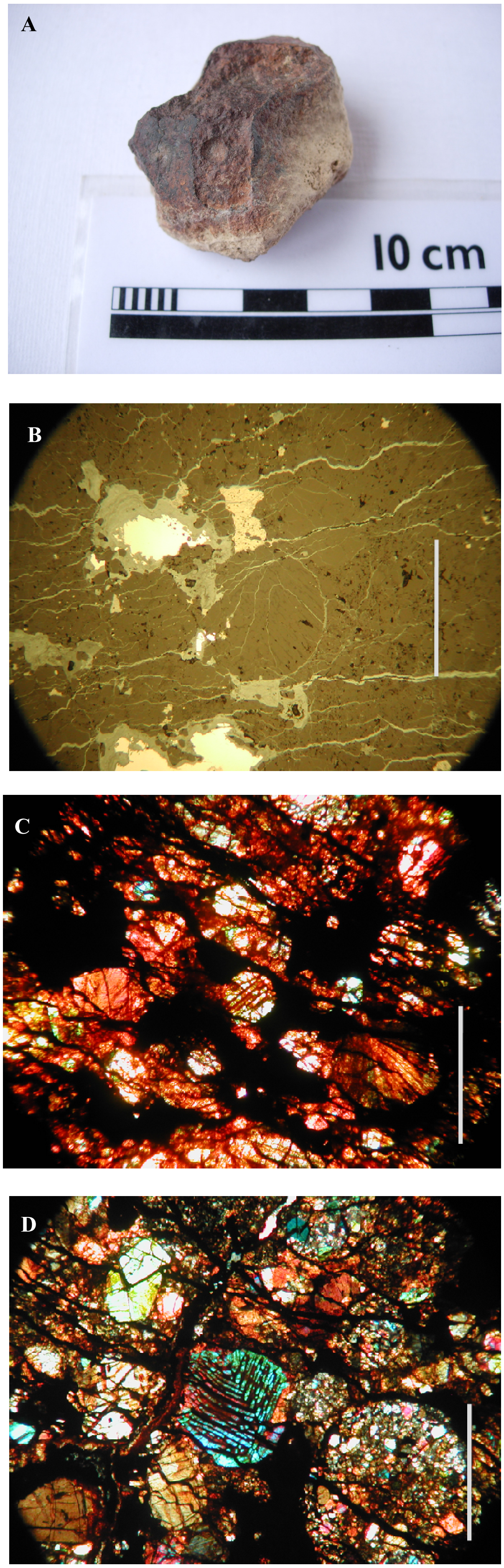
Point counting gave 74 % silicates, 1 % metal, 5 % sulphide and 13 % altered material. The rest, 7 %, were unknown material.

Chondrule measurements gave a mean diameter of the chondrules of 0.61 mm. The mean diameter of the chondrules in reflected light is 0.78 mm which is much larger than the measurements made in transmitted light. The main types of chondrules found are PO and RP chondrules, other chondrules such as BO, PP and POP also occurs in the meteorite (figure 13B, C and D).

In barred chondrules the bars are not only composed of olivine but also of pyroxene. The bars sometimes appear to have grown outwards changing composition on the way out.

The olivine grains display all the colours of the rainbow. Some of the olivine grains are >0.5 mm and appear as individual grains. The homogeneity of the olivine grains is 1.7 % and the mean composition is $Fa_{18\pm2}$.

Most of the pyroxene grains have a somewhat elongated appearance while the olivine grains are more rounded almost spherical. It is common with polysynthetic twinning in the pyroxene. Most of the pyroxene compositions are narrow in range although a few have higher CaO content and lower FeO content than the others (figure 10E). One of these values



is from a lighter area within a pyroxene grain situated inside a chondrule. The chondrule also contained light coloured inclusions of iron sulphide. The other high CaO value is from a small grain, light in colour, within the plagioclase matrix. These grains are so small that they were not discovered in light microscopy. It is also worth mentioning that large pyroxene grains seem to be “spotty”, small patches that look lighter in colour; these patches have higher CaO values and usually lower iron amounts than the surrounding grain. The mean composition of the low-Ca pyroxenes is $Fs_{16\pm2}$.

The margin of almost all metal is affected by the weathering. The metal grains have a mean diameter of 0.14 mm and are evenly distributed throughout the thin section, the majority is closer to the edges than the centre. The grains are not uniform in size and are irregular in shape, most of them seem surrounded by altered material. Many have silicate inclusions and a few occur together with sulphide minerals (possibly troilite). The metal appears white in reflective light and has a very weak anisotropy where the colouration goes from dark grey to black; a few grains appear to be isotropic.

The sulphide grains are not only present as single grains but also as aggregates. Some differ in their appearance under the microscope with light coloured and dark coloured parts. Some are intergrowths of iron sulphide and iron oxide which gives a “spotty” appearance in reflected light. Sulphide mineral grains occur more frequently at chondrule rims than metal grains do. Also when both are present in chondrule rims the amount of sulphide grains is usually higher than the amount of metal grains.

Calcium-phosphates are fairly common, including chlorapatite and are comparable to the silicates in size, at most a few millimetres. Chromite occurs throughout the sample and the interstitial material in chondrules is plagioclase.

7.6 06-26 Dhofar

06-26 Dhofar is a find (figure 14A) with abundant chondrules although not as many as in 06-18 Dhofar. Major mineral phases are olivine and pyroxene, other occurring phases are metal and sulphides, there are also a few metal-sulphide aggregates, and there is at least one compound chondrule (figure 14C).

Chondrule measurements in transmitted light give a mean diameter of 0.66 mm. The mean diameter of chondrules in the reflected light is 0.62 mm which is consistent with the measurements made in transmitted light. There are essentially two different kinds of barred olivine, one with a thin rim and another with a thick rim (figure 14B). The bars have the same interference colour as the rim and the same extinction angle. However, some chondrules appear to be of mixed origin as one half is porphyritic and the other half is barred (figure 14D). In some chondrules tiny grains of sulphide was discovered.

Point counting gave 72 % silicates, 8 % sulphides, 3 % metal 14% veins and altered material. A total of 3 % were unknown material.

No undulose extinction can be seen in any grains. In this sample no pyroxene grains show twinning and the mean composition of the low CaO pyroxene grains is $Fs_{16\pm2}$. The high CaO values are from a barred chondrule where the bars are pyroxene not olivine. The CaO content in the bars are higher than in the single pyroxene grains (figure 10F). Between the pyroxene bars is plagioclase with an oligoclase composition.

The homogeneity of the olivine grains is 4.4 % and the mean composition is $Fa_{18\pm2.}$ The olivine grains occur both as single grains and as chondrules.

The metal grains were measured in their shortest and longest dimension giving a mean diameter of 0.15 mm. It is not uncommon to observe small inclusions in the sulphide mineral grains (possibly troilite) in this thin section. The metal was distributed throughout the whole thin section and range in size from 0.04 mm to 0.48 mm in the shortest dimension, they were irregular in shape and some formed aggregates with sulphides. In some metal grains, silicates are present, these are usually more rounded in shape than the silicate grains as a whole. No sulphide grains seem affected by weathering, although most of the metal appear to be so. The metal grains are larger and more numerous than in previously described Dhofar meteorites in this study. In reflected light, the metal shows a weak anisotropy very dark grey to black. It is noticeable because the surrounding altered material is isotropic. The sulphides appear to form aggregates with iron oxides and therefore show a patchy appearance in reflected light; grains with a strong anisotropy is interpreted to be troilite. It also appears as if the metallic minerals are equally affected by weathering throughout the whole sample. Aggregates of metallic minerals and sulphides are rather common, but they also occur as single grains.

The altered material is for the most part high in oxygen and iron, the few chromite grains analyzed contained impurities of Mg, Al and Ti in very small amounts. Chlorapatite is quite common and chemi-

Fig. 13. Photographs of 06-18 Dhofar, A) the chondrite as a whole, the bottom half has been buried while the upper half has been subjected to weather and wind. The reddish discolouration is due to oxidation. Large scale at bottom in cm. Photograph by Erik Jonsson. B) a chondrule in the centre of the photograph, which also shows how altered material surrounds metal grains, above the chondrule. The photograph is taken in reflected light, scale bar on the right is 0.5 mm long. C) a barred olivine chondrule in the centre with a rather thick rim, a good example of how small chondrules can be and a contrast to the bright colours of the BO chondrule in the photograph below it, scale bar on the right is 0.5 mm long. D) a barred olivine chondrule displaying a V-shaped pattern of olivine bars. The photograph is taken in crossed polarized light, scale bar on the right is 0.5 mm long.

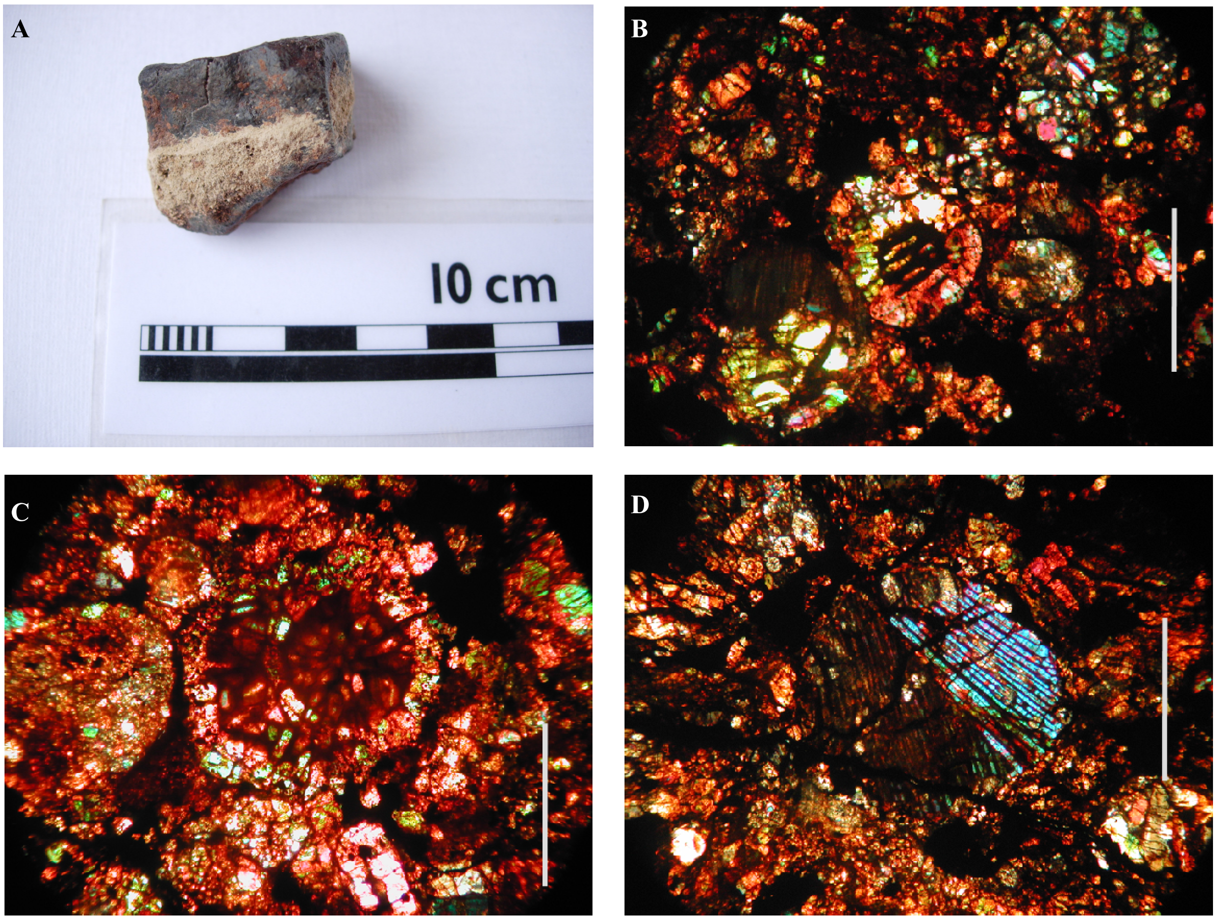


Fig. 14. Photographs of 06-26 Dhofar, A) shows the bottom half that has been buried in the sand and the upper half that has been subjected to weather and wind. The red oxidized patches are visible to the naked eye, large scale in cm. Photograph by Erik Jonsson. B) a BO chondrule with a thick rim, the bars themselves are very thin and few in number, photograph is taken in crossed polarized light, scale bar on the right is 0.5 mm long. C) a compound chondrule in crossed polarized light, scale bar on the right is 0.5 mm long. D) a BO chondrule where the bars on the left side of the chondrule are almost at extinction angle while the right half is in the brightest position. The photograph is taken in crossed polarized light, scale bar on the right is 0.5 mm long.

cal analysis showed the presence of "merrilite" ($Ca_{19}Mg_2(PO_4)_{14}$). Plagioclase occurs in addition to interstitial material in barred chondrules also as individual grains.

8 Discussion

8.1 Analytical precision

The meteorites have been analyzed both with optical and electron microscopy, and a question of importance is the accuracy of the results obtained.

When using EDS the resulting wt% should be between 98 and 102, some of the obtained results were higher or much lower than this, even though the dead time for the standardization cobalt was good ~35 %. The metal usually varied between 70 and 100 wt% while the results for the silicates usually stayed around 100 wt%. Sometimes the results for the silicate minerals soared to 108 wt%. The stoichiometry was perfect for the pyroxenes and the atomic % should not be affected by these high values. The material between the grains, the matrix, had varying wt%, most of it had good results especially the mesostasis in the chondrules.

The altered material which is present in all samples, as a rule had very poor wt% result; this may be caused by a high amount of OH since hydrogen, cannot be detected by the EDS detector. It might also be affected if it contains carbon since the sample was coated with carbon this element could not be analyzed.

The high silicate wt% were attempted to be lowered with different adjustments, but these had no effect at all. Standard cobalt measurements was done repeatedly to test if the results changed. However, in most cases the instrument appeared to be stable. Since the stoichiometry was next to perfect, no more attempts were made in adjusting the instrument. The occasionally poor total sum indicate that the results are not wholly reliable but the relationship between the different elements, the atomic%, should not change even if wt% were lowered for the silicates. It is still an unsatisfying result.

In the optical microscopy results the human error may be considerable, therefore the conclusions have not been based on these results alone, but rather on the chemical analyses with the optical results supporting the chemical results. In general the accuracy of the SEM is ±2 %, this is not sufficient to explain the different atomic% for individual grains with the same general composition, but it also shows that even with these atomic% the NWA-869X and the Dhofar meteorites would still not be considered to belong to the same group.

In determining the minerals based on the elements present and the atomic% of these it has been show that even with the same settings some have perfect elemental relationships others do not, and these have caused some problems. Some minerals have an atomic% composition intermediate between olivine and pyroxene, and it is uncertain whether these should be considered to be olivine although the Mg, Fe content is not twice the amount of Si, or should be considered as a pyroxene with too much Mg and Fe. Some of the analyzed phosphates are interpreted as chlorapatite ($Ca_5(PO_4)_3Cl$). During optical observations and chemical analyses no shock minerals have been detected.

8.2 NWA-869X and NWA-UKW

Most of the indicative factors suggests NWA-869X is an L chondrite, although two factors, the pyroxene composition and the mean size of the metal grains, contradict this. When measuring the size of the chondrules and the metal grains there is always a degree of uncertainty and the human factor can not be avoided. But the error should be less than 0.4 mm per chondrule, and even less in the metal sizes ~0.04 mm since these have sharper boundaries. There is also a difference in the chondrule sizes measured in transmitted and reflected light. This might be because the boundaries or rims of the chondrule are easier to distinguish in reflected light than in transmitted. The impact this has on the mean size of the chondrules are not significant as to assign the chondrite to a different group.

The mean value of the metal grains in the NWA-869X chondrite, 0.2 mm, is consistent with the mean value of H chondrites. The mean value of the metal grains in the NWA-UKW is 0.08 mm which is slightly indicative of an EL chondrite. Since no chondrules were observed in this sample the metal grain size is of no aid in determining the subclass. Another significant factor is the alteration of the metal grains that in NWA-UKW is rather severe as to the metal in NWA-869X which is not affected at all. This leads to the conclusion that the size of the metal grains in weathered meteorites, be it an OC or E chondrite, are not good indicators in classifying chondrites.

No olivine grains are observed in the NWA-UKW chondrite and it is therefore assigned to the E chondrite group, but it does not mean that there are no olivine grains in other parts of the meteorite, although the pyroxene grains far outnumber olivine. All the pyroxenes are very low in both FeO and CaO which suggest an enstatite chondrite. The low values of CaO imply that it has low petrographic type, but the presence of albitic plagioclase suggests that the chondrite is of petrographic type 4-6. Type 6 must be excluded because of the relatively low CaO values, petrographic type 6 should have rather high values, and 5 is excluded because the matrix is not recrystallized.

The NWA-UKW chondrite is not related to the NWA 869X even though they were found in the same area in north-western Africa and thought to be from the same fall. NWA 869X is a breccia, which the different "areas" of the sample indicates, light in colour compared to NWA-UKW, it is less weathered and has more grains that still are of original colour. The composition of the pyroxene grains differs greatly as does the matrix. In the NWA-869X the matrix is lighter in colour suggesting low weathering, in transmitted light the matrix is opaque. The NWA-UKW has a dark and complete opaque matrix in transmitted light. The NWA-UKW also has a bright red mineral lining the largest vein in the thin section, whereas this texture has not been observed in the sample of NWA-869X. In the NWA-UKW with the highest magnification, streaks of smeared material were observed in the veins, which was barely noticeable in the SEM. In the NWA-UKW there are veins going in all directions spreading like a fine web throughout the sample, chemical analysis on these shows that they are high in Fe and Ca, which suggests weathering and not shock as the forming mechanism. In general for both thin sections there were no signs of shock detected, however these signs are sometimes difficult to identify, undulose extinction is of course easier observed than mosaic pattern, but neither were observed.

NWA-UKW is more difficult to classify because of the lack of olivine, but no re-crystallization of the matrix indicates petrographic type below 5. The matrix is opaque which suggest petrographic type 3, but not enough to draw any certain conclusions. The absence of chondrules further inhibit classification.

On the other hand, based on mineralogy no niningerite was found in the NWA-UKW which excludes EH4 and EH5 and no ferroan alabandite was found either, which also excludes EL6. Left are EH3, EH6 and EL3-5. Since the matrix is opaque the petrographic type should be above 3, and since no recrystallization of the matrix was observed it should also be below 5, hence the remaining possibilities for classification of the chondrite are EH3, EL3-4.

NWA-869X has a mean olivine composition that is higher in fayalite than the mean olivine composition in the chondrites found in the Dhofar desert region in Oman of this study (fig. 15) and the olivine is more homogenous in composition. The pyroxene composition is scattered and not homogenous (figure 17). It is also clear that it differs from the other chon-

Table 8. The table show the differences and similarities between the meteorites in this study.

	NWA-869X	NWA-UKW	05-1A Dhofar	06-1 Dhofar	06-18 Dhofar	06-26 Dhofar
Mean olivine composition (±2)	Fa_{23}		Fa_{18}	Fa_{18}	Fa_{18}	Fa_{18}
Olivine homogeneity	0.08 %		3.2 %	2.4 %	1.7 %	4.4 %
Mean pyroxene composition (±2)	Fs_{17}	Fs_{1}	Fs_{17}	Fs_{16}	Fs_{16}	Fs_{16}
Mean chondrule diameter, transmitted light (±0.4)	0.70 mm		0.71 mm	0.54 mm	0.61 mm	0.66 mm
Mean metal grain diameter (±0.04)	0.2 mm	0.08 mm	0.021 mm	0.06 mm	0.136 mm	0.154 mm

drites in the olivine /pyroxene comparison (figure 18) where the NWA-869X yet again has more scattered values than the Dhofar meteorites, this may be an indication of the chondrite being a breccia.

The homogeneity of the olivine grains suggests a petrographic type 5 and a matrix that is not opaque indicates a petrographic type above 3, the matrix is however not re-crystallized which suggests it being of petrographic type 4.

8.2.1 NWA-869X summary

Based on the optical results the NWA-869X appears to be an OC intermediate between an L and H chondrite, this is based on the large amount of chondrules. In reflected light a few, <5 % metal grains appears to be altered or affected by weathering, this gives the thin section the designation W1 for the weathering grade.

The olivine results from the SEM analysis suggests that it is an L chondrite, but are contradicted by the low Ca pyroxene results obtained from SEM. The scattered values of pyroxene (figure 10A) also suggests it is a breccia, and the olivine/pyroxene comparison clearly sets it apart from the Dhofar meteorites. The petrographic type on the other hand appears to be intermediate between 4 and 5. The matrix is not re-crystallized which suggests petrographic type 4 but the homogeneity of the olivine grains suggests petrographic type 5.

Figure 16 A illustrates a rather small olivine grain with zoning and also shows how little veining there is in this chondrite compared to the others in this study.

