Macedonian Journal of Chemistry and Chemical Engineering, Vol. **28**, No. 1, pp. 41–48 (2009)
MJCCA9 – 532
ISSN 1857 – 5552
Received: March 3, 2009
UDC: 552.6 : 543.402(497.772)
Accepted: May 8, 2009

Professional paper

METEORITE *STRUGA* – OVERVIEW OF PREVIOUS CHEMICAL AND RECENT SPECTROSCOPIC ANALYSES

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Meteorite *Struga* fell more than 35 years ago near the town of Struga, Republic of Macedonia. Its fall was notified in the *Bulletien of the Geological Institute* in Skopje in 1973. Since that time, only one chemical analysis has been reported (in 1990) and most recently, preliminary spectrosocpic investigations (in 2006 and in 2008) have been performed. However, this meteorite has not yet been classified in the World's Database of Meteorites. The aim of this paper is to collect and summarize all available data published until now on this meteorite and open the possibility to clasify it and list it in the World's Database of Meteorites. In order to make the results more available, the details of the previous chemical and the recent spectrosocpic analyses on this meteorite are presented in this paper. Collected information from both analyses were used for the description of the characteristics of this meteorite. Previous chemical analysis and the recent spectrosocpic investigations are in good agreement and confirm the earlier classification of this meteorite as stony chondrite of H type.

Key words: stony chondrite; minerals in meteorites; chemical analysis; Raman and IR spectroscopic analysis

МЕТЕОРИТ *СТРУГА* – ПРЕГЛЕД НА ПРЕТХОДНАТА ХЕМИСКА И ПОСЛЕДНИТЕ СПЕКТРОСКОПСКИ АНАЛИЗИ

Пред повеќе од 35 години во рибарското место Калиште во непосредна близина на Струга, Република Македонија, падна метеоритот *Сшруīа*. Овој настан беше првпат објавен во „Наша вистина" – февруарско/мартовскиот број на *Гласникоӣ на Геолошкиоӣ инсӣиӣуӣ* во Скопје. Во 1990 година, е објавена прва детална хемиска анализа, а пред извесно време (во 2006 и 2008 година) се објавени првите резултати од спектроскопската анализа на овој метеорит. Сепак, и покрај овие испитувања, овој метеорит сè уште не е официјално регистриран во светската база на метеорити. Целта на овој труд е да се соберат сите досегашни резултати од испитувањата за овој метеорит, хемиски и спектросокопски, и да се отвори постапка за негово регистрирање во светската база на метеорити. Добиените информации од двете анализи (хемиската и спектроскопската) се искоритени за да се опишат карактеристиките на овој минерал. Претходната хемиска анализа и последните спектроскопски испитувања се во добра согласност и ја потврдуваат поранешната класификација на овој метеорит како камен хондрит од типот **H**.

Клучни зборови: камен хондрит; минерали во метеоритите; хемиска анализа; раманска и инфрацрвена спектроскопска анализа

INTRODUCTION

The meteorite *Struga* fell on September 27th 1972, around six o'clock in the morning, in the vicinity of the fisherman village Kalište near the town of Struga, located by the Ohrid Lake. Its fall was witnessed by the children going to school. They noticed a big light body, traveling towards them with great speed and hissing sound. It fell in the nearby field, about 40 m from the main road.

The first details about the meteorite and its fall were reported by Risto Stojanov in *"Naša*

Vistina" – the *Bulletien of the Geological Institute* (Skopje), in February/March 1973 [1]. He noted that the fall of the meteorite made a crater of around 1.5 m in radius; with many small pieces scattered around it. He assumed that its original weight was around 40 kg [1]. The early investigation on this meteorite indicated that it is most probably a stony chondrite[1], with 31 % magnetic fraction (mainly elementary iron) and 69 % non-magnetic fraction (mainly olivine and rhombohedral pyroxene) [1]. Part of this meteorite, about 2700 g, was donated to the Natural History Museum in Skopje, where it is presently exhibited in the Museum's mineralogical collection, its photograph is shown on Fig. 1.