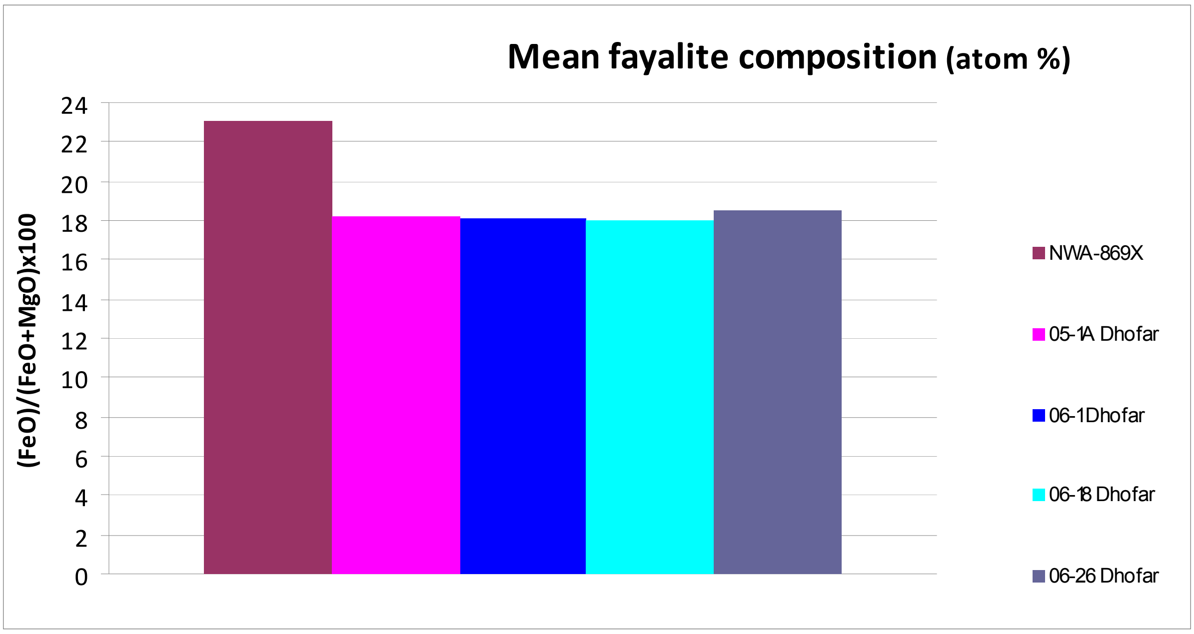
The barred and radial chondrules also suggest that the chondrules were subjected to rapid cooling.

8.2.2 NWA-UKW summary

Based on the description under section 7.2 above this meteorite is classified as an E chondrite mainly because of the lack of olivine and the composition of the pyroxene grains. It is also obvious that heavy weathering has occurred and based on the appearance in reflected light it is either a W4 or W5, more probable a W4 since no alteration of silicates have been observed.

EH3 and EL3-4 are the possible classes. The metal contained Si in small amounts which confirms it being an Enstatite chondrite. Petrographic type appear to be 4 since no re-crystallization of matrix has been observed; on the other hand the matrix is opaque which suggest petrographic type 3.

Fig. 15. The figure illustrates the difference in olivine composition between the NWA-869X chondrite and the Dhofar chondrites. As can be seen the mean fayalite composition of the NWA-869X chondrite is much higher than that of the Dhofar chondrites which are more uniform in composition.



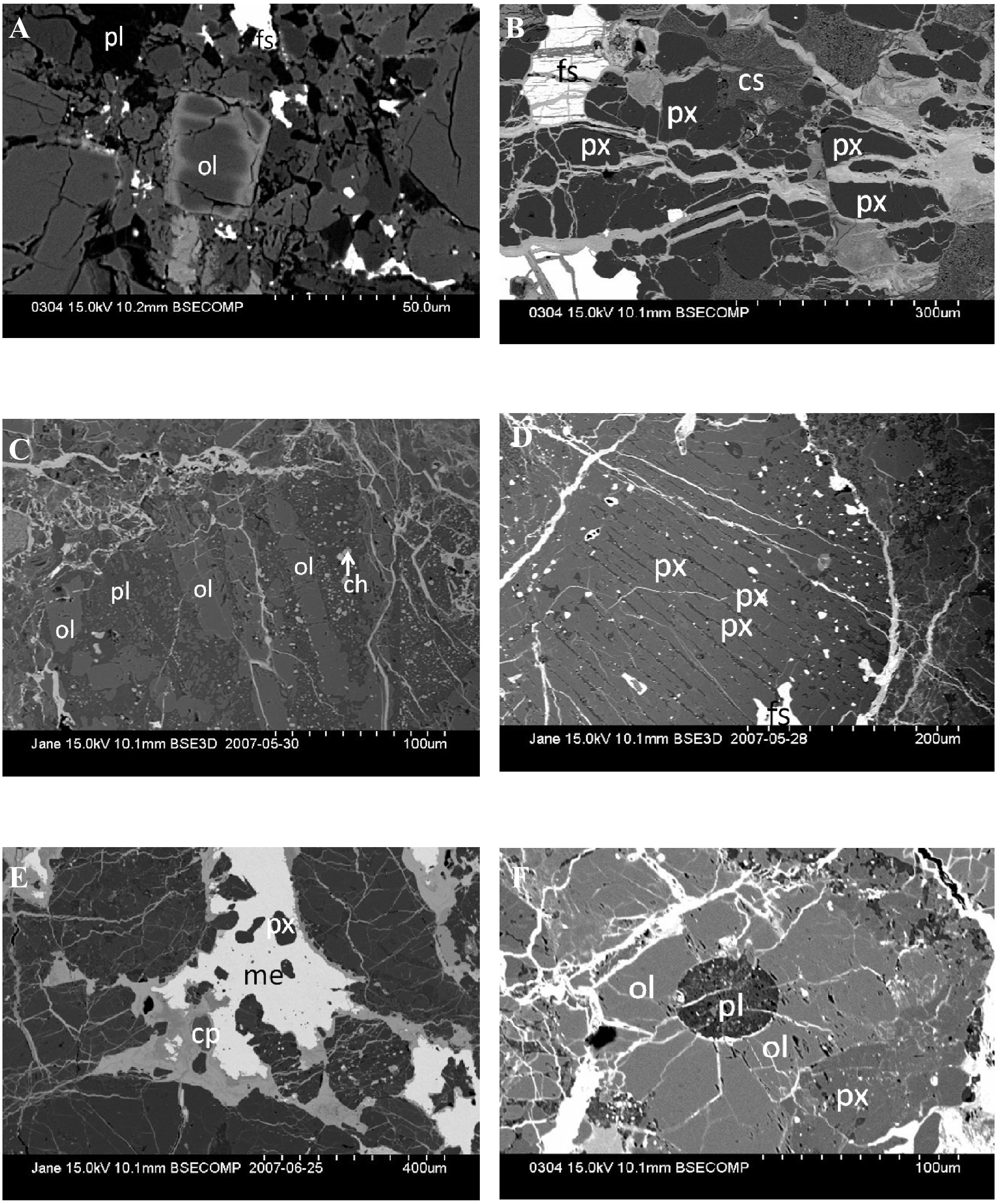


Fig. 16. Images from SEM analysis, ol = olivine, px = pyroxene, pl = plagioclase, ch = chromite, fs = iron sulphide, cs = CaSO, cp = calcium phosphate, me = metal

A) NWA-869X, a zoned olivine, with a more iron rich edge. B) NWA-UKW, a photograph showing the complexity of this chondrite. C) 05-1A Dhofar, bars in a chondrule with plagioclase as the interstitial material. D) 06-1 Dhofar, bars of pyroxene not olivine in a barred chondrule. E) 06-18 Dhofar, shows that even metal grains can hold inclusions. F) 06-26 Dhofar, shows a rounded plagioclase grain in an olivine grain next to a pyroxene grain.

Figure 16 B show a portion of the chondrite illustrating that no grains escape veining.

8.3 The Dhofar meteorites

All the Dhofar meteorites have rather sharp edges which suggests that the original meteorite broke apart close to Earth, otherwise the ablation would have smoothed the edges.

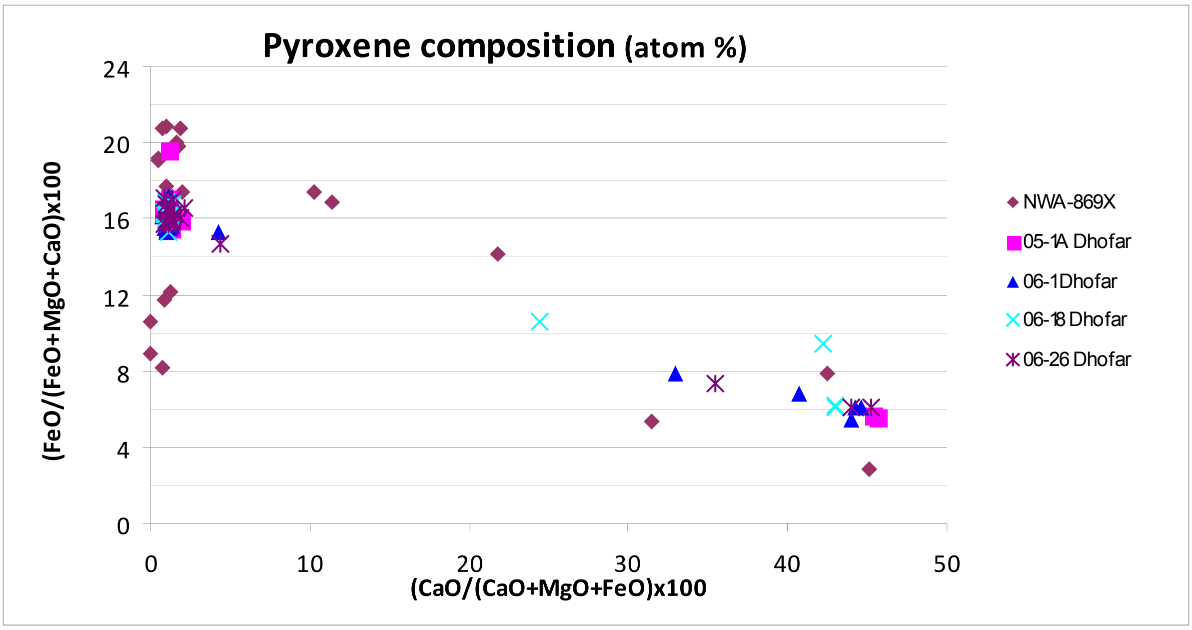
In 05-1A Dhofar all the metal is located around the edges, with the only exception being metal inclusions in a chondrule. The chondrule diameter is greater and the metal grain size is smaller than they ought to be in relation to the chemical composition of the constituent minerals. This incompatibility can be explained by secondary processes such as weathering.

Weathering has altered the original metal grains and is responsible for the decrease in size. The chondrules are also affected by coarsening of the groundmass which happens when the petrographic type changes to a higher type. When the groundmass coarsens it intergrowths with the chondrules, obliterating the smaller chondrules and the mean diameter become to large. If this is the case the weathering effect would reduce both the possibility of recognising small chondrules as well as their outlines. This may be the case for the other Dhofar chondrites as well. No alteration of silicates has been observed in the Dhofar meteorites unless the discoloration is taken into account. This implies that although all metal were more or less altered the weathering has not influenced the silicates to any significant degree and the weathering grade should be W3. Figure 16 C illustrates a BO chondrule without a rim and shows the difficulty of measuring chondrules.

In 06-1 Dhofar most of the metal/oxide is found around the edges just like 05-1A Dhofar although in the former the amount of metal is much lower than the amount of sulphide, possibly troilite. The difference is much greater than in the other Dhofar chondrites which may be the result of weathering since estimation gave that >95 % of the metal but no silicate was affected by the weathering. The 06-1 Dhofar chondrite differs from the other Dhofar chondrites in the amount of matrix, which is more abundant in this chondrite, and in size of the individual grains, which is smaller. The main difference between the Dhofar chondrites is the weathering grade. This may be due to the different locations in which they were found, since even in deserts the humidity in the ground may differ between locations and hence give rise to different degrees of weathering. In the POP chondrules of 06-1 Dhofar the olivine amount is lower and the grains also smaller than the pyroxene. In figure 16 D a barred chondrule is illustrated showing that the bars are actually pyroxene not olivine. This is more common that initially expected.

06-18 Dhofar contains both un-broken chondrules and fragments thereof; this has not been observed in the other Dhofar chondrites. Some chondrules are smaller than individual grains of pyroxene and in some cases smaller than the olivine grains. The vast majority of the metal grains appear to be altered, whereas the sulphide minerals do not show any evidence of alteration. This implies that the weathering is rather high; W3 is the most appropriate since the sulphides seem unaffected. This is in contrast to the other Dhofar chondrites that show a higher degree of weathering. In figure 16 E the metal depicted contain

Fig. 17. The figure shows a comparison between the FeO and CaO atomic % of the pyroxene grains in all the chondrites except NWA-UKW, which is due to its low values. The pyroxene values are scattered for all the chondrites, but the majority of the values are low in their CaO amount. See figure 10 for the pyroxene triangular plots of all the chondrites and figure 9 for the pyroxene values of NWA-UKW.



pyroxene inclusions, this is not uncommon.

Some pyroxene grains show a sweeping extinction, going from one side of the grain to the other. These “grains” are not thought to have undulose extinction, but are rather thought to be aggregates of tiny grains of the same mineral.

In 06-26 Dhofar the grains are closely packed with the chondrules and hence a smaller amount of matrix. A fragment of a barred olivine chondrule which might be the result of shock, but no undulose extinction has been observed. The photograph in figure 16 F shows a plagioclase inclusion in an olivine grain. It is more common with olivine and pyroxene intergrowths looking like this than intergrowths with plagioclase.

In determining the chondrite class for the chondrites several criteria were investigated, the problem with some of them is that they are conflicting. Optical analyses placed all the Dhofar chondrites in the L group, whereas the chemical analyses placed them in the H group. In this case the chemical analyses are considered to be more reliable than the optical due to human error. Optical microscopy has other benefits, the distribution of metal and sulphide is easily observed as well as the distribution of chondrules.

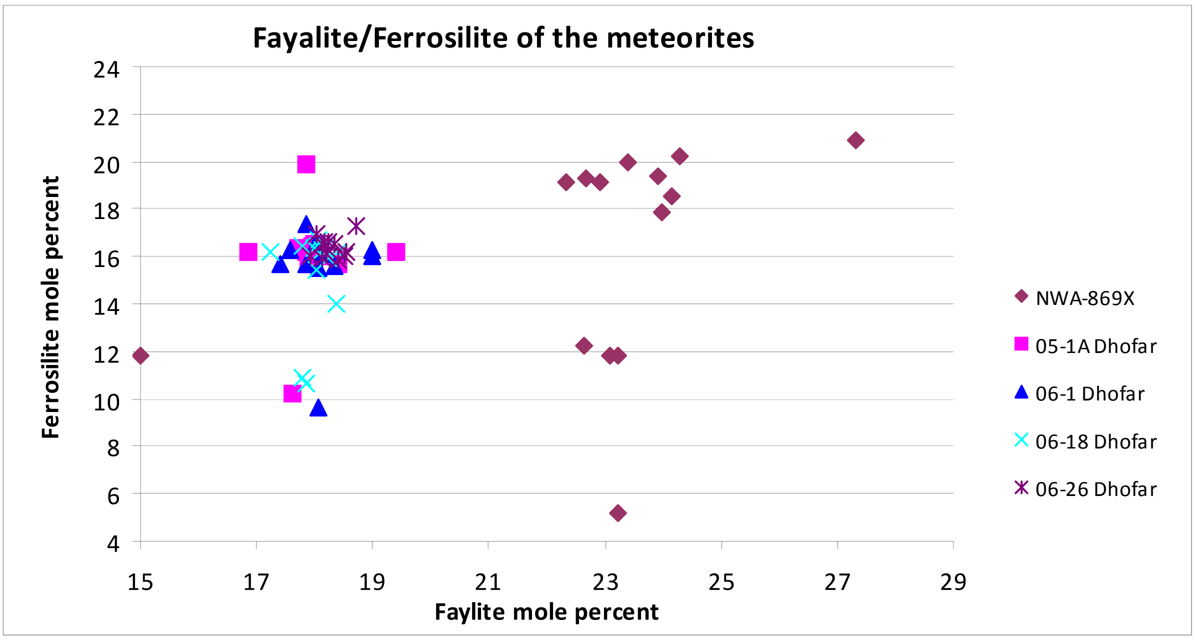
There are many similarities between the Dhofar chondrites. These may not be obvious when comparing the results from measurements, but they are obvious from the textures and mineralogy. The main difference is the amount and appearance of chondrules and the size of the metal and sulphide grains. When comparing the chondrule diameter to the metal grain size clear differences appear (figure 19). 06-1 Dhofar appears to be an EL chondrite although this is not the case. In 05-1A Dhofar the metal grain size is affected by the weathering; most of them have altered rims and has decreased in size. The same must be true for chondrules, as weathering progress the sharp boundary between chondrules and matrix is obliterated, alteration does not only affect the metal but the chondrite as a whole. As weathering is high this is most probably the case and the measurements of size are of little value.

The Dhofar chondrites have most of their metal around the edges, the amount of metal is low compared to sulphide and the silicates are not affected by weathering. Only a few silicate grains have maintained their original colour and some pyroxene show polysynthetic twinning. The olivine and pyroxene compositions are similar. The composition of the metal is also similar but some are high in Ni while others are low.

No signs of shock were observed but it could be that the signs have been obscured by the weathering. The analyzed samples are only small fragments from a meteorite, a question is whether weathering can disguise shock effects and if so, to what degree. Undulose extinction is readily detected but has not been observed in any of the thin sections and neither has other indicative features such as mosaic pattern in olivine grains. It is possible that that the investigated meteorites originate deep beneath the surface of the parent body and thus were protected against any form of shock related to collisions between celestial bodies. It is unlikely that undulose extinction in olivine and/or plagioclase has been missed and the possibility remains that the shock effect has been disguised by weathering.

The Dhofar chondrites may come from the same fall, the similarities are striking and since the only

Fig. 18. The figure clearly shows that the Dhofar chondrites belong to another group separate from the NWA-869X. With a few exceptions the Dhofar meteorites are concentrated around a single spot (Fa_{18}/Fs_{16}), while the NWA-869X values are more scattered, although most of its fayalite values are higher than the values of the Dhofar meteorites.



feature really distinguishing them is the weathering this is a possibility worth mentioning and investigate further. The evidence from this study supports the idea that they come from the same parent body.

The barred and radial textures of the chondrules suggests that they have been subjected to rapid cooling.

The Dhofar meteorites may very well be from the same fall since they only differ in their weathering grade. They may however occur close together due to the accumulation factor rather than the possibility that the meteorites are from the same fall. However, in this study it is believed that they are most probably from the same fall or the very least from the same parent body.

8.3.1 05-1A Dhofar summary

Based on the observations in the optical microscope this meteorite was thought to be an L chondrite with petrographic type 4, indicated by non-recrystallized matrix.

The chemical analysis made by EDS suggests that this is an H chondrite, based on the FeO amount in the olivine and the pyroxene. Since the result from SEM is more reliable this will be the classification of the chondrite. From the Fayalite vs Ferrosilite diagram (figure 19) it is obvious that the chondrite is fairly homogenous. The petrographic type is set to 4 by the homogeneity of the olivine grains (3.2 %). The weathering grade appears to be W3 since there is not a complete alteration of the metal and sulphide grains.

Due to heavy staining some minerals were difficult to identify but are interpreted to be pyroxene since olivine has bright interference colours that most probably would show through the altered colour.

8.3.2 06-1 Dhofar summary

Based on the same statements made above this meteorite was at first classified as an intermediate (L-H) chondrite with petrologic type 4, no re-crystallized material is observed in the matrix. Weathering grade is determined to be W4 since no alteration of the silicates is observed.

The homogeneity of the olivine grains support the petrographic type being 4 and the weathering grade appear to be W3-4. The mean composition of the olivine and the pyroxene both suggests this to be an H chondrite and as previously discussed the chemical analyses are more reliable than the optical.

8.3.3 06-18 Dhofar summary

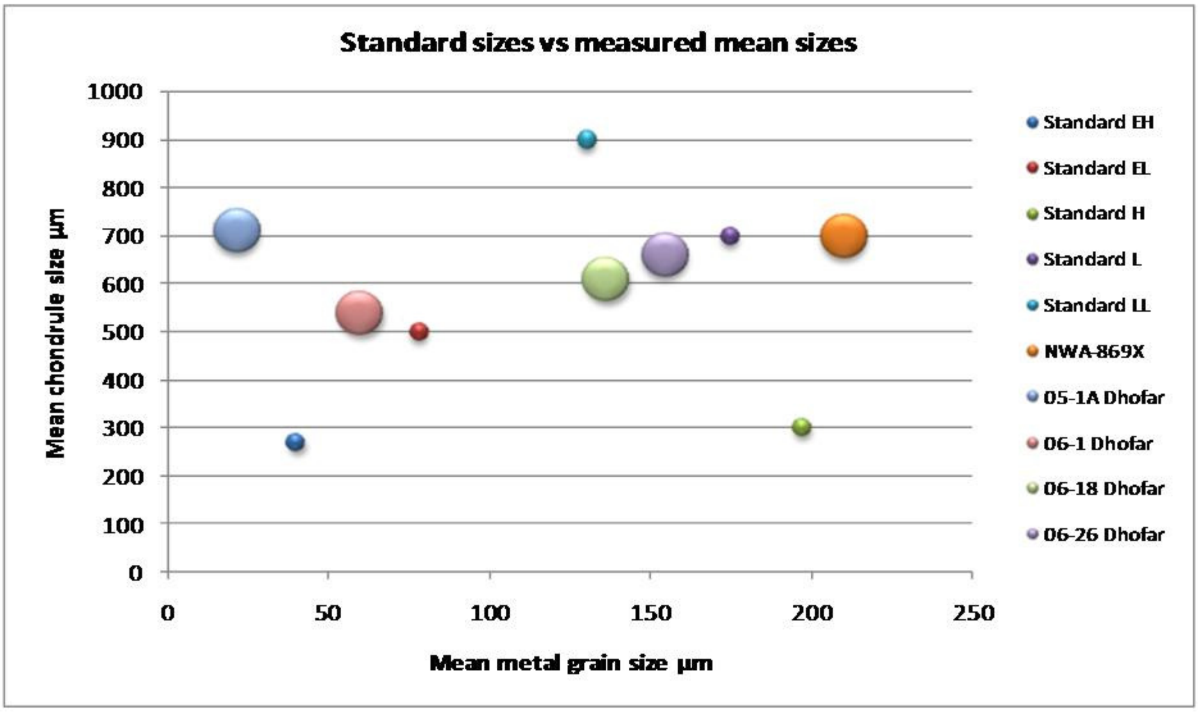
This meteorite was first classified as an L chondrite with petrologic type 4 based on the grain size and that no re-crystallized matrix outside the chondrules was observed in optical microscopy.

The petrographic type 4 is also assigned to this chondrite based on the homogeneity of the olivine grains. The composition of the olivine grains and the pyroxene grains indicates that it is an H chondrite not an L chondrite. The weathering grade on the other hand appear to be somewhat lower than for the other Dhofar chondrites making it a W2-W3

8.3.4 06-26 Dhofar summary

If the classification is based only on the chondrule diameter this meteorite would be an LL chondrite. The petrographic type is 4 based on the fact that most

Fig. 19. The figure shows the standard measurements of chondrule and metal size for the different chondrites (small spheres) as well as the mean sizes measured on the chondrites in this study (large spheres). Modified after Norton 2002.



of the chondrules are well defined, no re-crystallized matrix is observed and the homogeneity of the olivine grains. Weathering grade is set to W3 since there is not a complete alteration of the metal and sulphide grains.

However the chondrite class is contradicted by the chemical analysis. The compositions of olivine and pyroxene do not support the LL classification made by optical microscopy but rather suggests that it is an H chondrite.

9 Conclusions

The first conclusion drawn is that although the tables are easily read, to actually apply the real meteorites texture and mineralogy to them is more difficult than initially thought. Although the table is clear the meteorites do not always follow them, there are specimens with properties intermediate between those listed in the tables.

NWA-869X, OC, L4-5, W1
NWA-UKW, E 3-4, W4
05-1A Dhofar, OC, H4, W3
06-1 Dhofar, OC, H4, W3-4
06-18 Dhofar, OC, H4, W2-3
06-26 Dhofar, OC, H4, W3

Although found in deserts which preserves meteorites well, they still show evidence of weathering, which indicates that they have spent a fair amount of time on Earth. An estimation of the time spent on Earth based on their weathering grade shows that the Dhofar meteorites and the NWA-UKW must have spent ~30 000 years in the desert while NWA-869X have spent ~10 000 years.

For more certain classification a bulk analysis would be advisable and of importance in the possibility of linking the Dhofar meteorites to the same fall or at least from the same parental body as is believed in this study.

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Appendix I Minerals and their chemical formula

Mineral	Chemical formula
akaganéite	$FeO(OH,Cl)$
alabandite	MnS
albite	$NaAlSi_3O_8$
anorthite	$CaAl_2Si_2O_8$
apatite	$Ca_5(PO_4)_3(F,Cl,OH)$
awaruite	Ni_3Fe
baddelyite	ZrO_2
bassanite	$CaSO_4.0.5H_2O$
bunsenite	NiO
cassidyite	$Ca_2(Ni,Mg)(PO_4)_2.2H_2O$
chaoite	C
chromite	$FeCr_2O_4$
collinsite	$Ca_2(Mg,Fe)(PO_4)_2.2H_2O$
daubreelite	$FeCr_2S_4$
diamond	C
diopside	$CaMgSi_2O_6$
epsomite	$MgSO_4.7H_2O$
goethite	$FeO(OH)$
hypersthene	$(Fe,Mg)SiO_3$
hyrcenite	$(Fe,Mg)Al_2O_4$
ilmenite	$FeTiO_3$
kamacite	α-(Fe,Ni)
lonsdaleite	C
magnesiowüstite	$(Mg,Fe)O$
magnetite	Fe_3O_4
majorite	$Mg_3(Fe,Si,Al)_2(SiO_4)_3$
martensite	alloy of iron and carbon
melilite	$(Ca,Na)_2(Al,Mg)(Si,Al)_2O_7$
oldhamite	CaS
olivine	$(Mg,Fe)_2SiO_4$
orthoclase	$KAlSi_3O_8$
osbornite	TiO
pentlandite	$(Fe,Ni)_9S_8$
pleonaste	$(Mg,Fe)Al_2O_4$
pyroxene	$(Mg,Fe)SiO_3$
pyrrhotite	FeS
ringwoodite	$(Mg,Fe)_2SiO_4$
rutile	TiO_2
serpentine	$Mg_3Si_2O_5(OH)_4$
sinoite	Si_2N_2O
spinel	$MgAl_2O_4$
suessite	$(Fe,Ni)_3Si$
taenite	γ-(Fe,Ni)
troilite	FeS

Appendix II Data from SEM analysis

NWA-869X

pyroxene 1

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	18,06	15,59	29,94	MgO	1,56
Al	0,41	0,32	0,77	Al2O3	0,03
Si	26,3	19,65	56,25	SiO2	1,97
Ca	0,71	0,37	1	CaO	0,04
Fe	11,09	4,17	14,26	FeO	0,42
O	45,67	59,9			6
Totals	102,23				
				Cation sum	4,02

2

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	21,16	17,72	35,09	MgO	1,77
Si	27,34	19,82	58,48	SiO2	1,98
Ca	0,35	0,18	0,49	CaO	0,02
Fe	6,52	2,38	8,39	FeO	0,24
O	47,08	59,91			6
Totals	102,45				
				Cation sum	4,02

3

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	18,4	15,82	30,5	MgO	1,59
Si	26,56	19,78	56,83	SiO2	1,98
Ca	0,62	0,32	0,87	CaO	0,03
Mn	0,39	0,15	0,5	MnO	0,01
Fe	10,79	4,04	13,88	FeO	0,4
O	45,82	59,89			6
Totals	102,58				
				Cation sum	4,02

4

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	21,4	18,38	35,49	MgO	1,84
Si	26,53	19,72	56,76	SiO2	1,98
Ca	0,31	0,16	0,43	CaO	0,02
Mn	0,58	0,22	0,75	MnO	0,02
Fe	4,42	1,65	5,69	FeO	0,17
O	45,87	59,86			6
Totals	99,11				
				Cation sum	4,02

5

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	9,51	9,33	15,78	MgO	0,92
Al	0,34	0,3	0,65	Al2O3	0,03
Si	24,7	20,97	52,84	SiO2	2,08
Ca	13,56	8,07	18,98	CaO	0,8
Mn	0,59	0,26	0,76	MnO	0,03
Fe	1,19	0,51	1,53	FeO	0,05
O	40,64	60,56			6
Totals	90,55				
				Cation sum	3,91

6

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	14,44	12,15	23,94	MgO	1,21
Al	0,97	0,74	1,84	Al2O3	0,07
Si	27,16	19,78	58,09	SiO2	1,98
Ca	11,82	6,03	16,54	CaO	0,6
Mn	0,54	0,2	0,7	MnO	0,02
Fe	2,77	1,02	3,57	FeO	0,1
O	46,98	60,08			6
Totals	104,69				
				Cation sum	3,99

7

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,12	16,47	33,35	MgO	1,65
Si	27,98	19,83	59,86	SiO2	1,99
Ca	0,4	0,2	0,56	CaO	0,02
Fe	10,05	3,58	12,93	FeO	0,36
O	48,16	59,92			6
Totals	106,71				
				Cation sum	4,01

8

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	18,98	15,92	31,47	MgO	1,6
Si	27,22	19,76	58,24	SiO2	1,98
Ca	0,55	0,28	0,77	CaO	0,03
Mn	0,46	0,17	0,59	MnO	0,02
Fe	10,91	3,98	14,04	FeO	0,4
O	46,98	59,88			6
Totals	105,11				
				Cation sum	4,02

9

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	18,76	15,91	31,1	MgO	1,59
Si	26,89	19,74	57,52	SiO2	1,98
Ca	0,26	0,14	0,37	CaO	0,01
Mn	0,35	0,13	0,45	MnO	0,01
Fe	11,38	4,2	14,64	FeO	0,42
O	46,44	59,87			6
Totals	104,08				
				Cation sum	4,02

10

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	18,24	15,84	30,24	MgO	1,59
Si	26,37	19,83	56,42	SiO2	1,99
Ca	0,36	0,19	0,51	CaO	0,02
Fe	11,17	4,22	14,37	FeO	0,42
O	45,39	59,91			6
Totals	101,54				
				Cation sum	4,01

11

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	21,82	18,48	36,19	MgO	1,85
Si	27,01	19,8	57,78	SiO2	1,98
Fe	4,92	1,81	6,33	FeO	0,18
O	46,54	59,9			6
Totals	100,29				
				Cation sum	4,02

12

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	18,49	15,78	30,66	MgO	1,58
Al	0,21	0,16	0,4	Al2O3	0,02
Si	26,77	19,77	57,26	SiO2	1,98
Ca	0,69	0,36	0,97	CaO	0,04
Fe	10,78	4	13,87	FeO	0,4
O	46,22	59,93			6
Totals	103,17				
				Cation sum	4,01

13

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	15,23	14,16	25,25	MgO	1,41
Al	0,34	0,28	0,64	Al2O3	0,03
Si	24,77	19,93	52,99	SiO2	1,99
Ca	4	2,26	5,6	CaO	0,23
Fe	8,24	3,34	10,6	FeO	0,33
O	42,5	60,04			6
Totals	95,09				
				Cation sum	3,99

14

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	16,13	14,25	26,74	MgO	1,42
Al	0,3	0,24	0,57	Al2O3	0,02
Si	26,17	20,01	55,98	SiO2	2
Ca	3,77	2,02	5,27	CaO	0,2
Fe	8,9	3,42	11,44	FeO	0,34
O	44,75	60,06			6
Totals	100,01				
				Cation sum	3,99

15

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	13,28	11,5	22,03	MgO	1,14
Al	1,47	1,15	2,78	Al2O3	0,11
Si	27,14	20,34	58,05	SiO2	2,02
Ca	7,5	3,94	10,49	CaO	0,39
Fe	6,93	2,61	8,92	FeO	0,26
O	45,94	60,46			6
Totals	102,26				
				Cation sum	3,92

16

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	18,58	16,3	30,81	MgO	1,63
Si	25,96	19,71	55,53	SiO2	1,98
Ca	0,18	0,1	0,25	CaO	0,01
Mn	0,38	0,15	0,49	MnO	0,01
Fe	10,19	3,89	13,11	FeO	0,39
O	44,9	59,85			6
Totals	100,19				
				Cation sum	4,02

17

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,24	16,95	31,89	MgO	1,69
Al	0,47	0,38	0,9	Al2O3	0,04
Si	26,07	19,89	55,78	SiO2	1,99
Ca	0,45	0,24	0,63	CaO	0,02
Mn	0,33	0,13	0,42	MnO	0,01
Fe	6,19	2,37	7,96	FeO	0,24
O	44,83	60,04			6
Totals	97,58				
				Cation sum	3,99

18

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	17,67	16,27	29,3	MgO	1,63
Si	24,76	19,74	52,97	SiO2	1,98
Ca	0,18	0,1	0,26	CaO	0,01
Mn	0,41	0,17	0,53	MnO	0,02
Fe	9,6	3,85	12,35	FeO	0,39
O	42,78	59,87			6
Totals	95,41				
				Cation sum	4,02

19

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	21,16	18,09	35,09	MgO	1,81
Si	26,83	19,85	57,41	SiO2	1,99
Fe	5,74	2,14	7,39	FeO	0,21
O	46,14	59,93			6
Totals	99,88				
				Cation sum	4,01

39

Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	9,66	9,14	16,02	MgO	0,91
Al	2,06	1,75	3,89	Al2O3	0,18
Si	23,56	19,29	50,41	SiO2	1,93
Ca	13,65	7,83	19,1	CaO	0,78
Sc	0,27	0,14	0,42	Sc2O3	0,01
Mn	0,66	0,28	0,85	MnO	0,03
Fe	3,5	1,44	4,5	FeO	0,14
O	41,82	60,12			6
Totals	95,19				
				Cation sum	3,98

20 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	17,97	16,09	29,8	MgO	1,61
Al	0,3	0,24	0,57	Al2O3	0,02
Si	25,6	19,84	54,77	SiO2	1,98
Ca	0,71	0,39	1	CaO	0,04
Fe	8,88	3,46	11,42	FeO	0,35
O	44,09	59,98			6
Totals	97,55				
				Cation sum	4

Oxygen by stoichiometry

Standard:Talorolivine15kV060404, Spinel 15kV060405, Wollastonit15kV060404, Hematit15kV060404, Rodonit 15kV060404

olivine

1 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	16,86	16,68	27,95	MgO	1,17
Si	16,61	14,23	35,54	SiO2	0,99
Fe	27,82	11,98	35,78	FeO	0,84
O	37,99	57,11			4
Totals	99,27				
				Cation sum	3,01

2 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	23,58	20,78	39,09	MgO	1,45
Al	0,51	0,41	0,97	Al2O3	0,03
Si	19,37	14,78	41,43	SiO2	1,03
Fe	17,06	6,55	21,95	FeO	0,45
O	42,93	57,49			4
Totals	103,45				
				Cation sum	2,96

3 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,97	22,07	41,41	MgO	1,55
Si	18,44	14,11	39,45	SiO2	0,99
Mn	0,39	0,15	0,51	MnO	0,01
Fe	17,21	6,62	22,14	FeO	0,47
O	42,49	57,05			4
Totals	103,51				
				Cation sum	3,01

4 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,48	22,05	40,58	MgO	1,55
Si	17,89	13,95	38,28	SiO2	0,98
Ca	0,36	0,2	0,51	CaO	0,01
Mn	0,39	0,15	0,5	MnO	0,01
Fe	17	6,67	21,87	FeO	0,47
O	41,62	56,98			4
Totals	101,74				
				Cation sum	3,02

5 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,95	21,95	41,38	MgO	1,54
Si	18,56	14,13	39,7	SiO2	0,99
Mn	0,39	0,15	0,51	MnO	0,01
Fe	17,54	6,71	22,56	FeO	0,47
O	42,7	57,06			4
Totals	104,14				
				Cation sum	3,01

6 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	22,87	20,75	37,92	MgO	1,45
Si	18,21	14,3	38,96	SiO2	1,00
Fe	19,76	7,8	25,42	FeO	0,55
O	41,46	57,15			4
Totals	102,3				
				Cation sum	3

7 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,73	21,73	41,01	MgO	1,52
Si	18,68	14,2	39,96	SiO2	0,99
Fe	18,22	6,97	23,44	FeO	0,49
O	42,77	57,1			4
Totals	104,4				
				Cation sum	3,01

8 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	14,45	16,14	23,96	MgO	1,13
Si	14,77	14,29	31,6	SiO2	1,00
Mn	0,49	0,24	0,63	MnO	0,02
Fe	25,05	12,19	32,23	FeO	0,85
O	33,65	57,14			4
Totals	88,41				
				Cation sum	3

9 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,67	22,08	40,9	MgO	1,55
Si	18,15	14,07	38,84	SiO2	0,99
Ca	0,26	0,14	0,37	CaO	0,01
Fe	17,14	6,68	22,06	FeO	0,47
O	41,93	57,03			4
Totals	102,16				
				Cation sum	3,01

10 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	23,2	22,2	38,46	MgO	1,56
Si	16,96	14,05	36,29	SiO2	0,99
Mn	0,51	0,22	0,66	MnO	0,01
Fe	15,61	6,51	20,09	FeO	0,46
O	39,21	57,03			4
Totals	95,5				
				Cation sum	3,01

11 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,95	22,95	41,37	MgO	1,61
Si	17,96	14,3	38,43	SiO2	1,00
Fe	14,01	5,61	18,03	FeO	0,39
O	40,9	57,15			4
Totals	97,83				
				Cation sum	3

12 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,42	23,06	42,14	MgO	1,61
Si	18,2	14,29	38,93	SiO2	1,00
Fe	13,92	5,5	17,91	FeO	0,39
O	41,45	57,15			4
Totals	98,98				
				Cation sum	3

13 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	22,79	22,15	37,79	MgO	1,55
Si	16,8	14,13	35,93	SiO2	0,99
Mn	0,41	0,18	0,53	MnO	0,01
Fe	15,3	6,48	19,69	FeO	0,45
O	38,64	57,07			4
Totals	93,94				
				Cation sum	3,01

14 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,25	22,03	40,21	MgO	1,54
Si	18,01	14,17	38,53	SiO2	0,99
Mn	0,41	0,17	0,53	MnO	0,01
Fe	16,56	6,55	21,31	FeO	0,46
O	41,34	57,08			4
Totals	100,58				
				Cation sum	3,01

15 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	23,57	22,21	39,09	MgO	1,56
Si	17,49	14,26	37,41	SiO2	1,00
Fe	15,58	6,39	20,04	FeO	0,45
O	39,9	57,13			4
Totals	96,54				
				Cation sum	3

16 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,87	21,96	41,24	MgO	1,54
Si	18,44	14,09	39,46	SiO2	0,99
Fe	17,95	6,9	23,1	FeO	0,48
O	42,53	57,05			4
Totals	103,8				
				Cation sum	3,01

17 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,44	21,84	40,52	MgO	1,53
Si	18,11	14,01	38,73	SiO2	0,98
Mn	0,49	0,19	0,63	MnO	0,01
Fe	17,85	6,95	22,96	FeO	0,49
O	41,96	57,01			4
Totals	102,85				
				Cation sum	3,02

18 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,16	22,1	40,07	MgO	1,55
Si	17,8	14,09	38,09	SiO2	0,99
Mn	0,44	0,18	0,56	MnO	0,01
Fe	16,53	6,58	21,26	FeO	0,46
O	41,05	57,05			4
Totals	99,98				
				Cation sum	3,01

19 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	35,56	28,67	58,97	MgO	2,01
Si	20,26	14,14	43,34	SiO2	0,99
Ca	0,26	0,13	0,36	CaO	0,01
O	46,59	57,07			4
Totals	102,67				
				Cation sum	3,01

20 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	23,57	21,8	39,09	MgO	1,53
Si	18,02	14,43	38,56	SiO2	1,01
Fe	16,28	6,55	20,94	FeO	0,46
O	40,71	57,21			4
Totals	98,58				
				Cation sum	2,99

Oxygen by stoichiometry

Standard: Talorolivine 15kV060404, Wollastonite 15kV060404, Rodonite 15kV060404, Hematite 15kV060404

metals

1 Element	Weight%	Atomic%
Fe	93,43	100
Totals	93,43	

2 Element	Weight%	Atomic%
Fe	90,06	97,4
Ni	2,52	2,6
Totals	92,58	

3 Element	Weight%	Atomic%
Fe	66,86	83,69
Ni	13,7	16,31
Totals	80,55	

4 Element	Weight%	Atomic%
Mg	0,39	1,02
Fe	84,74	97,11
Ni	1,72	1,88
Totals	86,85	

5	Element	Weight%	Atomic%
	Fe	62,05	83,13
	Ni	13,24	16,87
	Totals	75,29	

sulphides 1	Element	Weight%	Atomic%
	S	37,19	52,55
	Fe	58,47	47,45
	Totals	95,66	

2	Element	Weight%	Atomic%
	Si	0,18	0,28
	S	38,72	52,21
	Fe	61,36	47,51
	Totals	100,26	

3	Element	Weight%	Atomic%
	S	39,61	52,57
	Fe	62,25	47,43
	Totals	101,86	

4	Element	Weight%	Atomic%
	S	38,72	52,51
	Fe	61	47,49
	Totals	99,72	

5	Element	Weight%	Atomic%
	S	35,3	52,39
	Fe	55,86	47,61
	Totals	91,15	

6	Element	Weight%	Atomic%
	S	37,81	51,98
	Fe	60,83	48,02
	Totals	98,63	

7	Element	Weight%	Atomic%
	Al	0,29	0,47
	Si	0,27	0,42
	S	37,76	51,77
	Fe	60,14	47,34
	Totals	98,46	

altered material 1	Element	Weight%	Atomic%
	O	35,44	65,76
	Si	1,67	1,77
	Ca	0,24	0,18
	Fe	60,75	32,29
	Totals	98,1	

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	0,61	0,54	1,01	MgO	0,05
	Al	8,47	6,76	16	Al2O3	0,62
	Si	35,64	27,34	76,25	SiO2	2,51
	O	48,54	65,36			6
	Totals	93,26				
					Cation sum	3,18

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	10,66	9,4	17,68	MgO	0,99
	Al	36,11	28,68	68,22	Al2O3	3,01
	Fe	12,37	4,75	15,91	FeO	0,5
	O	42,67	57,17			6
	Totals	101,81				
					Cation sum	4,49