Fig.1. Meteorite *Struga* exibited in the National History Museum in Skopje.
(Photograph was taken with the kind permission of the Director of the Museum Dr Gute Mladenovski, in 2005)

Besides the first and preliminary classification of the fallen meteorite, given in 1973 by Risto Stojanov [1], no other analyses were made for more than 15 years. In 1990, the first and detailed chemical analysis on this meteorite was reported by Gordana Musović, at the *XIIth Congress of Geologists of Yugoslavia* [4]. The meteorite was then given the name *Struga* and was classified as stony meteorite – ordinary chondrite of **H** group (or bronzite) [4][2].

The recent Raman and infrared investigations on mineralogical composition of this meteorite [7, 8] also confirmed that this meteorite is ordinary chondrite of H type. The minerals olivine, pyroxene and plagioclase were reported as the main mineral components in this meteorite, but also present were anatase and iron oxides such as magnetite and hematite.

Among more than 23 000 meterotites ("falls" or "finds") collected worldwide until now, this is so far the first and only information of the meteorite fall on the territory of the Republic of Macedonia[3]. However, this meteorite has not yet been officially classified and, consequently, not registered/listed in the World's Database of Meteorites.

According to the Guide to Meteorite Nomenclature [9], in order to register a meteorite it has to be given: (1) a name (and/or number); (2) class and petrological type; (3) time and place of fall (coordinates); (4) designation for shock (S); (5) weathering grade (W) or (WG) and (6) (Fa) (fayalite molecular %) or (Fo) (forsterite molecular %). Only after identifying and reporting these data, meteorite *Struga* can be approved by the Nomenclature Committee of the Meteoritical Society. Once approved, meteorite *Struga* will appear in *The Meteoritical Bulletin* published by *the Journal of Meteoritical Society* and will then be listed in the world's database of meteorites.

The aim of the present paper is to give an overview of the previous investigations on this meteorite and to present, in short, the recent spectroscopic results. The final aim is to collect all data on the meteorite *Struga* in order to make an application for its registration in the world's database of meteorites.

I. PREVIOUS ANALYSES

*The main results from the **chemical analysis** on the meteorite Struga – published in 1990 [4]*

The chemical analysis on the meteorite *Struga*, reported by G. Musović in 1990 [4], contained some important data about its chemical composition. Since this article was written in Ser-

[1] Chondrites are stony meteorites that have not melted since their aggregation early in the history of the Solar System. They have unfractionated elemental compositions that (apart from the most volatile of elements, such as hydrogen and helium) are close to the composition of the Sun, and thus of the original material from which the Solar System is formed. Almost all chondrites contain chondrules, spherical to sub-spherical assemblages of olivine, pyroxene and feldspar, up to 1 mm in diameter, that have been partially or totally melted prior to parent-body accretion [2, 3].

[2] According to the *Catalogue of Meteorites* (September 2000) [5, 6], only 4,5 % of the total number of meteorites are registered as "falls" and the rest as "finds". The majority of these "falls" are accounted to stony chondrite meteorites (82 %). Among these, 31,4 % are stony chondrite of type H (or bronzite types).

[3] According to data published in the *Catalogue of Meteorites* [5, 6], until the year 2000, 125 countries in the world have reported and registered meteorites. Republic of Macedonia, so far has not yet reported/registered a meteorite (neither "fallen" nor "find").

bian language, in order to make the results more available to the wider public, the main points of the chemical analysis for this meteorite will be presented below and summarized in Table 1.

(i) Some visual and macroscopic observations reported by G. Musović [4].

– The colour of the basic mass of the meteorite is ash grey, with, another, light-brown-yellowish colour scattered over it. The crust has dark dim colour (Fig. 1).

– The meteorite is very hard; its texture contains small and fine grains, less than 1 mm.

– The macroscopic mineralogical observation confirms the existence of mainly petrogenic minerals (feldspars, pyroxenes and olivines) and the presence of about 30% metal grains.

– The approximate ratio of magnetic *vs* non-magnetic fraction is 24.53 % to 75.47 %.

(ii) Summary of the results from the chemical analysis reported by G. Musović [4] are given on Table 1.