4	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	7,56	6,62	10,2	Na2O	0,65
	Al	11,71	8,74	22,13	Al2O3	0,85
	Si	30,91	22,16	66,12	SiO2	2,16
	Ca	1,74	0,87	2,43	CaO	0,08
	O	48,96	61,61			6
	Totals	100,88				
					Cation sum	3,74

5	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	10,48	9,46	17,38	MgO	0,99
	Al	35,22	28,62	66,54	Al2O3	3
	Fe	12,13	4,76	15,61	FeO	0,5
	O	41,7	57,16			6
	Totals	99,53				
					Cation sum	4,5

6	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	0,32	0,31	0,53	MgO	0,03
	Al	0,65	0,58	1,23	Al2O3	0,06
	Si	2,81	2,39	6,01	SiO2	0,23
	P	16,92	13,03	38,76	P2O5	1,25
	Cl	5	3,37	0		0,32
	Ca	34,81	20,72	48,7	CaO	1,98
	Fe	0,42	0,18	0,53	FeO	0,02
	O	39,86	59,43			5,68
	Totals	100,79				
					Cation sum	3,56

phosphates 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	P	18,2	14,21	41,7	P2O5	5,65
	Cl	6,44	4,39	0		1,75
	Ca	37,52	22,64	52,5	CaO	9
	Fe	0,7	0,3	0,89	FeO	0,12
	O	38,68	58,46			23,25
	Totals	101,54				
					Cation sum	14,78

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,31	0,33	0,41	Na2O	0,13
	P	17,79	14,2	40,77	P2O5	5,63
	Cl	6,67	4,65	0		1,84
	Ca	36,05	22,23	50,44	CaO	8,81
	W	1,28	0,17	1,61	WO3	0,07
	O	37,81	58,41			23,16
	Totals	99,9				
					Cation sum	14,64

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	P	17,63	14,26	40,4	P2O5	5,66
	Cl	6,56	4,64	0		1,84
	Ca	35,95	22,46	50,31	CaO	8,91
	Fe	0,61	0,27	0,78	FeO	0,11
	O	37,3	58,37			23,16
	Totals	98,05				
					Cation sum	14,68

4	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,32	0,33	0,43	Na2O	0,13
	P	18,28	13,97	41,88	P2O5	5,58
	Cl	6,62	4,42	0		1,77
	Ca	38,49	22,74	53,85	CaO	9,08
	Fe	0,81	0,34	1,04	FeO	0,14
	O	39,31	58,19			23,23
	Totals	103,82				
					Cation sum	14,93

5	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,43	0,45	0,58	Na2O	0,18
	P	18,37	14,19	42,1	P2O5	5,65
	Cl	6,64	4,48	0		1,78
	Ca	37,09	22,14	51,9	CaO	8,82
	Fe	1,07	0,46	1,37	FeO	0,18
	O	38,99	58,29			23,22
	Totals	102,59				
					Cation sum	14,83

feldspar 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	3,16	3,73	5,24	MgO	0,52
	Al	6,87	7,31	12,99	Al2O3	1,03
	Cr	37,85	20,88	55,32	Cr2O3	2,93
	Mn	0,64	0,33	0,82	MnO	0,04
	Fe	20,84	10,7	26,8	FeO	1,51
	O	31,82	57,05			8
	Totals	101,17				
					Cation sum	6,03

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	4,57	4,3	7,57	MgO	0,55
	Al	6,28	5,33	11,87	Al2O3	0,68
	Si	28,34	23,13	60,63	SiO2	2,95
	Ca	6,34	3,62	8,87	CaO	0,47
	Fe	1,75	0,72	2,24	FeO	0,09
	O	43,91	62,9			8,00
	Totals	91,17				
					Cation sum	4,72

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	6,49	6,2	8,75	Na2O	0,80
	Mg	0,26	0,23	0,43	MgO	0,03
	Al	10,46	8,5	19,75	Al2O3	1,11
	Si	28,23	22,05	60,39	SiO2	2,87
	Ca	1,95	1,07	2,73	CaO	0,13
	Fe	0,89	0,35	1,14	FeO	0,04
	O	44,92	61,6			8
	Totals	93,19				
					Cation sum	4,99

Oxygen by stoichiometry and All elements Analyzed
Standard: Albite 15kV060404, Talorolivine 15kV060404, Spinel 15kV060405,
Sc 15kV990601, Rodonite 15kV060404, FeS2 15kV990601, SiO2 15kV990601,
Apatite 15kV060404, KCl 15kV990601, Hematite 15kV060404, Taylorolivine 15kV060317

NWA-UKW

pyroxene 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	25,04	20,09	41,51	MgO	2,02
	Si	28,24	19,62	60,41	SiO2	1,97
	Ca	0,6	0,29	0,84	CaO	0,03
	Fe	0,54	0,19	0,69	FeO	0,02
	O	49,04	59,81			6
	Totals	103,46				
					Cation sum	4,03

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	24,59	19,94	40,77	MgO	2
	Si	28,14	19,75	60,2	SiO2	1,98
	Ca	0,56	0,28	0,78	CaO	0,03
	Fe	0,43	0,15	0,56	FeO	0,02
	O	48,59	59,88			6
	Totals	102,31				
					Cation sum	4,02

3 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,7	19,99	40,95	MgO	2
Si	28,11	19,7	60,13	SiO2	1,97
Ca	0,46	0,23	0,65	CaO	0,02
Fe	0,66	0,23	0,85	FeO	0,02
O	48,65	59,85			6
Totals	102,58				
				Cation sum	4,03

4 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	23,9	20,07	39,64	MgO	2,01
Si	27,08	19,68	57,92	SiO2	1,97
Ca	0,5	0,25	0,7	CaO	0,03
Fe	0,45	0,16	0,57	FeO	0,02
O	46,9	59,84			6
Totals	98,83				
				Cation sum	4,03

5 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	22,7	19,98	37,64	MgO	2,00
Si	25,92	19,74	55,45	SiO2	1,98
Ca	0,53	0,28	0,74	CaO	0,03
Fe	0,33	0,13	0,43	FeO	0,01
O	44,77	59,87			6
Totals	94,26				
				Cation sum	4,02

6 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,82	20,03	41,16	MgO	2,01
Si	28,36	19,81	60,67	SiO2	1,99
Ca	0,5	0,24	0,7	CaO	0,02
O	48,84	59,91			6
Totals	102,53				
				Cation sum	4,01

7 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,31	20,05	41,97	MgO	2,01
Si	28,86	19,79	61,74	SiO2	1,98
Ca	0,55	0,27	0,78	CaO	0,03
O	49,76	59,89			6
Totals	104,49				
				Cation sum	4,02

8 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,7	19,96	40,95	MgO	2,00
Si	28,37	19,84	60,69	SiO2	1,99
Ca	0,56	0,27	0,78	CaO	0,03
O	48,8	59,92			6
Totals	102,43				
				Cation sum	4,01

9 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,69	20,15	44,25	MgO	2,02
Si	30,03	19,62	64,24	SiO2	1,96
Fe	0,58	0,19	0,75	FeO	0,02
Mo	0,6	0,11	0,9	MoO3	0,01
O	52,24	59,93			6
Totals	110,13				
				Cation sum	4,01

10 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,59	19,97	44,1	MgO	2,00
Si	30,44	19,79	65,12	SiO2	1,98
Ca	0,49	0,22	0,69	CaO	0,02
Fe	0,39	0,13	0,51	FeO	0,01
O	52,49	59,89			6
Totals	110,41				
				Cation sum	4,02

11 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,48	19,94	43,91	MgO	2,00
Si	30,34	19,77	64,91	SiO2	1,98
Ca	0,58	0,26	0,81	CaO	0,03
Fe	0,41	0,14	0,53	FeO	0,01
O	52,34	59,89			6
Totals	110,15				
				Cation sum	4,02

12 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,37	20,12	43,72	MgO	2,02
Si	29,85	19,72	63,87	SiO2	1,98
Ca	0,64	0,3	0,9	CaO	0,03
O	51,62	59,86			6
Totals	108,49				
				Cation sum	4,02

13 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,17	20,23	43,4	MgO	2,03
Si	29,22	19,55	62,51	SiO2	1,96
Ca	0,54	0,25	0,76	CaO	0,03
Fe	0,57	0,19	0,73	FeO	0,02
O	50,89	59,77			6
Totals	107,39				
				Cation sum	4,04

14 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,65	20,08	40,88	MgO	2,01
Si	27,83	19,62	59,55	SiO2	1,97
Ca	0,56	0,27	0,78	CaO	0,03
Fe	0,58	0,21	0,75	FeO	0,02
O	48,32	59,81			6
Totals	101,95				
				Cation sum	4,03

15 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,47	20,14	42,24	MgO	2,02
Si	28,58	19,57	61,15	SiO2	1,96
Ca	0,66	0,31	0,92	CaO	0,03
Fe	0,56	0,19	0,72	FeO	0,02
O	49,75	59,78			6
Totals	105,03				
				Cation sum	4,04

16 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,82	20,11	41,15	MgO	2,02
Si	27,88	19,55	59,64	SiO2	1,96
Ca	0,53	0,26	0,74	CaO	0,03
Fe	0,86	0,3	1,1	FeO	0,03
O	48,55	59,78			6
Totals	102,64				
				Cation sum	4,04

17 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,88	19,82	41,26	MgO	1,99
Si	28,64	19,75	61,27	SiO2	1,98
Ca	0,59	0,28	0,82	CaO	0,03
Fe	0,78	0,27	1	FeO	0,03
O	49,46	59,88			6
Totals	104,35				
				Cation sum	4,02

18 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	22,44	20,01	37,2	MgO	2
Si	25,66	19,81	54,89	SiO2	1,98
Ca	0,51	0,28	0,71	CaO	0,03
O	44,2	59,9			6
Totals	92,8				
				Cation sum	4,02

19 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,36	20,08	40,38	MgO	2,01
Si	27,69	19,76	59,24	SiO2	1,98
Ca	0,56	0,28	0,78	CaO	0,03
O	47,8	59,88			6
Totals	100,41				
				Cation sum	4,02

20 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,4	20,12	40,45	MgO	2,02
Si	27,49	19,63	58,82	SiO2	1,97
Ca	0,49	0,24	0,68	CaO	0,02
Fe	0,51	0,18	0,66	FeO	0,02
O	47,72	59,82			6
Totals	100,61				
				Cation sum	4,03

21 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,47	19,7	40,57	MgO	1,97
Si	28,43	19,82	60,82	SiO2	1,99
Ca	0,62	0,3	0,86	CaO	0,03
Fe	0,76	0,27	0,97	FeO	0,03
O	48,96	59,91			6
Totals	103,23				
				Cation sum	4,01

22 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	23,6	19,79	39,13	MgO	1,98
Si	27,51	19,96	58,85	SiO2	2
Ca	0,53	0,27	0,74	CaO	0,03
O	47,08	59,98			6
Totals	98,72				
				Cation sum	4

23 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	23,82	19,98	39,49	MgO	2
Al	0,21	0,16	0,39	Al2O3	0,02
Si	27,15	19,72	58,09	SiO2	1,98
Ca	0,49	0,25	0,69	CaO	0,02
O	46,99	59,9			6
Totals	98,66				
				Cation sum	4,02

24 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	23,81	20,07	39,47	MgO	2,01
Si	27,08	19,76	57,93	SiO2	1,98
Ca	0,56	0,28	0,78	CaO	0,03
O	46,74	59,88			6
Totals	98,18				
				Cation sum	4,02

25 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	23,65	20,08	39,22	MgO	2,01
Si	26,93	19,79	57,61	SiO2	1,98
Ca	0,47	0,24	0,66	CaO	0,02
O	46,44	59,89			6
Totals	97,49				
				Cation sum	4,02

26 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,76	20,08	41,05	MgO	2,01
Si	28,12	19,74	60,15	SiO2	1,98
Ca	0,63	0,31	0,88	CaO	0,03
O	48,58	59,87			6
Totals	102,08				
				Cation sum	4,02

27 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,4	20,1	42,11	MgO	2,02
Si	28,6	19,59	61,18	SiO2	1,96
Ca	0,5	0,24	0,69	CaO	0,02
Fe	0,82	0,28	1,05	FeO	0,03
O	49,73	59,79			6
Totals	105,04				
				Cation sum	4,04

28 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,2	20,1	41,79	MgO	2,02
Si	28,47	19,65	60,9	SiO2	1,97
Ca	0,52	0,25	0,72	CaO	0,03
Fe	0,48	0,17	0,61	FeO	0,02
O	49,36	59,83			6
Totals	104,03				
				Cation sum	4,03

29 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,55	20,06	42,36	MgO	2,01
Si	28,79	19,56	61,58	SiO2	1,96
Ca	0,69	0,33	0,97	CaO	0,03
Fe	0,81	0,28	1,04	FeO	0,03
O	50,12	59,78			6
Totals	105,95				
				Cation sum	4,04

30 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,41	20,12	42,13	MgO	2,02
Si	28,59	19,6	61,16	SiO2	1,97
Ca	0,51	0,25	0,72	CaO	0,02
Fe	0,68	0,24	0,88	FeO	0,02
O	49,69	59,8			6
Totals	104,88				
				Cation sum	4,03

31 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	29,25	20,02	48,51	MgO	2,01
Si	33,17	19,65	70,96	SiO2	1,97
Ca	0,75	0,31	1,04	CaO	0,03
Fe	0,63	0,19	0,81	FeO	0,02
O	57,52	59,83			6
Totals	121,32				
				Cation sum	4,03

32 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,72	19,88	40,99	MgO	1,99
Si	28,39	19,76	60,73	SiO2	1,98
Ca	0,55	0,27	0,77	CaO	0,03
Fe	0,63	0,22	0,8	FeO	0,02
O	49,01	59,88			6
Totals	103,29				
				Cation sum	4,02

33 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,32	20,05	41,99	MgO	2,01
Si	28,69	19,67	61,38	SiO2	1,97
Ca	0,45	0,22	0,64	CaO	0,02
Fe	0,67	0,23	0,86	FeO	0,02
O	49,73	59,83			6
Totals	104,87				
				Cation sum	4,03

34 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,29	19,85	41,94	MgO	1,99
Si	29,02	19,71	62,07	SiO2	1,97
Ca	0,56	0,27	0,78	CaO	0,03
Fe	0,93	0,32	1,2	FeO	0,03
O	50,19	59,86			6
Totals	105,99				
				Cation sum	4,03

35 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,49	20,26	42,27	MgO	2,03
Si	28,51	19,61	60,99	SiO2	1,97
Ca	0,67	0,32	0,93	CaO	0,03
O	49,52	59,81			6
Totals	104,19				
				Cation sum	4,03

36 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	24,92	19,94	41,32	MgO	2,00
Si	28,67	19,86	61,34	SiO2	1,99
Ca	0,56	0,27	0,78	CaO	0,03
O	49,29	59,93			6
Totals	103,43				
				Cation sum	4,01

37 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,22	20,07	41,81	MgO	2,01
Si	28,56	19,68	61,11	SiO2	1,97
Ca	0,55	0,27	0,77	CaO	0,03
Fe	0,43	0,15	0,55	FeO	0,02
O	49,48	59,84			6
Totals	104,24				
				Cation sum	4,03

Oxygen bu stoichiometry
Standard: Talorolivine 15kV060404, Wollastonite 15kV060404, Hematite 15kV060404, Mo15kV 990601, Spinel 15kV060405,

sulphides 1 Element	Weight%	Atomic%
S	39,9	53,31
Fe	60,85	46,69
Totals	100,75	

2 Element	Weight%	Atomic%
S	39,49	53,26
Fe	60,35	46,74
Totals	99,84	

3 Element	Weight%	Atomic%
S	39,02	53,24
Fe	59,67	46,76
Totals	98,69	

4 Element	Weight%	Atomic%
S	37,81	52,17
Ti	0,51	0,47
Cr	0,9	0,76
Fe	58,36	46,22
Po	1,78	0,37
Totals	99,36	

5 Element	Weight%	Atomic%
S	38,81	52,55
Ti	0,63	0,57
Cr	0,58	0,48
Fe	59,36	46,14
Po	1,27	0,26
Totals	100,65	

6 Element	Weight%	Atomic%
S	40,24	52,54
Ti	0,4	0,35
Cr	0,71	0,57
Fe	61,71	46,26
Totals	103,06	

7 Element	Weight%	Atomic%
S	38,59	52,13
Ti	0,62	0,56
Cr	0,79	0,66
Fe	59,75	46,35
Totals	99,75	

8 Element	Weight%	Atomic%
Si	0,18	0,27
S	42,43	54,84
Ti	1,01	0,87
Fe	59,32	44,02
Totals	102,94	

9 Element	Weight%	Atomic%
S	40,93	52,94
Ti	0,93	0,8
Fe	62,3	46,26
Totals	104,16	

10 Element	Weight%	Atomic%
S	39,75	52,26
Ti	0,65	0,57
Cr	0,75	0,61
Fe	61,71	46,57
Totals	102,85	

11 Element	Weight%	Atomic%
S	39,97	52,46
Ti	0,42	0,37
Cr	0,8	0,65
Fe	61,75	46,53
Totals	102,94	

12 Element	Weight%	Atomic%
Al	0,28	0,43
S	40,43	52,74
Ti	0,54	0,47
Fe	61,91	46,36
Totals	103,16	

13	Element	Weight%	Atomic%
	S	39,41	52,55
	Ti	0,55	0,49
	Cr	0,85	0,7
	Fe	60,43	46,26
	Totals	101,24	

14	Element	Weight%	Atomic%
	S	36,63	52,75
	Fe	57,16	47,25
	Totals	93,79	

15	Element	Weight%	Atomic%
	S	38,92	52,42
	Ti	0,57	0,52
	Cr	0,88	0,73
	Fe	59,91	46,33
	Totals	100,28	

16	Element	Weight%	Atomic%
	S	39,4	52,88
	Ti	0,42	0,38
	Cr	1,11	0,92
	Fe	59,48	45,83
	Totals	100,41	

17	Element	Weight%	Atomic%
	S	38,03	52,96
	Ti	0,51	0,48
	Cr	1	0,86
	Fe	57,19	45,71
	Totals	96,73	

18	Element	Weight%	Atomic%
	S	37,39	51,77
	Ti	0,48	0,44
	Cr	1,19	1,02
	Fe	58,83	46,77
	Totals	97,89	

19	Element	Weight%	Atomic%
	S	37,62	52,35
	Ti	0,77	0,72
	Cr	1,02	0,88
	Fe	57,65	46,06
	Totals	97,07	

20	Element	Weight%	Atomic%
	S	38,74	52,55
	Cr	0,61	0,51
	Fe	60,28	46,94
	Totals	99,63	

21	Element	Weight%	Atomic%
	Al	0,29	0,47
	S	38,81	52,16
	Ti	0,51	0,46
	Cr	0,76	0,63
	Fe	59,97	46,28
	Totals	100,34	

22	Element	Weight%	Atomic%
	S	38,4	52,56
	Ti	0,41	0,37
	Cr	0,81	0,68
	Fe	59,03	46,39
	Totals	98,64	

23	Element	Weight%	Atomic%
	Si	0,18	0,27
	S	38,55	52,27
	Ti	0,33	0,3
	Cr	0,73	0,61
	Fe	59,78	46,55
	Totals	99,56	

24	Element	Weight%	Atomic%
	Al	0,24	0,4
	Si	0,24	0,38
	S	38,37	53,04
	Ti	0,62	0,57
	Fe	57,47	45,61
	Totals	96,95	

feldspar 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	7,02	6,37	9,46	Na2O	0,83
	Al	10,66	8,25	20,15	Al2O3	1,07
	Si	29,73	22,09	63,6	SiO2	2,87
	K	0,41	0,22	0,5	K2O	0,03
	Ca	2,29	1,19	3,2	CaO	0,15
	Fe	0,91	0,34	1,31	Fe2O3	0,04
	O	47,19	61,54			8
	Totals	98,22				
					Cation sum	5

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	7,3	6,19	9,84	Na2O	0,8
	Al	11,7	8,45	22,1	Al2O3	1,09
	Si	33,25	23,08	71,12	SiO2	2,97
	Fe	0,37	0,13	0,53	Fe2O3	0,02
	O	50,98	62,14			8
	Totals	103,59				
					Cation sum	4,87

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	7,5	6,35	10,11	Na2O	0,83
	Al	11,5	8,3	21,72	Al2O3	1,08
	Si	31,92	22,14	68,29	SiO2	2,88
	K	0,46	0,23	0,56	K2O	0,03
	Ca	2,57	1,25	3,6	CaO	0,16
	Fe	0,54	0,19	0,77	Fe2O3	0,02
	O	50,56	61,54			8
	Totals	105,05				
					Cation sum	5

daubréelite 1	Element	Weight%	Atomic%
	S	45,73	58,68
	Cr	34,42	27,23
	Mn	3,59	2,69
	Fe	15,47	11,4
	Totals	99,21	

2	Element	Weight%	Atomic%
	S	45,44	59
	Cr	34,3	27,46
	Mn	2,84	2,15
	Fe	15,28	11,39
	Totals	97,86	

3	Element	Weight%	Atomic%
	S	46,44	58,94
	Cr	34,78	27,22
	Mn	1,55	1,15
	Fe	17,41	12,69
	Totals	100,19	

metal 1	Element	Weight%	Atomic%
	Si	1,08	2,28
	Fe	89,48	95,3
	Ni	2,39	2,42
	Totals	92,95	

2	Element	Weight%	Atomic%
	Si	1,17	2,47
	Fe	89,78	95,04
	Ni	2,47	2,49
	Totals	93,42	

3	Element	Weight%	Atomic%
	Al	0,35	0,79
	Si	1,09	2,36
	Fe	87,1	94,4
	Ni	2,38	2,45
	Totals	90,92	

4	Element	Weight%	Atomic%
	Si	1,03	2,23
	Fe	86,9	95,13
	Ni	2,53	2,64
	Totals	90,46	

5	Element	Weight%	Atomic%
	Al	0,27	0,6
	Si	1,08	2,29
	Fe	89,08	94,67
	Ni	2,41	2,43
	Totals	92,84	

altered material 1	Element	Weight%	Atomic%
	O	40,65	71,94
	Mg	0,31	0,36
	Si	0,97	0,98
	Fe	51,16	25,94
	Ni	1,62	0,78
	Totals	94,71	

2	Element	Weight%	Atomic%
	O	39,48	70,41
	Mg	0,33	0,38
	Si	0,64	0,65
	S	0,59	0,53
	Fe	54,86	28,03
	Totals	95,9	

3 Element	Weight%	Atomic%
O	39,6	70,43
Mg	0,29	0,34
Si	0,64	0,65
S	0,65	0,58
Fe	54,95	28
Totals	96,13	

4 Element	Weight%	Atomic%
O	39,26	71,04
Al	0,44	0,47
Si	1,27	1,31
Cl	0,51	0,41
Ca	0,29	0,21
Fe	50,2	26,02
Ni	1,09	0,54
Totals	93,05	

5 Element	Weight%	Atomic%
O	39,77	70,75
Si	1,07	1,09
S	0,64	0,57
Ca	0,26	0,19
Fe	53,79	27,41
Totals	95,54	

6 Element	Weight%	Atomic%
O	40,19	69,42
Mg	1,83	2,08
Si	3,71	3,65
Cl	0,46	0,36
Ca	0,7	0,48
Fe	47,06	23,29
Ni	1,53	0,72
Totals	95,47	

7 Element	Weight%	Atomic%
O	39,7	70,56
Mg	0,31	0,36
Si	0,69	0,7
Ca	0,22	0,16
Fe	55,43	28,22
Totals	96,35	

Oxygen by stoichiometry and All elements analyzed
Standard: Talorolivine 15kV060404, Spinel 15kV060405, Wollastonite15kV060404, KCl 15kV990601, Hematit15kV060404, Taylorolivine 15kV060317, Titanite 15kV060404, SiO2 15kV990601, K-fsp 15kV060404, YbF3 15kV990601, Rodonite 15kV060404, Apatite 15kV060404, W 15kV990601, FeS2 15kV990601, Chromite 15kV060317, Albite 15kV060404

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pyroxene

1 Element	Weight%	Atomic%	Formula	Number of ions
Mg	19,67	16,66	MgO	1,67
Si	27	19,79	SiO2	1,98
Ca	0,54	0,28	CaO	0,03
Mn	0,48	0,18	MnO	0,02
Fe	8,7	3,21	FeO	0,32
O	46,55	59,89		6
Totals	102,94			
			Cation sum	4,02

2 Element	Weight%	Atomic%	Formula	Number of ions
Mg	18,76	16,79	MgO	1,68
Si	25,47	19,74	SiO2	1,98
Ca	0,48	0,26	CaO	0,03
Mn	0,35	0,14	MnO	0,01
Fe	8,21	3,2	FeO	0,32
O	44,02	59,87		6
Totals	97,3			
			Cation sum	4,02

3 Element	Weight%	Atomic%	Formula	Number of ions
Mg	20,01	16,74	MgO	1,68
Si	27,1	19,63	SiO2	1,97
Ca	0,74	0,38	CaO	0,04
Mn	0,55	0,2	MnO	0,02
Fe	8,89	3,24	FeO	0,32
O	47,04	59,81		6
Totals	104,33			
			Cation sum	4,03

4 Element	Weight%	Atomic%	Formula	Number of ions
Mg	20,33	16,73	MgO	1,68
Si	27,75	19,77	SiO2	1,98
Ca	0,38	0,19	CaO	0,02
Mn	0,42	0,15	MnO	0,02
Fe	9,16	3,28	FeO	0,33
O	47,9	59,88		6
Totals	105,94			
			Cation sum	4,02

5 Element	Weight%	Atomic%	Formula	Number of ions
Mg	20,23	16,73	MgO	1,68
Si	27,7	19,83	SiO2	1,99
Ca	0,45	0,23	CaO	0,02
Fe	9,15	3,29	FeO	0,33
O	47,68	59,92		6
Totals	105,21			
			Cation sum	4,01

6 Element	Weight%	Atomic%	Formula	Number of ions
Mg	11,09	9,71	MgO	0,97
Al	0,2	0,16	Al2O3	0,02
Si	26,34	19,96	SiO2	2
Ca	17,04	9,05	CaO	0,9
Fe	2,89	1,1	FeO	0,11
O	45,11	60,02		6
Totals	102,67			
			Cation sum	4

7 Element	Weight%	Atomic%	Formula	Number of ions
Mg	19,97	16,78	MgO	1,68
Si	27,35	19,89	SiO2	1,99
Ca	0,51	0,26	CaO	0,03
Fe	8,54	3,12	FeO	0,31
O	46,95	59,95		6
Totals	103,32			
			Cation sum	4,01

8 Element	Weight%	Atomic%	Formula	Number of ions
Mg	20,26	16,82	MgO	1,69
Si	27,38	19,68	SiO2	1,97
Ca	0,38	0,19	CaO	0,02
Mn	0,35	0,13	MnO	0,01
Fe	9,21	3,33	FeO	0,33
O	47,42	59,84		6
Totals	105,02			
			Cation sum	4,03

9 Element	Weight%	Atomic%	Formula	Number of ions
Mg	20,15	16,85	MgO	1,69
Si	27,26	19,72	SiO2	1,98
Ca	0,54	0,28	CaO	0,03
Fe	9,04	3,29	FeO	0,33
O	47,12	59,86		6
Totals	104,11			
			Cation sum	4,02

10 Element	Weight%	Atomic%	Formula	Number of ions
Mg	20,02	16,69	MgO	1,67
Si	27,52	19,86	SiO2	1,99
Ca	0,46	0,23	CaO	0,02
Mn	0,46	0,17	MnO	0,02
Fe	8,55	3,1	FeO	0,31
O	47,29	59,93		6
Totals	104,31			
			Cation sum	4,01

11 Element	Weight%	Atomic%	Formula	Number of ions
Mg	10,11	8,91	MgO	0,88
Al	1,43	1,14	Al2O3	0,11
Si	26,54	20,24	SiO2	2,01
Ca	15,5	8,28	CaO	0,82
Fe	2,7	1,04	FeO	0,1
O	45,13	60,4		6
Totals	101,42			
			Cation sum	3,93

12 Element	Weight%	Atomic%	Formula	Number of ions
Mg	20,05	16,88	MgO	1,69
Si	27,09	19,74	SiO2	1,98
Ca	0,51	0,26	CaO	0,03
Fe	8,88	3,25	FeO	0,33
O	46,81	59,87		6
Totals	103,35			
			Cation sum	4,02

13 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,33	16,73	33,72	MgO	1,67
Si	27,92	19,89	59,73	SiO2	1,99
Ca	0,31	0,16	0,44	CaO	0,02
Fe	9,16	3,28	11,79	FeO	0,33
O	47,94	59,94			6
Totals	105,68				
				Cation sum	4,01

14 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,57	16,9	34,11	MgO	1,7
Si	27,51	19,57	58,86	SiO2	1,96
Ca	0,44	0,22	0,62	CaO	0,02
Fe	9,84	3,52	12,66	FeO	0,35
O	47,88	59,78			6
Totals	106,26				
				Cation sum	4,04

15 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,77	17,29	34,44	MgO	1,74
Si	26,91	19,39	57,56	SiO2	1,95
Ca	0,33	0,17	0,46	CaO	0,02
Fe	9,54	3,46	12,27	FeO	0,35
O	47,18	59,7			6
Totals	104,72				
				Cation sum	4,05

16 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,52	16,75	34,03	MgO	1,68
Si	28,08	19,84	60,08	SiO2	1,99
Ca	0,41	0,2	0,58	CaO	0,02
Fe	9,25	3,29	11,9	FeO	0,33
O	48,31	59,92			6
Totals	106,58				
				Cation sum	4,01

17 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,35	16,61	33,74	MgO	1,66
Si	28,02	19,8	59,95	SiO2	1,98
Ca	0,53	0,26	0,74	CaO	0,03
Mn	0,49	0,18	0,63	MnO	0,02
Fe	9,17	3,26	11,8	FeO	0,33
O	48,3	59,9			6
Totals	106,85				
				Cation sum	4,02

Oxygen by stoichiometry
Standard: Talorolivine 15kV060404, Wollastonit15kV060404, Spinell 15kV060405, Rodonite 15kV060404, Hematit15kV060404

olivine 1 Element	Weight%	Atomic%	Formula	Number of ions
Mg	23,79	20,43	MgO	1,42
Si	20,74	15,41	SiO2	1,07
Ca	4,15	2,16	CaO	0,15
Mn	0,39	0,15	MnO	0,01
Fe	11,08	4,14	FeO	0,29
O	44,23	57,71		4
Totals	104,39			
			Cation sum	2,95

2 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,97	23,65	MgO	1,66
Si	19,12	13,99	SiO2	0,98
Mn	0,36	0,13	MnO	0,01
Fe	14,2	5,23	FeO	0,37
O	44,36	57		4
Totals	106,01			
			Cation sum	3,02

3 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,36	23,57	MgO	1,65
Si	18,87	14,08	SiO2	0,99
Mn	0,49	0,19	MnO	0,01
Fe	13,65	5,12	FeO	0,36
O	43,56	57,04		4
Totals	103,93			
			Cation sum	3,01

4 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,52	23,57	MgO	1,65
Si	19,05	14,12	SiO2	0,99
Mn	0,43	0,16	MnO	0,01
Fe	13,63	5,08	FeO	0,35
O	43,84	57,06		4
Totals	104,47			
			Cation sum	3,01

5 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,87	23,67	MgO	1,66
Si	19	13,97	SiO2	0,98
Mn	0,5	0,19	MnO	0,01
Fe	14	5,18	FeO	0,37
O	44,14	56,99		4
Totals	105,51			
			Cation sum	3,02

6 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,5	23,55	MgO	1,65
Si	19,05	14,12	SiO2	0,99
Mn	0,41	0,16	MnO	0,01
Fe	13,74	5,12	FeO	0,36
O	43,85	57,06		4
Totals	104,55			
			Cation sum	3,01

7 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,62	23,55	MgO	1,65
Si	19,21	14,18	SiO2	0,99
Mn	0,4	0,15	MnO	0,01
Fe	13,58	5,04	FeO	0,35
O	44,06	57,09		4
Totals	104,87			
			Cation sum	3,01

8 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,32	23,43	MgO	1,64
Si	18,98	14,1	SiO2	0,99
Mn	0,39	0,15	MnO	0,01
Fe	14,12	5,28	FeO	0,37
O	43,76	57,05		4
Totals	104,57			
			Cation sum	3,01

9 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	27,87	23,48	46,2	MgO	1,65
Si	19,5	14,23	41,72	SiO2	0,99
Fe	14,13	5,18	18,17	FeO	0,36
O	44,6	57,11			4
Totals	106,1				
				Cation sum	3,01

10 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,52	23,6	MgO	1,66
Si	18,93	14,05	SiO2	0,99
Mn	0,38	0,14	MnO	0,01
Fe	13,88	5,18	FeO	0,37
O	43,77	57,03		4
Totals	104,49			
			Cation sum	3,03

11 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,32	23,47	MgO	1,65
Si	19,09	14,2	SiO2	1,00
Mn	0,34	0,13	MnO	0,01
Fe	13,67	5,11	FeO	0,36
O	43,75	57,1		4
Totals	104,18			
			Cation sum	3,02

12 Element	Weight%	Atomic%	Formula	Number of ions
Mg	27,64	23,79	MgO	1,68
Si	18,69	13,93	SiO2	0,98
Mn	0,38	0,14	MnO	0,01
Fe	13,83	5,18	FeO	0,37
O	43,56	56,96		4
Totals	104,09			
			Cation sum	3,04

13 Element	Weight%	Atomic%	Formula	Number of ions
Mg	26,8	23,15	MgO	1,63
Si	18,87	14,11	SiO2	0,99
Mn	0,32	0,12	MnO	0,01
Fe	14,81	5,57	FeO	0,40
O	43,46	57,05		4
Totals	104,26			
			Cation sum	3,03

14 Element	Weight%	Atomic%	Formula	Number of ions
Mg	26,77	23,3	MgO	1,64
Si	18,65	14,05	SiO2	0,99
Mn	0,41	0,16	MnO	0,01
Fe	14,43	5,47	FeO	0,39
O	43,11	57,02		4
Totals	103,37			
			Cation sum	3,03

15 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	28,13	23,48	46,65	MgO	1,65
Si	19,48	14,08	41,67	SiO2	0,99
Mn	0,48	0,18	0,61	MnO	0,01
Fe	14,39	5,23	18,51	FeO	0,37
O	44,97	57,04			4
Totals	107,44				
				Cation sum	3,01

16 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	28,15	23,54	46,67	MgO	1,65
Si	19,3	13,97	41,29	SiO2	0,98
Mn	0,5	0,18	0,64	MnO	0,01
Fe	14,63	5,33	18,82	FeO	0,37
O	44,85	56,98			4
Totals	107,43				
				Cation sum	3,02

17 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	27,81	23,54	46,1	MgO	1,65
Si	19,21	14,07	41,09	SiO2	0,99
Fe	14,52	5,35	18,68	FeO	0,38
O	44,34	57,04			4
Totals	105,87				
				Cation sum	3,01

18 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	25,29	21,43	41,93	MgO	1,49
Si	20,11	14,75	43,01	SiO2	1,03
Ca	2,6	1,34	3,63	CaO	0,09
Mn	0,47	0,17	0,6	MnO	0,01
Fe	13,36	4,93	17,19	FeO	0,34
O	44,55	57,38			4
Totals	106,37				
				Cation sum	2,97

19 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	27,56	23,57	45,69	MgO	1,65
Si	18,85	13,95	40,32	SiO2	0,98
Fe	14,76	5,5	18,99	FeO	0,39
O	43,84	56,98			4
Totals	105				
				Cation sum	3,02

Oxygen by stoichiometry
Standard: Talorolivine 15kV060404, Wollastonite15kV060404, Hematite15kV060404, Rodonite 15kV060404

feldspar 1	Element	Weight%	Atomic%	Formula	Number of ions
	Na	7,5	6,48	Na2O	0,84
	Al	11,62	8,55	Al2O3	1,11
	Si	31,23	22,09	SiO2	2,87
	Ca	2,11	1,05	CaO	0,13
	Fe	0,72	0,26	FeO	0,03
	O	49,57	61,56		8
	Totals	102,75			
				Cation sum	5,00

2	Element	Weight%	Atomic%	Formula	Number of ions
	Na	7,96	6,86	Na2O	0,89
	Al	11,25	8,26	Al2O3	1,08
	Si	30,79	21,73	SiO2	2,84
	Ca	1,19	0,59	CaO	0,08
	Fe	3,78	1,34	FeO	0,17
	O	49,41	61,21		8
	Totals	104,39			
				Cation sum	5,07

3	Element	Weight%	Atomic%	Formula	Number of ions
	Na	7,41	6,32	Na2O	0,83
	Mg	1,78	1,43	MgO	0,19
	Al	11,17	8,11	Al2O3	1,07
	Si	30,77	21,45	SiO2	2,81
	K	0,73	0,37	K2O	0,05
	Ca	1,71	0,83	CaO	0,11
	Fe	1,16	0,41	FeO	0,05
	O	49,9	61,08		8
	Totals	104,63			
				Cation sum	5,09

4	Element	Weight%	Atomic%	Formula	Number of ions
	Mg	3,02	3,82	MgO	0,53
	Al	4,57	5,2	Al2O3	0,73
	Si	0,18	0,19	SiO2	0,03
	Cr	37,43	22,11	Cr2O3	3,11
	Mn	0,62	0,35	MnO	0,05
	Fe	20,73	11,4	FeO	1,60
	O	29,65	56,93		8
	Totals	96,2			
				Cation sum	6,05

5	Element	Weight%	Atomic%	Formula	Number of ions
	Na	5,11	4,43	Na2O	0,59
	Mg	4,62	3,79	MgO	0,49
	Al	7,08	5,23	Al2O3	0,69
	Si	29,54	20,96	SiO2	2,76
	Ca	8,75	4,35	CaO	0,57
	Fe	1,58	0,56	FeO	0,08
	O	48,72	60,68		8
	Totals	105,4			
				Cation sum	5,19

6	Element	Weight%	Atomic%	Formula	Number of ions
	Na	7,48	6,52	Na2O	0,85
	Mg	0,54	0,44	MgO	0,05
	Al	11,04	8,2	Al2O3	1,07
	Si	30,65	21,88	SiO2	2,85
	Ca	1,79	0,9	CaO	0,12
	Fe	1,96	0,7	FeO	0,09
	O	48,97	61,36		8
	Totals	102,44			
				Cation sum	5,04

7	Element	Weight%	Atomic%	Formula	Number of ions
	Na	7,95	6,74	Na2O	0,88
	Al	11,87	8,58	Al2O3	1,12
	Si	31,8	22,09	SiO2	2,87
	Ca	1,84	0,9	CaO	0,12
	Fe	0,53	0,19	FeO	0,03
	O	50,44	61,5		8
	Totals	104,43			
				Cation sum	5,01

8	Element	Weight%	Atomic%	Formula	Number of ions
	Mg	0,7	0,61	MgO	0,08
	Al	10,6	8,31	Al2O3	1,03
	Si	28,99	21,83	SiO2	2,71
	S	2,55	1,68	SO3	0,21
	Ca	1,91	1,01	CaO	0,12
	Fe	4,96	1,88	FeO	0,23
	O	48,91	64,68		8
	Totals	98,62			
				Cation sum	4,37

9	Element	Weight%	Atomic%	Formula	Number of ions
	Na	6,61	5,97	Na2O	0,79
	Mg	1,73	1,48	MgO	0,19
	Al	10,61	8,15	Al2O3	1,07
	Si	28,81	21,28	SiO2	2,79
	Ca	1,47	0,76	CaO	0,09
	Fe	3,17	1,18	FeO	0,16
	O	47,19	61,18		8
	Totals	99,6			
				Cation sum	5,08

10	Element	Weight%	Atomic%	Formula	Number of ions
	Na	7,63	6,67	Na2O	0,86
	Mg	0,31	0,25	MgO	0,03
	Al	11,21	8,35	Al2O3	1,09
	Si	30,82	22,05	SiO2	2,87
	Ca	1,91	0,96	CaO	0,12
	Fe	0,76	0,27	FeO	0,04
	O	48,93	61,44		8
	Totals	101,58			
				Cation sum	5,03

11	Element	Weight%	Atomic%	Formula	Number of ions
	Na	7,42	6,44	Na2O	0,84
	Al	11,73	8,67	Al2O3	1,12
	Si	31,38	22,27	SiO2	2,89
	Ca	1,59	0,79	CaO	0,11
	Fe	0,42	0,15	FeO	0,01
	O	49,53	61,69		8
	Totals	102,08			
				Cation sum	4,97

12	Element	Weight%	Atomic%	Formula	Number of ions
	Na	7,48	6,42	Na2O	0,84
	Al	11,98	8,75	Al2O3	1,13
	Si	31,26	21,94	SiO2	2,85
	Ca	1,89	0,93	CaO	0,12
	Fe	1,15	0,41	FeO	0,05
	O	49,96	61,55		8
	Totals	103,74			
				Cation sum	5,00

chromite 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	2,23	2,62	3,69	MgO	0,18
	Al	3,72	3,95	7,03	Al2O3	0,27
	Ti	1,29	0,77	2,15	TiO2	0,05
	V	0,58	0,33	1,04	V2O5	0,02
	Cr	41,76	22,99	61,03	Cr2O3	1,60
	Fe	23,38	11,98	30,08	FeO	0,83
	O	32,07	57,36			4
	Totals	105,02				
					Cation sum	2,97

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	2,23	2,62	3,69	MgO	0,18
	Al	3,72	3,95	7,03	Al2O3	0,27
	Ti	1,29	0,77	2,15	TiO2	0,05
	V	0,58	0,33	1,04	V2O5	0,02
	Cr	41,76	22,99	61,03	Cr2O3	1,60
	Fe	23,38	11,98	30,08	FeO	0,83
	O	32,07	57,36			4
	Totals	105,02				
					Cation sum	2,97

altered material 1	Element	Weight%	Atomic%
	O	41,58	69,07
	Mg	1,47	1,6
	Si	5,26	4,98
	S	3,53	2,92
	K	1,62	1,1
	Ca	0,77	0,51
	Fe	41,62	19,81
	Totals	95,84	

2	Element	Weight%	Atomic%
	O	39,23	68,1
	Si	0,95	0,93
	Ca	0,43	0,3
	Fe	61,67	30,67
	Totals	102,28	

3	Element	Weight%	Atomic%
	O	38,93	67,87
	Mg	0,51	0,59
	Si	1,32	1,31
	Ca	0,47	0,32
	Fe	59,88	29,91
	Totals	101,1	

4	Element	Weight%	Atomic%	Number of ions
	O	34,42	63,21	0,11
	Mg	0,53	0,64	0,26
	Si	1,53	1,6	5,29
	Fe	64,63	34	0,09
	Ni	1,1	0,55	6
	Totals	102,21		
				5,74