Table 1

Metal oxide content, metal content and stochiometric content of the main minerals in meteorite Struga

Metal oxide (%)		Metal (%)		Stochiometric content of the main minerals (%)	
SiO_2	35.60	Fe (met.)	19.32	**Olivines**	
MgO	21.96	Fe (total)	29.77	Forsterite (Mg_2SiO_4)	22.74
FeO	9.30	FeS	5.08	Fayalite (Fe_2SiO_4)	7.99
Al_2O_3	2.42	Ni	1.94	Ca_2SiO_4	0.60
CaO	1.90	Co	0.096	Tephroite (Mn_2SiO_4)	0.20
Na_2O	1.01	C	0.078	**Pyroxenes**	
Cr_2O_3	0.54			Enstatite ($MgSiO_3$)	22.04
MnO	0.28			Forresilite ($FeSiO_3$)	6.26
P_2O_5	0.28			Wollastonite ($CaSiO_3$)	2.77
K_2O	0.18			$MnSiO_3$	0.26
TiO_2	0.12			**Feldspars/Plagioclases**	
				Albite ($NaAlSi_3O_8$)	8.49
				Orthoclase ($KAlSi_3O_8$)	1.05
				Anortite ($CaAl_2Si_2O_8$)	0.70

(iii) The chemical analysis performed by G. Musović [4] also revealed that:

– The content of Fe in the magnetic fraction is 90.24 %, and the one of Ni is 9.14 %. Some metals, such as Co, Cu, Zn, P and C are found to be less than 1 % in total.

– The microelements found in the magnetic fraction are Cu, Zn, Sn, Mo and traces of Y. The microelements detected in the non-magnetic fraction are Pb, Cu and Sn and some traces of Zn and Mo.

– The ratio of the total amounts of olivines : pyroxenes : feldspars is 31.53 % : 31.33 % : 10.24 % respectively. This relation shows identical proportional representation of meta-silicates and ortho-silicates, whose typical representatives are pyroxene and olivine.

– The minerals plagioclases, chromite, triolite as well as nickel-ferrous iron were also separated and analyzed.

– The nickel ferrous iron was clearly magnetic; the ratio between the Fe and Ni was 1:10, which indicates that the mineral pleisite is present.

– During the analysis and chemical treatment, the iron mineral maintained its characteristics; the high metallic glow and crystal shape, which indicated that the gamma modification of iron (stable at temperatures around 900 ^{o}C) exists in the studied meteorite.

II. PRESENT SPECTROSCOPIC ANALYSIS

The results from the recent spectroscopic (IR and Raman) analysis on the meteorite Struga [7, 8]

Since the most important data for identification of the meteorites are connected with its mineralogical composition, an attempt was made to identify the major and/or minor minerals in the *Struga* meteorite by means of micro-Raman and FT-infrared spectroscopy. In the recent spectroscopic Raman and infrared [7, 8] analysis on this meteorite, the major minerals olivine, pyroxene and plagioclase were identified [7], along with some minor minerals, such as anatase, magnetite and hematite [8]. On the basis of the position of the Raman doublet in olivine (820 cm^{-1}/850 cm^{-1}), the forsterite value (Fo = Mg/(Mg+Fe)) was estimated to be 0.87 % [7, 8]. The abundance of the pyroxene minerals and the type of feldspars present in the studied meteorite were also determined. The experimental procedure and the results from the spectroscopic investigation on the meteorite *Struga* will be given below.

EXPERIMENTAL

– *Meteorite sample:* The sample of the meteorite *Struga*, taken for spectroscopic analysis (presented on Fig. 2), was provided from a private collection[4]. Its weigh was approximately 9 g; one of its sides was polished for the purpose of recording Raman spectra.

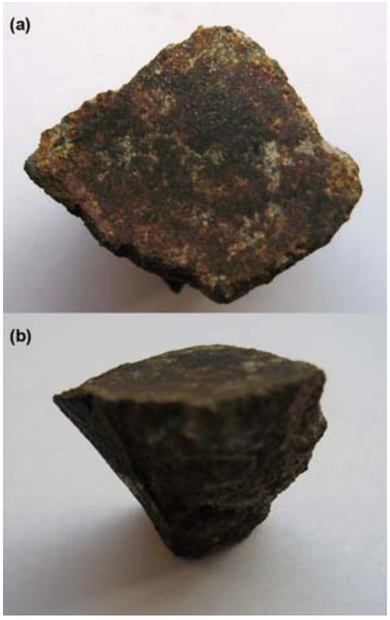

Fig. 2. A part of meteorite *Struga* (from a private collection) taken for spectroscopic analysis: (a) polished side; (b) front side