5	Element	Weight%	Atomic%
	O	43,87	71,93
	Mg	1,27	1,37
	Si	2,66	2,49
	Ca	0,52	0,34
	Fe	50,83	23,87
	Totals	99,15	

6	Element	Weight%	Atomic%
	O	36,21	65,61
	Mg	0,25	0,3
	Si	0,45	0,46
	Fe	64,79	33,63
	Totals	101,69	

	Element	Weight%	Atomic%
7	Element	Weight%	Atomic%
	O	33,99	64,76
	Si	0,32	0,35
	Fe	63,93	34,89
	Totals	98,24	

8	Element	Weight%	Atomic%
	O	36,7	67,47
	Mg	0,66	0,8
	Al	0,2	0,22
	Si	2,13	2,23
	S	0,51	0,46
	Ca	0,47	0,35
	Fe	54,06	28,47
	Totals	94,73	

9	Element	Weight%	Atomic%
	O	42	72,37
	Mg	0,34	0,38
	Si	1,15	1,13
	Ca	0,4	0,28
	Fe	51,05	25,2
	Ni	1,35	0,63
	Totals	96,29	

10	Element	Weight%	Atomic%
	O	41,01	69,75
	Mg	1,32	1,48
	Si	5,58	5,4
	Ca	0,41	0,28
	Fe	44,45	21,66
	Ni	3,1	1,44
	Totals	95,86	

11	Element	Weight%	Atomic%
	O	35,38	64,33
	Cl	0,31	0,25
	Fe	65,89	34,32
	Ni	2,2	1,09
	Totals	103,78	

12	Element	Weight%	Atomic%	Formula	Number of ions
	Mg	0,7	0,63	MgO	0,06
	Si	1,35	1,05	SiO2	0,09
	S	23,85	16,29	SO3	1,46
	Ca	26,97	14,74	CaO	1,32
	Fe	1,23	0,48	FeO	0,04
	O	48,82	66,81		6
	Totals	102,91			
				Cation sum	2,98

13	Element	Weight%	Atomic%	Formula	Number of ions
	Mg	1,29	1,17	MgO	0,11
	Si	2,39	1,88	SiO2	0,17
	S	22,65	15,6	SO3	1,41
	Ca	24,16	13,32	CaO	1,2
	Fe	3,73	1,48	FeO	0,13
	O	48,19	66,55		6
	Totals	102,42			
				Cation sum	3,02

phosphate 1	Element	Weight%	Atomic%	Formula	Number of ions
	Na	1,99	2,08	Na2O	0,10
	Mg	2,23	2,21	MgO	0,11
	P	19,86	15,42	P2O5	0,76
	Ca	31,62	18,98	CaO	0,94
	Fe	0,47	0,2	FeO	0,01
	O	40,61	61,06		3,00
	Totals	96,78			
				Cation sum	1,92

Oxygen by stoichiometry and All elements analyzed

Standard: SiO2 15kV990601, Talorolivine 15kV060404, Wollastonite15kV060404,

Spinel 15kV060405, Titanite 15kV060404, V 15kV990601, Chromite 15kV060317,

Sc 15kV990601, FeS2 15kV990601, KCl 15kV990601, K-fsp 15kV060404, Mo 15kV990601

Hematit15kV060404, Taylorolivine 15kV060317, Albite 15kV060404, Apatite 15kV060404

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pyroxene 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	18,75	16,73	31,09	MgO	1,67
	Si	25,75	19,89	55,09	SiO2	1,99
	Ca	0,33	0,18	0,46	CaO	0,02
	Mn	0,41	0,16	0,52	MnO	0,02
	Fe	8	3,11	10,29	FeO	0,31
	O	44,22	59,94			6
	Totals	97,45				
					Cation sum	4,01

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	18,95	16,7	31,42	MgO	1,67
	Si	25,83	19,7	55,26	SiO2	1,98
	Ca	0,45	0,24	0,63	CaO	0,02
	Fe	9,14	3,51	11,76	FeO	0,35
	O	44,69	59,85			6
	Totals	99,06				
					Cation sum	4,02

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,86	16,83	32,92	MgO	1,69
	Si	26,83	19,69	57,39	SiO2	1,97
	Ca	0,42	0,22	0,59	CaO	0,02
	Mn	0,44	0,16	0,56	MnO	0,02
	Fe	8,83	3,26	11,36	FeO	0,33
	O	46,46	59,84			6
	Totals	102,83				
					Cation sum	4,03

4	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	20,03	16,69	33,22	MgO	1,67
	Si	27,46	19,8	58,75	SiO2	1,98
	Ca	0,53	0,27	0,74	CaO	0,03
	Mn	0,4	0,15	0,52	MnO	0,01
	Fe	8,81	3,19	11,33	FeO	0,32
	O	47,33	59,9			6
	Totals	104,56				
					Cation sum	4,02

5	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,9	16,82	33	MgO	1,68
	Si	27,11	19,83	58	SiO2	1,99
	Ca	0,36	0,19	0,51	CaO	0,02
	Mn	0,46	0,17	0,59	MnO	0,02
	Fe	8,36	3,08	10,76	FeO	0,31
	O	46,66	59,92			6
	Totals	102,85				
					Cation sum	4,01

6	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,85	0,82	1,14	Na2O	0,08
	Mg	10,3	9,38	17,08	MgO	0,94
	Si	25,65	20,22	54,87	SiO2	2,03
	Ca	15,21	8,4	21,28	CaO	0,84
	Mn	0,42	0,17	0,55	MnO	0,02
	Fe	2,78	1,1	3,57	FeO	0,11
	O	43,29	59,91			6
	Totals	98,49				
					Cation sum	4,02

7	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	18,94	16,9	31,4	MgO	1,69
	Si	25,7	19,85	54,97	SiO2	1,99
	Ca	0,39	0,21	0,54	CaO	0,02
	Fe	8,02	3,12	10,32	FeO	0,31
	O	44,19	59,92			6
	Totals	97,24				
					Cation sum	4,01

8	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,42	0,41	0,57	Na2O	0,04
	Mg	10,64	9,85	17,64	MgO	0,99
	Al	0,29	0,24	0,55	Al2O3	0,02
	Si	24,62	19,74	52,67	SiO2	1,98
	Ca	15,2	8,54	21,27	CaO	0,86
	Cr	0,62	0,27	0,9	Cr2O3	0,03
	Fe	2,59	1,05	3,33	FeO	0,1
	O	42,56	59,89			6
	Totals	96,95				
					Cation sum	4,02

9	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	21,04	16,88	34,88	MgO	1,69
	Si	28,39	19,72	60,73	SiO2	1,98
	Ca	0,35	0,17	0,49	CaO	0,02
	Fe	9,66	3,37	12,42	FeO	0,34
	O	49,1	59,86			6
	Totals	108,53				
					Cation sum	4,02

10	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	20,5	16,87	34	MgO	1,69
	Si	27,64	19,69	59,13	SiO2	1,97
	Ca	0,3	0,15	0,42	CaO	0,02
	Mn	0,49	0,18	0,63	MnO	0,02
	Fe	9,13	3,27	11,75	FeO	0,33
	O	47,86	59,84			6
	Totals	105,93				
					Cation sum	4,03

11	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	15,8	16,67	26,2	MgO	1,67
	Al	0,11	0,11	0,21	Al2O3	0,01
	Si	21,67	19,78	46,35	SiO2	1,98
	Ca	0,38	0,24	0,53	CaO	0,02
	Mn	0,4	0,19	0,52	MnO	0,02
	Fe	6,74	3,1	8,67	FeO	0,31
	O	37,38	59,92			6
	Totals	82,49				
					Cation sum	4,01

12 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,77	16,79	32,78	MgO	1,68
Si	27	19,86	57,76	SiO2	1,99
Ca	0,31	0,16	0,44	CaO	0,02
Fe	8,82	3,26	11,34	FeO	0,33
O	46,42	59,93			6
Totals	102,32				
				Cation sum	4,01

13 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,7	16,88	32,66	MgO	1,69
Si	26,7	19,8	57,13	SiO2	1,98
Ca	0,37	0,19	0,52	CaO	0,02
Fe	8,65	3,23	11,12	FeO	0,32
O	46,01	59,9			6
Totals	101,43				
				Cation sum	4,02

14 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	12,62	11,4	20,93	MgO	1,14
Al	0,44	0,36	0,84	Al2O3	0,04
Si	25,83	20,18	55,25	SiO2	2,01
Ca	11,6	6,35	16,23	CaO	0,63
Fe	3,88	1,52	4,99	FeO	0,15
O	43,87	60,18			6
Totals	98,23				
				Cation sum	3,97

15 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Na	0,33	0,3	0,45	Na2O	0,03
Mg	18,29	15,66	30,32	MgO	1,57
Al	0,42	0,32	0,8	Al2O3	0,03
Si	26,72	19,81	57,17	SiO2	1,99
Ca	1,58	0,82	2,21	CaO	0,08
Mn	0,54	0,2	0,69	MnO	0,02
Fe	7,97	2,97	10,25	FeO	0,30
O	46,04	59,91			6
Totals	101,88				
				Cation sum	4,01

16 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Na	0,49	0,46	0,66	Na2O	0,04
Mg	11,35	10,03	18,82	MgO	1,00
Al	0,31	0,24	0,58	Al2O3	0,02
Si	26,1	19,96	55,84	SiO2	2,00
Ca	14,54	7,79	20,35	CaO	0,78
Cr	0,59	0,24	0,86	Cr2O3	0,02
Fe	3,37	1,3	4,34	FeO	0,13
O	44,69	59,99			6
Totals	101,44				
				Cation sum	4,00

17 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,78	16,8	32,79	MgO	1,68
Si	26,98	19,84	57,72	SiO2	1,99
Ca	0,39	0,2	0,54	CaO	0,02
Fe	8,73	3,23	11,23	FeO	0,32
O	46,41	59,92			6
Totals	102,29				
				Cation sum	4,01

18 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,35	18,06	33,75	MgO	1,83
Si	23,69	18,19	50,67	SiO2	1,85
Ca	0,29	0,15	0,4	CaO	0,02
Mn	0,49	0,19	0,63	MnO	0,02
Fe	11,13	4,3	14,32	FeO	1,67
O	43,82	59,1			6
Totals	99,77				
				Cation sum	4,15

19 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,6	16,76	32,5	MgO	1,68
Si	26,55	19,66	56,8	SiO2	1,97
Ca	0,42	0,22	0,59	CaO	0,02
Mn	0,54	0,2	0,69	MnO	0,02
Fe	8,95	3,33	11,51	FeO	0,33
O	46,03	59,83			6
Totals	102,09				
				Cation sum	4,03

Oxygen by stoichiometry
Standard: Talorolivine 15kV060404, Wollastonite15kV060404
Albite 15kV060404, Spinell 15kV060405, Chromite 15kV060317
Rodonite 15kV060404, Hematit15kV060404

olivine 1 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,42	23,48	43,81	MgO	1,65
Si	18,56	14,28	39,7	SiO2	1,01
Fe	13,18	5,1	16,96	FeO	0,36
O	42,31	57,14			4
Totals	100,47				
				Cation sum	3,02

2 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,21	23,47	43,45	MgO	1,65
Si	18,43	14,29	39,42	SiO2	1,01
Fe	13,07	5,1	16,81	FeO	0,36
O	41,98	57,14			4
Totals	99,68				
				Cation sum	3,02

3 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,97	23,44	44,72	MgO	1,65
Si	18,53	13,95	39,65	SiO2	0,98
Mn	0,38	0,14	0,48	MnO	0,01
Fe	14,51	5,49	18,67	FeO	0,39
O	43,13	56,97			4
Totals	103,52				
				Cation sum	3,04

4 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,75	23,44	44,36	MgO	1,64
Si	18,72	14,2	40,05	SiO2	0,99
Fe	13,8	5,26	17,75	FeO	0,37
O	42,89	57,1			4
Totals	102,16				
				Cation sum	3,01

5 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	27,27	23,17	45,22	MgO	1,63
Si	19,4	14,26	41,5	SiO2	1,01
Fe	14,69	5,43	18,9	FeO	0,38
O	44,25	57,13			4
Totals	105,61				
				Cation sum	3,02

6 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	27,63	23,55	45,82	MgO	1,66
Si	19,21	14,17	41,1	SiO2	1,00
Fe	13,98	5,19	17,98	FeO	0,37
O	44,07	57,09			4
Totals	104,89				
				Cation sum	3,02

7 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	27,23	23,67	45,15	MgO	1,67
Si	18,72	14,08	40,05	SiO2	0,99
Fe	13,76	5,21	17,71	FeO	0,37
O	43,2	57,04			4
Totals	102,91				
				Cation sum	3,03

8 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,61	23,6	44,12	MgO	1,66
Si	18,42	14,14	39,4	SiO2	1,00
Mn	0,39	0,15	0,5	MnO	0,01
Fe	13,03	5,03	16,77	FeO	0,36
O	42,34	57,07			4
Totals	100,79				
				Cation sum	3,02

9 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	10,66	8,3	17,68	MgO	0,55
Al	2,34	1,64	4,42	Al2O3	0,11
Si	30,8	20,75	65,88	SiO2	1,37
Ca	15,89	7,5	22,24	CaO	0,50
Fe	3,04	1,03	3,91	FeO	0,07
O	51,4	60,78			4
Totals	114,13				
				Cation sum	2,59

10 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	27,44	23,79	45,49	MgO	1,68
Si	18,71	14,04	40,02	SiO2	0,99
Mn	0,38	0,14	0,49	MnO	0,01
Fe	13,26	5,01	17,06	FeO	0,36
O	43,28	57,02			4
Totals	103,06				
				Cation sum	3,03

11 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,84	23,36	44,5	MgO	1,64
Si	18,91	14,25	40,45	SiO2	1,00
Fe	13,88	5,26	17,86	FeO	0,37
O	43,18	57,13			4
Totals	102,81				
				Cation sum	3,00

12 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,73	23,78	44,33	MgO	1,67
Si	18,11	13,94	38,74	SiO2	0,98
Fe	13,69	5,3	17,62	FeO	0,37
O	42,15	56,97			4
Totals	100,68				
				Cation sum	3,02

13 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,1	23,47	43,27	MgO	1,65
Si	18,17	14,15	38,88	SiO2	0,99
Fe	13,53	5,3	17,41	FeO	0,37
O	41,75	57,08			4
Totals	99,55				
				Cation sum	3,01

14 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	26,19	23,65	43,42	MgO	1,66
Si	18,14	14,18	38,81	SiO2	0,99
Fe	12,93	5,08	16,63	FeO	0,36
O	41,61	57,09			4
Totals	98,86				
				Cation sum	3,01

Oxygen by stoichiometry
Standard: Talorolivine 15kV060404, Wollastonite15kV060404,
Spinel 15kV060405, SiO2 15kV990601, Albite 15kV060404
Hematite15kV060404, Rodonite 15kV060404

sulphide 1	Element	Weight%	Atomic%
	S	41,15	54,4
	Fe	60,07	45,6
	Totals	101,23	

2	Element	Weight%	Atomic%
	S	42,04	55,31
	Fe	59,16	44,69
	Totals	101,21	

3	Element	Weight%	Atomic%
	O	5,49	14,01
	Si	0,19	0,28
	S	35,45	45,12
	Fe	55,55	40,59
	Totals	96,67	

4	Element	Weight%	Atomic%
	O	4,2	10,75
	S	38,63	49,27
	Fe	51,86	37,98
	Ni	2,31	1,61
	Po	2,02	0,39
	Totals	99,02	

5	Element	Weight%	Atomic%
	O	5,04	12,76
	S	38,49	48,65
	Fe	50,71	36,8
	Ni	2,59	1,79
	Totals	96,84	

6	Element	Weight%	Atomic%
	S	41,08	55,16
	Fe	58,16	44,84
	Totals	99,24	

7	Element	Weight%	Atomic%
	S	40,12	57,29
	Fe	52,1	42,71
	Totals	92,21	

8	Element	Weight%	Atomic%
	S	38,13	52,92
	Fe	59,09	47,08
	Totals	97,23	

altered material 1	Element	Weight%	Atomic%
	O	39,89	70,39
	Mg	1,16	1,34
	Si	0,67	0,68
	Ca	0,8	0,57
	Fe	52,31	26,44
	Ni	0,63	0,3
	Mo	0,95	0,28
	Totals	96,41	

2	Element	Weight%	Atomic%
	O	47,15	68,26
	S	22,8	16,47
	Ca	26,11	15,09
	Fe	0,45	0,18
	Totals	96,51	

3	Element	Weight%	Atomic%
	O	50,79	64,31
	Na	5,24	4,62
	Mg	0,41	0,34
	Al	6,93	5,2
	Si	33,4	24,09
	K	1,9	0,99
	Ca	0,66	0,33
	Fe	0,33	0,12
	Totals	99,66	

feldspar 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	6,6	5,76	8,9	Na2O	0,75
	Mg	1,84	1,52	3,05	MgO	0,20
	Al	9,66	7,19	18,26	Al2O3	0,93
	Si	30,71	21,95	65,7	SiO2	2,87
	Ca	4,02	2,01	5,62	CaO	0,27
	Fe	0,69	0,25	0,89	FeO	0,03
	O	48,89	61,33			8
	Totals	102,42				
					Cation sum	5,04

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	7,6	6,82	10,25	Na2O	0,89
	Al	10,98	8,39	20,74	Al2O3	1,09
	Si	30,36	22,29	64,95	SiO2	2,89
	Ca	1,43	0,73	2	CaO	0,09
	Fe	0,62	0,23	0,8	FeO	0,03
	O	47,74	61,54			8
	Totals	98,73				
					Cation sum	5,00

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	5,85	5,43	7,89	Na2O	0,74
	Mg	2,99	2,63	4,96	MgO	0,36
	Al	11,26	8,91	21,28	Al2O3	1,22
	Si	25,29	19,22	54,11	SiO2	2,63
	S	0,54	0,36	1,34	SO3	0,06
	Cl	1,61	0,97	0		0,13
	Ca	1,66	0,89	2,33	CaO	0,13
	Fe	3,27	1,25	4,21	FeO	0,17
	O	45,25	60,35			8
	Totals	97,73				
					Cation sum	5,29

4	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	1,5	1,36	2,49	MgO	0,17
	Al	10,67	8,72	20,15	Al2O3	1,09
	Si	30,51	23,96	65,28	SiO2	2,99
	K	0,34	0,19	0,41	K2O	0,03
	Ca	2,14	1,18	3	CaO	0,15
	Fe	1,2	0,47	1,54	FeO	0,05
	O	46,51	64,11			8
	Totals	92,87				
					Cation sum	4,48

5	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	4,75	3,74	7,87	MgO	0,48
	Al	9,43	6,69	17,81	Al2O3	0,85
	Si	33,76	23,02	72,23	SiO2	2,92
	Ca	5,26	2,52	7,37	CaO	0,32
	Fe	2,47	0,85	3,18	FeO	0,11
	O	52,78	63,18			8
	Totals	108,46				
					Cation sum	4,67

6	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	7,76	6,85	10,46	Na2O	0,89
	Mg	0,22	0,18	0,36	MgO	0,03
	Al	11,01	8,28	20,81	Al2O3	1,08
	Si	30,78	22,23	65,86	SiO2	2,89
	Ca	1,44	0,73	2,01	CaO	0,09
	Fe	0,71	0,26	0,91	FeO	0,04
	O	48,49	61,48			8
	Totals	100,41				
					Cation sum	5,01

7	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	7,94	6,93	10,7	Na2O	0,90
	Al	10,89	8,1	20,58	Al2O3	1,05
	Si	31,71	22,65	67,83	SiO2	2,95
	K	0,79	0,41	0,96	K2O	0,05
	Ca	0,79	0,4	1,11	CaO	0,05
	O	49,05	61,52			8
	Totals	101,18				
					Cation sum	5,01

8	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	7,11	6,47	9,58	Na2O	0,85
	Mg	0,41	0,35	0,68	MgO	0,05
	Al	10,39	8,06	19,64	Al2O3	1,06
	Si	28,31	21,1	60,55	SiO2	2,78
	Cl	0,43	0,25	0		0,03
	K	0,45	0,24	0,55	K2O	0,03
	Ca	1,64	0,86	2,3	CaO	0,11
	Fe	4,82	1,8	6,19	FeO	0,24
	Ni	0,29	0,1	0,36	NiO	0,01
	O	46,44	60,76			8
	Totals	100,28				
					Cation sum	5,13

chromite 1	Element	Weight%	Atomic%
	O	32,79	60,07
	Mg	1,63	1,96
	Al	3,06	3,32
	Si	0,24	0,25
	Cr	36,32	20,47
	Mn	0,75	0,4
	Fe	25,77	13,53
	Totals	100,56	

2	Element	Weight%	Atomic%
	O	32,59	60,34
	Mg	1,8	2,19
	Al	3,28	3,6
	Ti	1,27	0,79
	Cr	37,53	21,38
	Mn	0,91	0,49
	Fe	21,15	11,21
	Totals	98,53	