Spectroscopic measurements

– *Raman spectroscopy*: The first Raman spectra of the *Struga* meteorite [7] were recorded on a FORAM 685-2 micro-Raman spectrometer with 685 nm He–Ne laser line and 20 mW power, in the spectral range 2000–400 cm^{-1}. All spectra were acquired using ×20 objectives, with resolution of 7 cm^{-1} and spectrum accumulation of 30 s. The most recent Raman measurements [8] were performed with multi-channel micro-Raman LabRam 300 spectrometer (Horiba Jobin Yvon), in the spectral range between 3000 and 100 cm^{-1}, with 532 nm YAG laser line and 6.7 mW power on the sample. The magnification of the objective of ×50 and ×100 was used and the resolution was around 3 cm^{-1}. The spectra were recorded on a X,Y mapping stage (covering an area of 0.05×0.05 mm) with a step of 3–5 μm, acquiring around 100 Raman spectra. LabSpec software [10] was used for data acquisition and GRAMS software [11] for data manipulation. All spectra were baseline corrected.

– *FTIR spectroscopy*: A small amount of the powdered sample was taken for the infrared spectroscopic analysis. The magnetic fraction was separated from non-magnetic fraction (by hand, using a magnet). Infrared spectra were recorded for both the bulk of the meteorite and its magnetic fraction. Mid-infrared spectra (4000–400 cm^{-1}) were recorded in KBr pallets and the far infrared spectra (650–250 cm^{-1}) were recorded in Nujol mull. Both infrared and far infrared spectra were recorded on FTIR Perkin-Elmer 2000 interferometer. All spectra were baseline corrected.

RESULTS AND DISCUSSION

Spectroscopic measurements

(i) Raman data. The method of point-to-point micro-Raman spectra allowed recording various sites of the polished surface of the meteorite, and by using the magnification of ×50 and ×100 of the Raman microscope, it was possible to focus the laser on a small spot of approximately 1–5 μm. The minerals pyroxene, olivine, plagioclase, magnetite, hematite and anatase were identified; the recorded Raman spectra are presented on Fig. 3. The last spectrum on Fig. 3 represents the mixture of main minerals present in this meteorite.

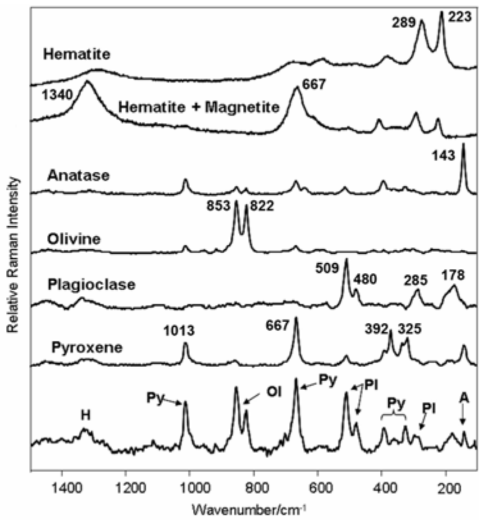

Fig. 3. Raman spectra of some minerals recorded from several points on the polished side of meteorite *Struga*. The last spectrum corresponds to the mixture of minerals: A = anatase; Pl = plagioclase; Py = pyroxene; Ol = olivine; H = hematite

[4] The sample of meteorite taken for spectroscopic analysis is the twin sample to meteorite *Struga* exhibited in the mineralogical collection in the National History Museum in Skopje.

The presence of *OLIVINE* in the *Struga* meteorite is clearly indicated by the characteristic doublet at 822/853 cm^{-1} (attributed to SiO_4 internal stretching vibrational modes). This doublet is a result of the coupling between the symmetric (ν_1) and anti symmetric (ν_3) stretching modes of Si–O_{nb} bonds in SiO_4 tetrahedra. The relative height of these peaks are a function of crystal orientation and their peak positions vary with fayalite (Fa)/forsterite (Fo) composition. It is reported in literature [12] that their peak positions shift upwards almost synchronously with the increasing of the Fo values (Fo = Mg/Mg+Fe) and can be used to detect the content of the fayalite (Fe_2SiO_4) and/or forsterite (Mg_2SiO_4) in the solid solution of the olivine–mineral $(FeMg)_2SiO_4$. [12]. In accordance with the calibration curve given in Ref. 12, the 822/853 cm^{-1} peak doublet in the Raman spectra of meteorite *Struga* (Fig. 4) leads to a conclusion that approximately 87 % of the mineral forsterite is present. This is in accordance with the results from the chemical analysis on this meteorite (see Table I), where the most abundant mineral in olivine was found to be forsterite, Mg rich olivine.

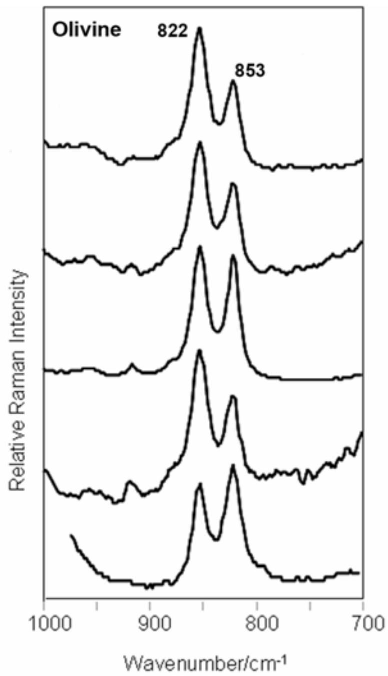

Fig. 4. Raman spectra of the mineral olivine recorded from different points on a polished surface of the meteorite *Struga*

As indicated by the chemical analysis, *PYROXENE* is equally abundant mineral as olivine in the *Struga* meteorite (Table I). The Raman spectral pattern of pyroxene is characterized by three spectral regions: (1) at about 1000 cm^{-1}, (2) near 670 cm^{-1}, and (3) 400 to 200 cm^{-1}. The frequencies of the Raman peaks in these regions shift gradually with Mg/Fe and Wo (wollastonite) content in pyroxenes. The recorded Raman spectra of *STRUGA* meteorite, with the Raman peaks at 1013, 667 and 325 cm^{-1} (Fig. 5) have a spectral pattern of clynopyroxene [13]. The major elemental composition of the (Mg, Fe, Ca)-pyroxenes can be semi-quantitatively determined on the basis of the peak positions of the characteristic Raman modes [13, 14]. Based on the correlation between the Raman peak positions at 325 cm^{-1} and at 667 cm^{-1} [14], the pyroxene mineral in Struga meteorite was identified as clynopyroxene with the approximate composition of the three constituent minerals: $En_{45}Fs_4Wo_{50}$ (En = Enstatite ($MgSiO_3$); Fs = Forresilite ($FeSiO_3$); Wo = Wollastonite ($CaSiO_3$)).

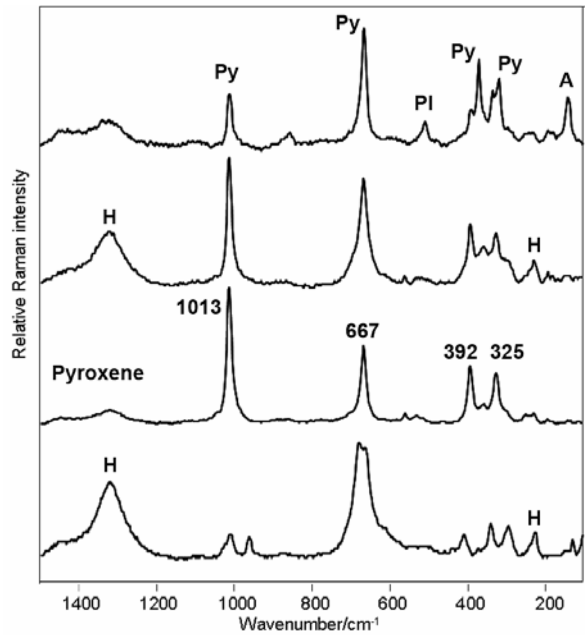

Fig. 5. Raman spectra of the mineral pyroxene recorded from recorded from different points on a polished surface of the meteorite *Struga*
A = anatase; Pl = plagioclase; Py = pyroxene; H = hematite

FELDSPARS/PLAGIOCLASES* were identified by the presence of the characteristic Raman bands (Fig. 6): (1) near 510 cm^{-1}, due to symmetric T–O stretching and O–T–O deformation modes of the TO_4 groups (T being Si or Al), (2) near 285 cm^{-1}, originating from the T–O–T and T–O–T lattice modes, and (3) between 170–180 cm^{-1}, due to lattice T–O–T and T–O lattice modes [15, 16].