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	1,64	2,16	2,72	MgO	0,15
	Al	3,28	3,89	6,2	Al2O3	0,27
	Ti	1,21	0,81	2,02	TiO2	0,05
	Cr	37,36	22,97	54,61	Cr2O3	1,61
	Mn	0,97	0,57	1,26	MnO	0,04
	Fe	21,83	12,49	28,09	FeO	0,88
	O	28,59	57,12			4
	Totals	94,9				
					Cation sum	3,02

phosphate 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	P	18,6	14,3	42,62	P2O5	1,36
	Cl	6,66	4,47	0		0,43
	Ca	37,75	22,43	52,82	CaO	2,14
	Fe	0,72	0,31	0,92	FeO	0,03
	O	39,29	58,49			5,57
	Totals	103,02				
					Cation sum	3,53

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	2,08	2,21	2,81	Na2O	0,11
	Mg	2,17	2,18	3,6	MgO	0,11
	P	19,54	15,39	44,78	P2O5	0,76
	Ca	31,19	18,98	43,64	CaO	0,94
	Fe	0,58	0,25	0,74	FeO	0,01
	O	40,01	60,99			3
	Totals	95,58				
					Cation sum	1,92

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	1,99	2,07	2,69	Na2O	0,10
	Mg	2,35	2,3	3,9	MgO	0,11
	Si	0,24	0,21	0,52	SiO2	0,01
	P	19,42	14,94	44,5	P2O5	0,74
	Ca	30,94	18,39	43,29	CaO	0,91
	Fe	3,06	1,31	3,94	FeO	0,06
	O	40,82	60,79			3
	Totals	98,83				
					Cation sum	1,93

4	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,31	0,34	0,42	Na2O	0,02
	P	17,54	14,09	40,2	P2O5	0,72
	Cl	5,98	4,2	0		0,22
	Ca	36,44	22,61	50,98	CaO	1,16
	Fe	0,86	0,38	1,11	FeO	0,02
	O	37,56	58,38			3
	Totals	98,7				
					Cation sum	1,92

5	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,34	0,37	0,46	Na2O	0,02
	P	17,81	14,27	40,8	P2O5	0,73
	Cl	6,32	4,43	0		0,23
	Ca	35,31	21,87	49,4	CaO	1,12
	Fe	1,49	0,66	1,92	FeO	0,03
	O	37,63	58,4			3
	Totals	98,9				
					Cation sum	1,91

Oxygen by stoichiometry and All elements analyzed
Standard: Albite 15kV060404, Apatite 15kV060404, KCl 15kV060404,
SiO2 15kV990601, FeS2 15kV990601, Taylorolivin 15kV060404, K-fsp 15kV060404,
Mo 15kV990601, Titanite 15kV060404, Chromite 15kV 060317, Rodonite 15kV060404,
Wollastonite15kV060404, Hematite15kV060404, Spinel 15kV060405, SrF2 15kV990601
Talorolivine 15kV060404

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pyroxene 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,26	0,23	0,35	Na2O	0,02
	Mg	14,89	12,75	24,7	MgO	1,28
	Si	26,86	19,9	57,47	SiO2	1,99
	Ca	9,26	4,81	12,96	CaO	0,48
	Cr	0,41	0,17	0,6	Cr2O3	0,02
	Mn	0,35	0,13	0,45	MnO	0,01
	Fe	5,58	2,08	7,18	FeO	0,21
	O	46,08	59,93			6
	Totals	103,69				
					Cation sum	4,01

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,7	0,64	0,95	Na2O	0,06
	Mg	11,17	9,69	18,52	MgO	0,97
	Si	26,57	19,95	56,84	SiO2	2
	Ca	15,49	8,15	21,67	CaO	0,82
	Cr	1,17	0,48	1,71	Cr2O3	0,05
	Fe	3,04	1,15	3,91	FeO	0,11
	O	45,46	59,94			6
	Totals	103,6				
					Cation sum	4,01

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,11	16,92	31,69	MgO	1,7
	Si	25,64	19,65	54,85	SiO2	1,97
	Ca	0,43	0,23	0,6	CaO	0,02
	Mn	0,47	0,18	0,6	MnO	0,02
	Fe	8,3	3,2	10,68	FeO	0,32
	O	44,47	59,82			6
	Totals	98,41				
					Cation sum	4,03

4	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,77	16,93	32,79	MgO	1,7
	Si	26,63	19,74	56,98	SiO2	1,98
	Ca	0,43	0,22	0,6	CaO	0,02
	Mn	0,38	0,14	0,49	MnO	0,01
	Fe	8,3	3,09	10,68	FeO	0,31
	O	46,01	59,87			6
	Totals	101,52				
					Cation sum	4,02

5	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	10,7	9,74	17,74	MgO	0,98
	Si	25,12	19,8	53,74	SiO2	1,98
	Ca	15,42	8,51	21,57	CaO	0,85
	Mn	0,38	0,15	0,49	MnO	0,02
	Fe	4,8	1,9	6,17	FeO	0,19
	O	43,3	59,9			6
	Totals	99,71				
					Cation sum	4,02

6	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	20,36	16,93	33,75	MgO	1,7
	Si	27,19	19,58	58,16	SiO2	1,96
	Ca	0,49	0,25	0,68	CaO	0,02
	Mn	0,45	0,16	0,58	MnO	0,02
	Fe	9,1	3,29	11,7	FeO	0,33
	O	47,3	59,79			6
	Totals	104,87				
					Cation sum	4,04

7	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,85	16,7	32,92	MgO	1,67
	Si	27,21	19,81	58,21	SiO2	1,98
	Ca	0,45	0,23	0,62	CaO	0,02
	Mn	0,38	0,14	0,5	MnO	0,01
	Fe	8,78	3,22	11,3	FeO	0,32
	O	46,87	59,91			6
	Totals	103,54				
					Cation sum	4,02

8	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,65	16,85	32,59	MgO	1,69
	Si	26,47	19,65	56,63	SiO2	1,97
	Ca	0,33	0,17	0,47	CaO	0,02
	Mn	0,55	0,21	0,7	MnO	0,02
	Fe	8,84	3,3	11,37	FeO	0,33
	O	45,91	59,82			6
	Totals	101,76				
					Cation sum	4,03

9	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,21	16,6	31,85	MgO	1,66
	Al	0,32	0,25	0,61	Al2O3	0,03
	Si	26,21	19,61	56,06	SiO2	1,96
	Ca	0,48	0,25	0,68	CaO	0,03
	Mn	0,39	0,15	0,5	MnO	0,01
	Fe	8,7	3,27	11,19	FeO	0,33
	O	45,58	59,87			6
	Totals	100,89				
					Cation sum	4,02

10	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,37	16,73	32,11	MgO	1,68
	Si	26,45	19,77	56,57	SiO2	1,98
	Ca	0,5	0,26	0,7	CaO	0,03
	Fe	8,94	3,36	11,5	FeO	0,34
	O	45,63	59,88			6
	Totals	100,88				
					Cation sum	4,02

11	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,64	16,83	32,56	MgO	1,69
	Si	26,66	19,77	57,03	SiO2	1,98
	Ca	0,35	0,18	0,49	CaO	0,02
	Fe	8,93	3,33	11,49	FeO	0,33
	O	46	59,89			6
	Totals	101,57				
					Cation sum	4,02

12	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,26	16,88	31,93	MgO	1,69
	Si	25,92	19,66	55,44	SiO2	1,97
	Ca	0,53	0,28	0,75	CaO	0,03
	Fe	8,76	3,34	11,27	FeO	0,34
	O	44,92	59,83			6
	Totals	99,39				
					Cation sum	4,03

13	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	20,16	16,78	33,43	MgO	1,68
	Si	27,35	19,7	58,52	SiO2	1,98
	Ca	0,45	0,23	0,63	CaO	0,02
	Fe	9,5	3,44	12,22	FeO	0,34
	O	47,33	59,85			6
	Totals	104,79				
					Cation sum	4,02

14	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	20,14	16,61	33,4	MgO	1,67
	Si	27,59	19,69	59,01	SiO2	1,97
	Ca	0,54	0,27	0,75	CaO	0,03
	Mn	0,48	0,18	0,62	MnO	0,02
	Fe	9,5	3,41	12,22	FeO	0,34
	O	47,76	59,85			6
	Totals	106,01				
					Cation sum	4,03

15	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	20,44	16,77	33,9	MgO	1,68
	Si	27,66	19,65	59,17	SiO2	1,97
	Ca	0,48	0,24	0,67	CaO	0,02
	Mn	0,51	0,18	0,65	MnO	0,02
	Fe	9,33	3,33	12	FeO	0,33
	O	47,98	59,82			6
	Totals	106,4				
					Cation sum	4,03

16	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	20,16	16,79	33,43	MgO	1,69
	Si	27,12	19,55	58,02	SiO2	1,96
	Ca	0,42	0,21	0,59	CaO	0,02
	Mn	0,56	0,21	0,72	MnO	0,02
	Fe	9,56	3,46	12,29	FeO	0,35
	O	47,24	59,78			6
	Totals	105,06				
					Cation sum	4,04

17	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	19,96	16,84	33,1	MgO	1,69
	Si	27,1	19,79	57,97	SiO2	1,98
	Ca	0,32	0,17	0,45	CaO	0,02
	Fe	9,04	3,32	11,63	FeO	0,33
	O	46,73	59,89			6
	Totals	103,15				
					Cation sum	4,02

Oxygen by stoichiometry

Standard: Albite 15kV060404, Talorolivine 15kV060404, Wollastonite15kV060404, Rodonite 15kV060404, Hematit15kV060404, Spinel 15kV060405 Chromite 15kV060317

olivine 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	26,93	23,57	44,66	MgO	1,65
	Si	18,57	14,07	39,73	SiO2	0,99
	Mn	0,36	0,14	0,47	MnO	0,01
	Fe	13,62	5,19	17,53	FeO	0,36
	O	42,89	57,03			4
	Totals	102,38				
					Cation sum	3,01

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	26,82	23,51	44,47	MgO	1,65
	Si	18,69	14,18	39,98	SiO2	0,99
	Mn	0,36	0,14	0,46	MnO	0,01
	Fe	13,33	5,09	17,15	FeO	0,36
	O	42,86	57,09			4
	Totals	102,06				
					Cation sum	3,01

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	26,35	23,39	43,7	MgO	1,64
	Si	18,46	14,18	39,49	SiO2	0,99
	Mn	0,37	0,15	0,48	MnO	0,01
	Fe	13,44	5,19	17,3	FeO	0,36
	O	42,33	57,09			4
	Totals	100,96				
					Cation sum	3,01

4	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	26,99	23,75	44,76	MgO	1,66
	Si	18,64	14,2	39,89	SiO2	0,99
	Fe	12,92	4,95	16,63	FeO	0,35
	O	42,71	57,1			4
	Totals	101,27				
					Cation sum	3,01

5	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	26,93	23,64	44,66	MgO	1,66
	Si	18,37	13,96	39,31	SiO2	0,98
	Mn	0,47	0,18	0,61	MnO	0,01
	Fe	13,72	5,24	17,65	FeO	0,37
	O	42,73	56,98			4
	Totals	102,23				
					Cation sum	3,02

6	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	25,59	23,45	42,42	MgO	1,64
	Si	17,85	14,17	38,2	SiO2	0,99
	Mn	0,39	0,16	0,5	MnO	0,01
	Fe	12,88	5,14	16,57	FeO	0,36
	O	40,98	57,08			4
	Totals	97,68				
					Cation sum	3,01

7	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	25,09	23,43	41,6	MgO	1,64
	Si	17,48	14,13	37,4	SiO2	0,99
	Mn	0,37	0,15	0,47	MnO	0,01
	Fe	12,86	5,23	16,54	FeO	0,37
	O	40,22	57,07			4
	Totals	96,02				
					Cation sum	3,01

8	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	27,27	23,59	45,22	MgO	1,65
	Si	18,84	14,11	40,31	SiO2	0,99
	Mn	0,37	0,14	0,47	MnO	0,01
	Fe	13,57	5,11	17,45	FeO	0,36
	O	43,41	57,05			4
	Totals	103,45				
					Cation sum	3,01

9	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	27,39	23,52	45,41	MgO	1,65
	Si	18,86	14,02	40,35	SiO2	0,98
	Mn	0,36	0,14	0,46	MnO	0,01
	Fe	14,2	5,31	18,27	FeO	0,37
	O	43,69	57,01			4
	Totals	104,5				
					Cation sum	3,02

10	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	27,67	23,6	45,89	MgO	1,65
	Si	19,08	14,08	40,82	SiO2	0,99
	Mn	0,38	0,14	0,49	MnO	0,01
	Fe	13,82	5,13	17,78	FeO	0,36
	O	44,02	57,04			4
	Totals	104,97				
					Cation sum	3,01

11	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	27,73	23,51	45,98	MgO	1,65
	Si	19,15	14,05	40,97	SiO2	0,99
	Mn	0,35	0,13	0,45	MnO	0,01
	Fe	14,32	5,29	18,43	FeO	0,37
	O	44,27	57,03			4
	Totals	105,82				
					Cation sum	3,01

12	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	26,83	23,39	44,49	MgO	1,64
	Si	18,73	14,13	40,07	SiO2	0,99
	Mn	0,37	0,14	0,48	MnO	0,01
	Fe	13,9	5,28	17,89	FeO	0,37
	O	43,09	57,06			4
	Totals	102,92				
					Cation sum	3,01

13	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	27,49	23,55	45,59	MgO	1,65
	Si	19,04	14,12	40,74	SiO2	0,99
	Fe	14,12	5,27	18,17	FeO	0,37
	O	43,83	57,06			4
	Totals	104,49				
					Cation sum	3,01

14	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	25,97	23,57	43,06	MgO	1,65
	Si	17,98	14,12	38,46	SiO2	0,99
	Fe	13,28	5,25	17,09	FeO	0,37
	O	41,38	57,06			4
	Totals	98,61				
					Cation sum	3,01

Oxygen by stoichiometry

Standard: Talorolivine 15kV060404, Wollastonite15kV060404, Hematite15kV060404, Rodonite 15kV060404

metal 1	Element	Weight%	Atomic%
	Fe	91,41	97,63
	Ni	2,33	2,37
	Totals	93,74	

2	Element	Weight%	Atomic%
	Fe	89,61	97,15
	Ni	2,77	2,85
	Totals	92,38	

3	Element	Weight%	Atomic%
	Fe	86,36	94,74
	Ni	5,04	5,26
	Totals	91,4	

chromite 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	0,31	0,42	0,42	Na2O	0,03
	Mg	1,7	2,16	2,82	MgO	0,15
	Al	3,36	3,85	6,35	Al2O3	0,27
	Ti	1,19	0,77	1,98	TiO2	0,05
	V	0,48	0,29	0,71	V2O3	0,02
	Cr	38,24	22,7	55,89	Cr2O3	1,59
	Mn	0,93	0,52	1,2	MnO	0,04
	Fe	22,25	12,3	28,63	FeO	0,86
	O	29,53	56,99			4
	Totals	97,99				
					Cation sum	3,02

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	2,84	3,55	4,71	MgO	0,25
	Al	3,42	3,86	6,47	Al2O3	0,27
	Ca	0,35	0,26	0,48	CaO	0,02
	Ti	1,38	0,87	2,3	TiO2	0,06
	Cr	38,99	22,82	56,98	Cr2O3	1,6
	Mn	0,65	0,36	0,84	MnO	0,03
	Fe	20,48	11,16	26,34	FeO	0,78
	O	30,02	57,11			4
	Totals	98,12				
					Cation sum	3

feldspar	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
1	Na	5,74	6	7,74	Na2O	0,79
	Mg	2,63	2,6	4,37	MgO	0,34
	Al	7,78	6,92	14,7	Al2O3	0,91
	Si	24,27	20,75	51,93	SiO2	2,74
	K	0,3	0,18	0,36	K2O	0,02
	Ca	2,93	1,76	4,1	CaO	0,23
	Fe	2,88	1,24	3,71	FeO	0,16
	O	40,36	60,56			8
	Totals	86,9				
					Cation sum	5,21
2	Na	5,73	5,83	7,72	Na2O	0,77
	Mg	1,7	1,63	2,81	MgO	0,21
	Al	8,06	6,99	15,23	Al2O3	0,92
	Si	25,59	21,33	54,74	SiO2	2,8
	K	0,41	0,25	0,5	K2O	0,03
	Ca	4,55	2,66	6,37	CaO	0,35
	Fe	0,99	0,42	1,28	FeO	0,05
	O	41,62	60,89			8
	Totals	88,65				
					Cation sum	5,14
3	Na	7,56	6,65	10,19	Na2O	0,86
	Mg	0,1	0,08	0,16	MgO	0,01
	Al	11,16	8,37	21,09	Al2O3	1,09
	Si	31,12	22,41	66,57	SiO2	2,91
	Ca	1,42	0,71	1,98	CaO	0,09
	Fe	0,4	0,14	0,51	FeO	0,02
	O	48,76	61,63			8
	Totals	100,51				
					Cation sum	4,98
4	Na	6,12	5,53	8,25	Na2O	0,72
	Al	12,55	9,66	23,71	Al2O3	1,26
	Si	28,22	20,88	60,37	SiO2	2,72
	Ca	4,28	2,22	5,98	CaO	0,29
	Fe	0,63	0,24	0,82	FeO	0,03
	O	47,33	61,47			8
	Totals	99,12				
					Cation sum	5,01
5	Na	7,31	6,43	9,86	Na2O	0,84
	Mg	0,79	0,66	1,31	MgO	0,09
	Al	11,39	8,54	21,52	Al2O3	1,11
	Si	30,12	21,69	64,44	SiO2	2,83
	Ca	2,06	1,04	2,88	CaO	0,14
	Fe	0,74	0,27	0,95	FeO	0,03
	O	48,54	61,37			8
	Totals	100,95				
					Cation sum	5,04

sulphide	Element	Weight%	Atomic%
1	O	2,92	7,92
	S	35,79	48,41
	Fe	55,44	43,05
	Ni	0,85	0,63
	Totals	95	
2	S	39,58	52,56
	Fe	62,23	47,44
	Totals	101,81	
3	Si	0,16	0,25
	S	39,39	53,21
	Fe	60	46,54
	Totals	99,54	
4	S	39,35	52,71
	Fe	61,49	47,29
	Totals	100,84	
5	S	39	52,56
	Fe	61,3	47,44
	Totals	100,3	
6	Si	0,37	0,59
	S	38,43	52,65
	Fe	59,46	46,77
	Totals	98,27	
7	S	38,98	53,11
	Fe	59,94	46,89
	Totals	98,92	
8	S	38,57	52,5
	Fe	60,79	47,5
	Totals	99,37	

phosphate	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
1	P	18,09	14,18	41,44	P2O5	1,8
	Cl	7,06	4,84	0		0,61
	Ca	37,12	22,49	51,94	CaO	2,85
	Fe	0,64	0,28	0,82	FeO	0,04
	O	38,36	58,22			7,39
	Totals	101,26				
					Cation sum	4,69
2	Mg	2,47	2,43	4,09	MgO	0,98
	P	20,4	15,8	46,74	P2O5	6,39
	Ca	33,25	19,91	46,52	CaO	8,05
	O	41,23	61,85			25
	Totals	97,35				
					Cation sum	15,42
3	P	18,49	14,23	42,37	P2O5	5,64
	Cl	7,03	4,73	0		1,87
	Ca	37,79	22,47	52,87	CaO	8,91
	Fe	0,61	0,26	0,79	FeO	0,1
	O	39,14	58,31			23,13
	Totals	103,06				
					Cation sum	14,66
4	Na	2,12	2,15	2,86	Na2O	0,88
	Mg	2,28	2,18	3,78	MgO	0,89
	P	20,69	15,53	47,4	P2O5	6,35
	Ca	32,84	19,04	45,94	CaO	7,79
	O	42,06	61,11			25
	Totals	99,98				
					Cation sum	15,91
5	Mg	2,54	2,5	4,21	MgO	1,01
	P	20,22	15,61	46,34	P2O5	6,33
	Ca	33	19,69	46,17	CaO	7,98
	Fe	1,15	0,49	1,47	FeO	0,2
	O	41,29	61,71			25
	Totals	98,19				
					Cation sum	15,51

altered material	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
1	Fe	62,3	33,87	89,06	Fe2O3	1,74
	Ni	14,81	7,66	18,85	NiO	0,39
	O	30,81	58,47			3
	Totals	107,92				
					Cation sum	2,13
2	Fe	71,08	34,85	101,63	Fe2O3	1,78
	Ni	13,81	6,44	17,57	NiO	0,33
	O	34,31	58,71			3
	Totals	119,2				
					Cation sum	2,11
3	Fe	70,84	34,97	101,29	Fe2O3	1,79
	Ni	13,38	6,28	17,03	NiO	0,32
	O	34,09	58,74			3
	Totals	118,32				
					Cation sum	2,11
4	Ca	0,33	0,3	0,46	CaO	0,01
	Fe	59,96	38,46	85,73	Fe2O3	1,94
	Ni	2,68	1,63	3,41	NiO	0,08
	O	26,63	59,61			3
	Totals	89,6				
					Cation sum	2,03
5	Fe	60,5	38,94	86,5	Fe2O3	1,96
	Ni	2,16	1,32	2,75	NiO	0,07
	O	26,59	59,74			3
	Totals	89,25				
					Cation sum	2,02