* Solid solutions between feldspar minerals : albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$) are called plagioclases.

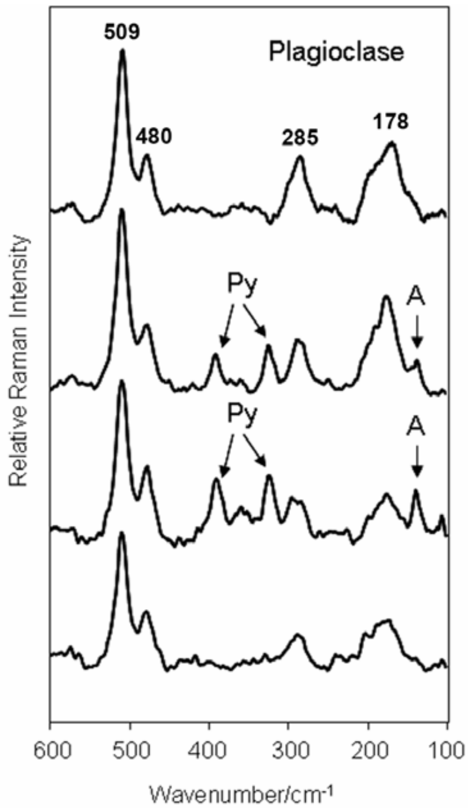

Fig. 6. Raman spectra of the mineral plagioclase recorded from recorded from different points on a polished surface of the meteorite *Struga* (A = anatase; Py = pyroxene)

Based on the correlation [16] between the Raman peak position at 509 cm^{-1} and at 171 cm^{-1} (observed in the Raman spectra of meteorite *Struga*), the feldspars/plagioclases in the *Struga* meteorite were identified as high temperature plagioclase [16]. The studies on seven types of different feldspars from the Haskin group [15] revealed that the chemical composition of the high temperature plagioclase is intermediate mixture of Na and Ca cations: $Na_xCa_{1-x}Al_{1+x}Si_{3-x}$ with Al–Si distribution structurally and compositionally disordered.

Some other minor minerals, such as anatase (TiO_2) and the iron oxides hematite (Fe_2O_3) and/or magnetite (Fe_3O_4), were also observed in the Raman spectra of *Struga* meteorite (Fig. 3).

(ii) Infrared data. The infrared spectrum of the meteorite *Struga* is shown on Fig. 7. The IR spectra of the bulk meteorite and its magnetic fraction are practically identical. The mid-infrared spectra (Fig. 7a), recorded in the 4000–400 cm^{-1} region showed one broad band (ranging from 1120 cm^{-1} to 890 cm^{-1}, with the centroide around 970 cm^{-1}) in the region of too bands due to antisymmetric stretching Si–O vibrations and the antisymmetric O–Si(Al)–O deformations (around 505 and 410 cm^{-1}). In the far-infared spectra, below 400 cm^{-1}, only few lattice modes were observed (Fig. 7b).

The mid-infrared spectra of the studied meteorite (Fig. 7a) indicate the presence of mixture of silicates (olivine, pyroxene and plagioclase) but also some crystalline water (~ 3400 cm^{-1}). The maximum of the broad band due to Si–O stretching vibrations (at 925 cm^{-1}) has many high frequency side bands at 950, 975, 1002, 1055 and 1120 cm^{-1}. The appearance of these bands is due to the Si–O mode originating from different silicate (mostly meta- and ortho-silicates) present in the meteorite. The band due to Si–O mode in olivine is reported at ~ 900 cm^{-1} [17, 18], in pyroxene, two strong bands have been found, at 965 and 1075 cm^{-1} [19] and in plagioclase, three bands were reported at 995, 1145 and 1160 cm^{-1} [20].

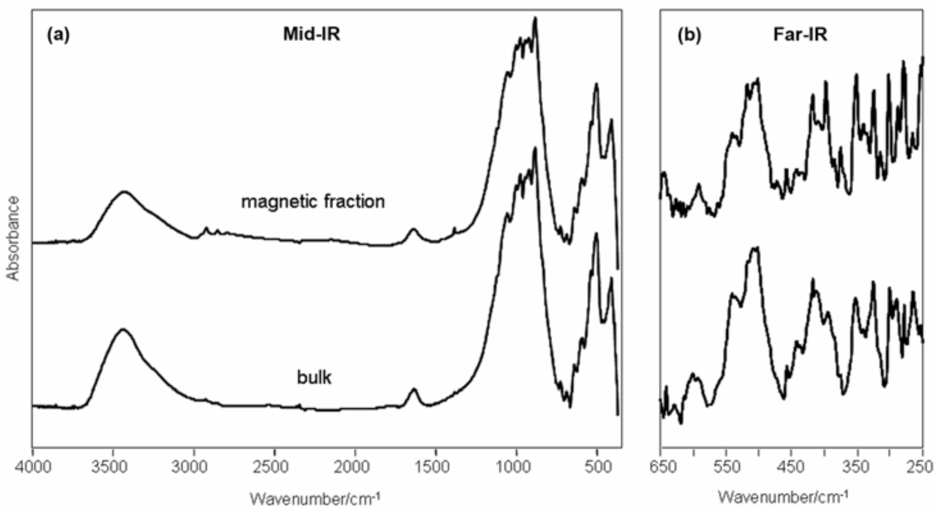

Fig. 7. Mid-IR (a) and far-IR (b) spectra of the magnetic fraction (upper spectrum) and of the bulk (lower spectrum) of the meteorite *Struga*

III. CONCLUSIONS

Chemical and spectroscopic analysis

The main idea behind this work was to summarize and present the results from previous chemical [4] and recent spectroscopic [7, 8] analyses.

The information obtained from the chemical analysis, although performed many years ago, is valuable and is in agreement with the present spectroscopic results. The recent spectroscopic study, on the other hand, demonstrates that basic, first order information on the mineralogy of the *Struga* meteorite could be obtained using *in situ* Raman measurement procedure. Data obtained from the IR spectra are supporting the Raman measurements but are not as informative.

The most important minerals, olivine, pyroxene and plagioclase, characteristic for chondrite meteorites have been identified both from the chemical and spectroscopic analysis, thus:

– Mg rich olivine, forsterite was found to be nearly 87%.

– Pyroxene mineral was identified as clynopyroxene with: $En_{45}Fs_4Wo_{50}$.

– Feldspars were mainly found as high temperature plagioclases (mostly sodium and potassium alumino-silacate).

– The presence of anatase (TiO_2) and iron oxides: hematite (Fe_2O_3) and magnetite (Fe_3O_4), were confirmed by their Raman spectra.

The collected information (chemical and spectroscopic) can be used to present the following description of the meteorite *Struga*:

- Name (and/or number): ***STRUGA***[5]
- Class and petrological type: **Chondrite of H type**[6], petrologic class: 5 or 6[7]
- Date, time and place of fall (coordinates): **27. 09 1972, around 6 a.m., Kalište (Struga), Republic of Macedonia (NAD83: 41° 08′ 27″ N; 20° 38′ 51″ E)**.
- Designation for shock (S): **Undetermined.**
- Weathering grade (W) or (WG): **Undetermined.**
- (Fo), Forsterite molecular %: **Fo: ~ 87 %**[8]

From this data, an initial information on this meteorite was obtained and the possibility for its final classification in the *Meteoritical Bulletin* published in *Meteoritics and Planetary Science* [9] has been opened.

5 The name *Struga*, although given to this meteorite nearly 20 years ago [4], is still its provisional name. It will only be accepted as a meteorite's name, after the approval from the Nomenclature Committee of the Meteoritical Society [9].

6 Ordinary chondrites of H type, have 25–31 % iron, more then half of it is in a free state. Meteorite Struga has ~ 30 % of total iron and ~ 19 % (more than half of it) is "free" iron (Table I).

7 The classification of stony chondrites depends on their composition and on their thermal methamorphism [17]. The presence of teanite (iron-nickel mineral) was detected from the chemical analysis [4] which confirms that *Struga* meteorite has been largely metamorphosed. In addition, in teanite, γ- modification of iron (stable at ≥ 900 °C) was also found from the chemical analysis. All this could indicate that the petrologic class of *Struga* meteorite is most probably 5 or 6.