Oxygen by stoichiometry and All elements analyzed
Standard: SiO2 15kV990601, Talorolivine 15kV060404, Wollastonit15kV060404 , Hematite15kV060404, Taylorolivine 15kV060317, Apatite 15kV060404, Titanite15kV060404, Chromite15kV060317, K-fsp15kV060404, V15kV990601, KCl15kV990601, FeS2 15kV990601, Albite15kV060404, Spinel15kV060405, Mo15kV990601

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pyroxene	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
1	Mg	19,61	16,41	32,51	MgO	1,65
	Al	0,2	0,15	0,38	Al2O3	0,02
	Si	26,96	19,52	57,67	SiO2	1,96
	Ca	0,87	0,44	1,21	CaO	0,04
	Cr	0,35	0,14	0,51	Cr2O3	0,01
	Mn	0,47	0,17	0,6	MnO	0,02
	Fe	9,16	3,34	11,79	FeO	0,33
	O	47,06	59,83			6
	Totals	104,67				
					Cation sum	4,03

2 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,93	16,62	33,05	MgO	1,66
Si	27,28	19,69	58,36	SiO2	1,97
Ca	0,45	0,23	0,63	CaO	0,02
Ti	0,27	0,11	0,45	TiO2	0,01
Mn	0,44	0,16	0,57	MnO	0,02
Fe	9,05	3,28	11,64	FeO	0,33
O	47,28	59,9			6
Totals	104,7				
				Cation sum	4,02

3 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,39	16,9	33,81	MgO	1,69
Si	27,49	19,72	58,82	SiO2	1,98
Ca	0,43	0,22	0,61	CaO	0,02
Mn	0,35	0,13	0,45	MnO	0,01
Fe	8,82	3,18	11,35	FeO	0,32
O	47,54	59,86			6
Totals	105,03				
				Cation sum	4,02

4 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,83	16,65	34,54	MgO	1,67
Si	28,71	19,86	61,42	SiO2	1,99
Ca	0,48	0,23	0,67	CaO	0,02
Mn	0,37	0,13	0,48	MnO	0,01
Fe	9,22	3,21	11,86	FeO	0,32
O	49,36	59,93			6
Totals	108,97				
				Cation sum	4,01

5 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,95	16,74	33,09	MgO	1,68
Si	27,15	19,71	58,08	SiO2	1,98
Ca	0,43	0,22	0,6	CaO	0,02
Mn	0,47	0,17	0,6	MnO	0,02
Fe	9,04	3,3	11,63	FeO	0,33
O	46,96	59,86			6
Totals	104				
				Cation sum	4,02

6 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,12	16,69	33,35	MgO	1,67
Si	27,43	19,7	58,68	SiO2	1,97
Ca	0,45	0,23	0,63	CaO	0,02
Mn	0,55	0,2	0,72	MnO	0,02
Fe	9,23	3,34	11,88	FeO	0,33
O	47,47	59,85			6
Totals	105,26				
				Cation sum	4,03

7 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,24	16,73	33,56	MgO	1,68
Si	27,72	19,83	59,3	SiO2	1,99
Ca	0,37	0,18	0,52	CaO	0,02
Mn	0,41	0,15	0,53	MnO	0,02
Fe	8,86	3,19	11,4	FeO	0,32
O	47,7	59,92			6
Totals	105,3				
				Cation sum	4,01

8 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,76	16,64	32,76	MgO	1,67
Si	26,95	19,65	57,65	SiO2	1,97
Ca	0,57	0,29	0,8	CaO	0,03
Mn	0,33	0,12	0,42	MnO	0,01
Fe	9,48	3,48	12,2	FeO	0,35
O	46,74	59,82			6
Totals	103,83				
				Cation sum	4,03

9 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,93	16,73	33,04	MgO	1,68
Si	27,29	19,84	58,39	SiO2	1,99
Ca	0,56	0,28	0,78	CaO	0,03
Fe	8,81	3,22	11,34	FeO	0,32
O	46,96	59,92			6
Totals	103,55				
				Cation sum	4,01

10 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,04	16,78	33,23	MgO	1,68
Si	27,2	19,7	58,18	SiO2	1,98
Ca	0,38	0,19	0,53	CaO	0,02
Mn	0,36	0,13	0,47	MnO	0,01
Fe	9,17	3,34	11,8	FeO	0,34
O	47,06	59,85			6
Totals	104,21				
				Cation sum	4,02

11 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,89	16,8	32,98	MgO	1,68
Si	27,06	19,79	57,9	SiO2	1,98
Ca	0,36	0,18	0,5	CaO	0,02
Mn	0,38	0,14	0,5	MnO	0,01
Fe	8,66	3,19	11,14	FeO	0,32
O	46,66	59,89			6
Totals	103,02				
				Cation sum	4,02

12 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,87	16,81	32,95	MgO	1,68
Si	26,93	19,71	57,61	SiO2	1,98
Ca	0,41	0,21	0,57	CaO	0,02
Mn	0,51	0,19	0,66	MnO	0,02
Fe	8,74	3,22	11,25	FeO	0,32
O	46,58	59,86			6
Totals	103,05				
				Cation sum	4,02

13 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	10,9	9,72	18,08	MgO	0,97
Si	25,88	19,97	55,37	SiO2	1,99
Ca	15,8	8,54	22,1	CaO	0,85
Ti	0,39	0,18	0,65	TiO2	0,02
Cr	0,63	0,26	0,92	Cr2O3	0,03
Fe	3,06	1,19	3,94	FeO	0,12
O	44,39	60,14			6
Totals	101,06				
				Cation sum	3,98

14 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	10,3	9,14	17,07	MgO	0,91
Al	0,95	0,76	1,79	Al2O3	0,08
Si	25,52	19,61	54,59	SiO2	1,95
Ca	15,8	8,51	22,1	CaO	0,85
Ti	0,58	0,26	0,97	TiO2	0,03
Cr	0,88	0,36	1,28	Cr2O3	0,04
Fe	2,96	1,14	3,81	FeO	0,11
O	44,64	60,22			6
Totals	101,61				
				Cation sum	3,96

15 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,29	16,28	31,98	MgO	1,63
Al	0,65	0,5	1,24	Al2O3	0,05
Si	26,66	19,48	57,03	SiO2	1,95
Ca	0,57	0,29	0,8	CaO	0,03
Cr	0,44	0,17	0,64	Cr2O3	0,02
Mn	0,4	0,15	0,52	MnO	0,02
Fe	8,77	3,22	11,28	FeO	0,32
O	46,7	59,91			6
Totals	103,49				
				Cation sum	4,02

16 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	18,82	16,23	31,21	MgO	1,62
Si	26,76	19,97	57,25	SiO2	2
Ca	1,67	0,87	2,33	CaO	0,09
Fe	7,84	2,94	10,09	FeO	0,29
O	45,79	59,99			6
Totals	100,88				
				Cation sum	4

17 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	12,26	11,11	20,32	MgO	1,11
Si	25,68	20,16	54,94	SiO2	2,01
Ca	12,54	6,9	17,54	CaO	0,69
Cr	0,63	0,27	0,92	Cr2O3	0,03
Fe	3,6	1,42	4,63	FeO	0,14
O	43,65	60,15			6
Totals	98,36				
				Cation sum	3,98

18 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,43	16,77	32,22	MgO	1,68
Si	26,37	19,71	56,42	SiO2	1,98
Ca	0,35	0,18	0,48	CaO	0,02
Fe	9,28	3,49	11,94	FeO	0,35
O	45,63	59,85			6
Totals	101,06				
				Cation sum	4,02

19 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	19,3	16,73	31,99	MgO	1,68
Si	26,16	19,63	55,97	SiO2	1,97
Ca	0,73	0,38	1,01	CaO	0,04
Mn	0,45	0,17	0,58	MnO	0,02
Fe	8,65	3,26	11,13	FeO	0,33
O	45,4	59,82			6
Totals	100,68				
				Cation sum	4,03

20 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	18,73	16,72	31,05	MgO	1,68
Si	25,59	19,77	54,73	SiO2	1,98
Ca	0,39	0,21	0,54	CaO	0,02
Fe	8,77	3,41	11,28	FeO	0,34
O	44,14	59,89			6
Totals	97,61				
				Cation sum	4,02

21 Element	Weight%	Atomic%	Compound%	Formula	Number of ions
Mg	20,23	16,75	33,54	MgO	1,68
Si	27,5	19,71	58,84	SiO2	1,98
Ca	0,49	0,25	0,69	CaO	0,02
Mn	0,59	0,22	0,76	MnO	0,02
Fe	8,94	3,22	11,5	FeO	0,32
O	47,57	59,86			6
Totals	105,32				
				Cation sum	4,02

Oxygen by stoichiometry
Standard: Talorolivine 15kV060404, Wollastonite15kV060404
Rodonite 15kV060404, Spinell 15kV060405, Titanite 15kV060404
Chromite 15kV060317, Hematite15kV060404

	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
olivine 1	Mg	27,49	23,54	45,59	MgO	1,65
	Si	19,01	14,09	40,67	SiO2	0,99
	Mn	0,41	0,16	0,53	MnO	0,01
	Fe	13,86	5,17	17,83	FeO	0,36
	O	43,84	57,04			4
	Totals	104,62				
					Cation sum	3,01
2	Mg	27,66	23,42	45,86	MgO	1,64
	Si	19,3	14,14	41,28	SiO2	0,99
	Mn	0,35	0,13	0,46	MnO	0,01
	Fe	14,21	5,24	18,28	FeO	0,37
	O	44,36	57,07			4
	Totals	105,88				
					Cation sum	3,01
3	Mg	27,62	23,45	45,8	MgO	1,65
	Si	19,1	14,04	40,87	SiO2	0,98
	Mn	0,55	0,21	0,72	MnO	0,01
	Fe	14,3	5,28	18,39	FeO	0,37
	O	44,2	57,02			4
	Totals	105,77				
					Cation sum	3,02
4	Mg	27,7	23,59	45,94	MgO	1,65
	Si	19,03	14,03	40,71	SiO2	0,98
	Fe	14,49	5,37	18,65	FeO	0,38
	O	44,06	57,01			4
	Totals	105,29				
					Cation sum	3,02
5	Mg	27,62	23,45	45,8	MgO	1,64
	Si	19,18	14,1	41,04	SiO2	0,99
	Mn	0,58	0,22	0,76	MnO	0,02
	Fe	14,05	5,19	18,08	FeO	0,36
	O	44,23	57,05			4
	Totals	105,67				
					Cation sum	3,01
6	Mg	26,29	22,18	43,6	MgO	1,55
	Si	20,29	14,81	43,4	SiO2	1,03
	Ca	0,93	0,47	1,3	CaO	0,03
	Mn	0,47	0,17	0,6	MnO	0,01
	Fe	13,48	4,95	17,34	FeO	0,34
	O	44,78	57,41			4
	Totals	106,24				
					Cation sum	2,97
7	Mg	27,63	23,57	45,81	MgO	1,65
	Si	19,06	14,08	40,78	SiO2	0,99
	Mn	0,41	0,16	0,54	MnO	0,01
	Fe	13,87	5,15	17,84	FeO	0,36
	O	43,99	57,04			4
	Totals	104,97				
					Cation sum	3,01
8	Mg	27,59	23,49	45,74	MgO	1,65
	Si	19,08	14,06	40,82	SiO2	0,99
	Fe	14,62	5,42	18,81	FeO	0,38
	O	44,08	57,03			4
	Totals	105,37				
					Cation sum	3,01
9	Mg	27,4	23,45	45,43	MgO	1,64
	Si	19,18	14,21	41,04	SiO2	1
	Fe	14,02	5,23	18,04	FeO	0,37
	O	43,9	57,11			4
	Totals	104,51				
					Cation sum	3
10	Mg	27,51	23,55	45,61	MgO	1,65
	Si	19,12	14,16	40,89	SiO2	0,99
	Fe	13,98	5,21	17,99	FeO	0,37
	O	43,89	57,08			4
	Totals	104,5				
					Cation sum	3,01
11	Mg	27,61	23,41	45,78	MgO	1,64
	Si	19,26	14,14	41,21	SiO2	0,99
	Mn	0,52	0,2	0,68	MnO	0,01
	Fe	14,04	5,18	18,06	FeO	0,36
	O	44,29	57,07			4
	Totals	105,72				
					Cation sum	3,01
12	Mg	27,17	23,58	45,04	MgO	1,65
	Si	18,69	14,04	39,99	SiO2	0,99
	Fe	14,18	5,36	18,25	FeO	0,38
	O	43,24	57,02			4
	Totals	103,28				
					Cation sum	3,01
13	Mg	25,58	22,58	42,41	MgO	1,58
	Si	18,32	14	39,19	SiO2	0,98
	S	0,25	0,17	0,63	SO3	0,01
	Fe	15,84	6,09	20,38	FeO	0,43
	O	42,62	57,17			4
	Totals	102,61				
					Cation sum	3
14	Mg	27,61	23,43	45,78	MgO	1,64
	Si	19,26	14,15	41,19	SiO2	0,99
	Fe	14,48	5,35	18,62	FeO	0,37
	O	44,25	57,07			4
	Totals	105,6				
					Cation sum	3,01

Oxygen by stoichiometry
Standard: Talorolivine 15kV060404, Wollastonite15kV060404, FeS2 15kV990601,
Rodonite 15kV060404, Hematit15kV060404

	Element	Weight%	Atomic%
metal 1	Fe	91,24	97,17
	Ni	2,8	2,83
	Totals	94,03	
2	Fe	90,13	97,27
	Ni	2,66	2,73
	Totals	92,8	
3	Fe	89,57	97,43
	Ni	2,48	2,57
	Totals	92,05	
4	Fe	91,42	97,16
	Ni	2,81	2,84
	Totals	94,23	
5	Fe	90,44	97,27
	Ni	2,67	2,73
	Totals	93,11	
6	Fe	89,57	97,43
	Ni	2,48	2,57
	Totals	92,05	
sulphide 1	S	40,1	54,36
	Fe	58,37	45,43
	Ni	0,29	0,21
	Totals	98,75	
2	O	3,69	9,07
	S	39,29	48,24
	Fe	60,56	42,69
	Totals	103,53	
3	O	3,78	9,48
	S	40,4	50,6
	Fe	52,47	37,74
	Ni	3,19	2,19
	Totals	99,84	
4	S	41,09	56,03
	Fe	54,25	42,47
	Ni	2,02	1,5
	Totals	97,35	
5	O	3,6	8,88
	S	40,42	49,68
	Fe	58,73	41,44
	Totals	102,75	

	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
chromite 1	Mg	2,03	2,56	3,36	MgO	0,18
	Al	3,4	3,87	6,43	Al2O3	0,27
	Ti	1,36	0,87	2,27	TiO2	0,06
	V	0,41	0,25	0,6	V2O3	0,02
	Cr	39,19	23,13	57,27	Cr2O3	1,62
	Fe	21,99	12,08	28,29	FeO	0,84
	O	29,84	57,25			4
	Totals	98,21				
					Cation sum	2,99

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	1,99	2,56	3,31	MgO	0,18
	Al	3,31	3,83	6,26	Al2O3	0,27
	Ti	1,31	0,85	2,19	TiO2	0,06
	Cr	38,52	23,09	56,3	Cr2O3	1,62
	Fe	22,42	12,51	28,85	FeO	0,88
	O	29,34	57,16			4
	Totals	96,9				
					Cation sum	3

altered material 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Cl	0,5	0,49	0		0,02
	Fe	62,92	39,27	89,95	Fe2O3	1,96
	Ni	1,13	0,67	1,44	NiO	0,03
	O	27,34	59,57			2,98
	Totals	91,89				
					Cation sum	1,99

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Si	0,64	0,77	1,38	SiO2	0,04
	Fe	64,94	39,08	92,85	Fe2O3	1,95
	O	28,64	60,15			3
	Totals	94,22				
					Cation sum	1,99

phosphates 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	2,44	2,37	4,04	MgO	0,12
	P	20,48	15,66	46,93	P2O5	0,76
	Ca	33,49	19,79	46,86	CaO	0,96
	Fe	0,82	0,35	1,18	Fe2O3	0,02
	O	41,77	61,83			3
	Totals	99,01				
					Cation sum	1,85

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	2,2	2,18	2,96	Na2O	0,11
	Mg	2,33	2,19	3,86	MgO	0,11
	P	20,73	15,29	47,51	P2O5	0,75
	Ca	33,32	18,99	46,62	CaO	0,93
	Fe	0,85	0,35	1,21	Fe2O3	0,02
	O	42,73	61,01			3
	Totals	102,16				
					Cation sum	1,92

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	2,48	2,37	4,11	MgO	0,11
	P	21,08	15,85	48,29	P2O5	0,77
	Ca	33,61	19,53	47,02	CaO	0,95
	Fe	0,69	0,29	0,99	Fe2O3	0,01
	O	42,56	61,96			3
	Totals	100,41				
					Cation sum	1,84

4	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	2,15	2,12	2,9	Na2O	0,1
	Mg	2,43	2,27	4,03	MgO	0,11
	P	21,16	15,52	48,49	P2O5	0,76
	Ca	33,49	18,98	46,85	CaO	0,93
	O	43,04	61,11			3
	Totals	102,28				
					Cation sum	1,91

feldspar 1	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Mg	6,63	5,91	11	MgO	0,76
	Al	4,96	3,98	9,38	Al2O3	0,51
	Si	28,46	21,94	60,89	SiO2	2,83
	Ca	10,1	5,46	14,13	CaO	0,7
	Fe	1,95	0,76	2,51	FeO	0,1
	O	45,8	61,96			8
	Totals	97,9				
					Cation sum	4,91

2	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	3,21	2,82	4,33	Na2O	0,36
	Al	9,25	6,93	17,47	Al2O3	0,9
	Si	32,93	23,7	70,44	SiO2	3,06
	K	8,16	4,22	9,83	K2O	0,54
	Ti	0,52	0,22	0,86	TiO2	0,03
	Fe	0,49	0,18	0,63	FeO	0,02
	O	49,01	61,93			8
	Totals	103,55				
					Cation sum	4,92

3	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	6,34	5,7	8,55	Na2O	0,75
	Mg	4,04	3,43	6,69	MgO	0,45
	Al	9,33	7,15	17,64	Al2O3	0,94
	Si	28,88	21,24	61,77	SiO2	2,79
	Ca	1,57	0,81	2,19	CaO	0,11
	Fe	1,87	0,69	2,41	FeO	0,09
	O	47,23	60,98			8
	Totals	99,26				
					Cation sum	5,12

4	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	4,7	4,33	6,33	Na2O	0,57
	Mg	1,01	0,88	1,68	MgO	0,12
	Al	9,2	7,22	17,38	Al2O3	0,94
	Si	29,25	22,06	62,56	SiO2	2,88
	K	4,31	2,34	5,19	K2O	0,31
	Ca	2,09	1,1	2,92	CaO	0,14
	Fe	2,39	0,91	3,08	FeO	0,12
	O	46,2	61,17			8
	Totals	99,15				
					Cation sum	5,08

5	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	6,63	5,84	8,94	Na2O	0,77
	Mg	1,68	1,4	2,79	MgO	0,18
	Al	9,24	6,94	17,46	Al2O3	0,91
	Si	30,2	21,78	64,6	SiO2	2,86
	K	1,13	0,58	1,36	K2O	0,08
	Ca	4,15	2,1	5,81	CaO	0,28
	Fe	0,93	0,34	1,19	FeO	0,04
	O	48,19	61,02			8
	Totals	102,15				
					Cation sum	5,11

6	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	5,65	5,04	7,62	Na2O	0,66
	Mg	1,9	1,6	3,15	MgO	0,21
	Al	8,16	6,19	15,41	Al2O3	0,81
	Si	30,58	22,31	65,43	SiO2	2,91
	S	0,31	0,2	0,78	SO3	0,03
	K	1,93	1,01	2,32	K2O	0,13
	Ca	3,48	1,78	4,88	CaO	0,23
	Fe	1,34	0,49	1,72	FeO	0,06
	O	47,95	61,39			8
	Totals	101,3				
					Cation sum	5,03

7	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	3,46	3,19	4,67	Na2O	0,42
	Mg	6,02	5,24	9,99	MgO	0,69
	Al	4,96	3,89	9,37	Al2O3	0,51
	Si	28,17	21,23	60,26	SiO2	2,8
	K	0,54	0,29	0,65	K2O	0,04
	Ca	9,25	4,89	12,95	CaO	0,64
	Fe	1,49	0,57	1,92	FeO	0,07
	O	45,9	60,72			8
	Totals	99,79				
					Cation sum	5,18

8	Element	Weight%	Atomic%	Compound%	Formula	Number of ions
	Na	6,55	5,99	8,82	Na2O	0,78
	Mg	0,27	0,23	0,44	MgO	0,03
	Al	9,95	7,75	18,79	Al2O3	1,01
	Si	30,14	22,56	64,48	SiO2	2,94
	K	2,73	1,47	3,29	K2O	0,19
	Ca	0,74	0,39	1,03	CaO	0,05
	Fe	0,71	0,27	0,91	FeO	0,03
	O	46,7	61,35			8
	Totals	97,77				
					Cation sum	5,04

Oxygen by stoichiometry and All elements analyzed

Standard: SiO2 15kV990601, Talorolivine 15kV060404, Wollastonit15kV060404 , Hematite15kV060404, Taylorolivine 15kV060317, Apatite 15kV060404, Titanite15kV060404, Chromite15kV060317, K-fsp15kV060404, V15kV990601, KCl15kV990601, FeS2 15kV990601, Albite15kV060404, Spinel15kV060405, Mo15kV990601

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