8 Forsterite, Mg rich olivine has been also found as a main olivine mineral from the chemical analysis [4] (Table I).

REFERENCES

[1] Р. Стојанов, *Наша вистина* – Гласник на Геолошкиот Институт – Скопје, Година: VII., бр.2–3 (75), Февруари/Март 1973, стр. 10.

[2] http://en.wikipedia.org/wiki/Meteorites_classification, – last access to internet: 3.03.2009.

[3] http://www.meteorite.fr/en/claddification/stonymain.htm, – last access to internet: 3.03.2009.

[4] G. Мусовиќ, 12-ти Конгрес на геолозите на Југославија, книга II: Минерологија и петрологија (12th Congress of geologists of Yugoslavia, Book II, Mineralogy & Petrology), Ohrid 1990, p. 337–348.

[5] Monica Grady, *Catalogue of Meteorites*, Fifth Edition, Cambridge University Press, September 2000.

[6] http://www.nhm.ac.uk/reserach-curation/resaerch/projects/metcat/ – last access to internet: 27.02.2009

[7] B. Minčeva-Šukarova, Preliminary Spectroscopic Investigations of the Meteorite *Struga*, *5th International Conference of the Chemical Societies of the South-East European Countries, ICOSECS5*, Ohrid, September 2006, Book of Abstracts Vol.II, **PCH-34**, p.534.

[8] B. Minčeva-Šukarova and H. G. M. Edwards, Micro-Raman and SEM-EDX analysis of the meteorite *STRUGA* from the Republic of Macedonia, *GeoRaman '08 – 8th International Conference on Raman Spectroscopy Applied to the Earth Sciences – Sansu Latu*, June 2008, Ghent, Belgium, Book of Abstracts, p.102.

[9] Meteoritics and Planetary Science, *Journal of Meteoritical Society*, University of Arizona, Department of Geosciences, www.meteoritics.org – last access to internet: 02.03.2009.

[10] LabSpec Version 5.25.15

[11] GRAMS Analyst™ for PE 2000 FT-IR, Version 3.01 B, Level II, Galactic Industries, Corp., 1991–1994.

[12] K. Kuebler, B. L. Jolliff, A. Wang and L. A. Haskin, Extracting Olivine (Fo–Fa) composition from Raman

spectral peak positions, Abstracts for the *36th Lunar and Planetary Science Conf.*, Houston, Texas, March 2005.

[13] E. Huang, C. H. Chen, T. Huang, E. H. Lin and Ji-an Xu, Raman spectroscopic characteristics of Mg-Fe-Ca pyroxens, *American Mineralogist*, **85,** 473–479 (2000).

[14] A. Wang, B. L. Jolliff, L. A. Haskin, K. Kuebler, Raman Spectra Features of Pyroxene – Application to Martian Meteorites Zagami & EEtA 79001, *30th Annual Lunar & Planetary Science Conf.*, Houston, Texas, March 1999, Abstract No. 1666.

[15] http://epsc.wustl.edu/haskin-group/Raman.htm – last access to internet: 26.02.2009

[16] J. J. Freeman, A. Wang, K. E. Kuebler, L. A. Haskin, Raman spectroscopic characterization of the feldspars – implications for *in situ* surface mineral characterization in planetary exploration, *34th Lunar and Planetary Science Conf.*, League City, Texas, March 2003, Abstract No. 1676.

[17] A. Morlok, G. C. Jones, M. M. Grady, FT-IR microspectroscopy of fine-grained planetary materials: Further results, *35th Lunar and Planetary Science Conf.*, League City, Texas, March (2004), Abstract No. 1622.

[18] P. Makreski, G. Jovanovski, S. Stojančevska, Minerals from Macedonia, XIII: Vibrational spectra of some commonly appearing nesosilicate minerals, *J. Mol. Struct*. **744–747**, 79–92 (2005).

[19] P. Makreski, G. Jovanovski, A. Gajović, T. Biljan, D. Angelovski, R. Jaćimović, Minerals from Macedonia, XVI: Vibrational spectra of some common appearing pyroxenes and pyroxenoids, *J. Mol. Struct*. **788**, 102–114 (2006).

[20] P. Makreski, G. Jovanovski, B. Kaitner, Minerals from Macedonia, XXIV. Spectra-structure characterization of tectosilicates, *J. Mol. Struct*. **924–926**, 413–419. (2009).