A study on chemical composition of Baszkówka and Mt. Tazerzait chondrites

Rajmund DYBCZYŃSKI, Jadwiga CHWASTOWSKA, Bożena DANKO, Krzysztof KULISA,
Halina POLKOWSKA-MOTRENKO, Zbigniew SAMCZYŃSKI, Elżbieta STERLIŃSKA and Zygmunt SZOPA

The elemental contents of two new meteorites, Baszkówka (Poland, 1994) and Mt.Tazerzait (Niger, 1991), were studied by instrumental and radiochemical neutron activation analysis (NAA), supplemented in the case of some elements by gravimetric, titrimetric, spectrophotometric and atomic absorption spectrometric measurements. In total 28 elements were determined for each meteorite. A striking similarity in the bulk chemical composition of the two meteorites was observed. In the case of Baszkówka some study of the elemental contents of the magnetic fraction and the distribution of elements between kamacite and taenite phases was also made. This study confirms that Baszkówka and Mt. Tazerzait are generally more similar to L chondrites than to any other class of chondrites. However both meteorites show also some distinctive features (e.g very low Hg content), distinguishing them from all other L chondrites known. Both meteorites may derive from a common parent body, which may be different from that typical for other chondrites.

Rajmund Dybczyński, Jadwiga Chwastowska, Bożena Danko, Krzysztof Kulisa, Halina Polkowska-Motrenko, Zbigniew Samczyński, Elżbieta Sterlińska and Zygmunt Szopa, Department of Analytical Chemistry, Institute of Nuclear Chemistry and Technology, Dorodna 16, PL-03-195 Warszawa, Poland, e-mail: rdybczyn@orange.ichtj.waw.pl (received: July 27, 2000; accepted: September 29, 2000).

INTRODUCTION

Meteorites, which are sometimes poetically called "Messengers from Space" (Heide and Wlotzka, 1995), are extraterrestrial objects, the analysis of which can provide unique information on the composition of the Earth's interior i.e. the region that is not and probably never will be accessible to our direct observation, because it is believed that the Earth as a whole has chondritic composition. Meteorites are rare. Although it is estimated that over 4000 meteorites fall to the Earth each year, only a small percentage of them is recovered. The world collection by 1969 amounted roughly to 3000. A further 10 000 have been found since, in the hot and cold deserts of the Antarctic, Australia and Africa (Ulyanov, 1998).

The full list of Polish meteorites does not exceed 20, and the one before the last (Łowicz) fell in 1935.

The Baszkówka meteorite which fell on August 25, 1994 in a small village (Baszkówka near Warszawa, Poland) is unique also in this respect that it is a single oriented stone weighing 15.5 kg covered with a beautiful glassy crust of solidified melt (regmaglypts) what suggests that the meteorite did not somersault when passing through the Earth's atmosphere. The meteorite was collected soon after its fall almost intact (Stępniewski *et al.,* 1996, 1998*b*). Such wellpreserved meteorites are extremely rare and represent only a fraction of one percent of all collected meteorites.

Dr. M. Stępniewski of the Polish Geological Institute deserves credit for this initiative to characterize this unique specimen by a representative group of Polish laboratories and persuading scientists of various disciplines to take part in this enterprise.

Neutron activation analysis (NAA) occupies a special place in the array of methods of inorganic trace analysis because of its high precision, favourable detection limits with respect to many elements and a unique feature i.e. the absence of blanks (Dybczyński, 1985; Parry, 1991; De Goeij and Woittiez, 1993). It is not surprising therefore that NAA has often been the method of choice when analysing meteorites (Xiao and Lipschutz, 1991; Lipschutz *et al.*, 1993; Zipfel *et al.,* 1995), and was also employed to study the elemental composition of Baszkówka, together with some wet chemical methods of analysis. Another new meteorite Mt. Tazerzait which fell in Africa (Niger) in 1991 but was first investigated in 1997, and which shows marked similarity to Baszkówka (Pilski and Walton, 1998) was studied by us as well.

Fig. 1. γ-ray spectra of Baszkówka and Mt.Tazerzait after 3–5 days of cooling

Baszkówka: sample mass — 0.213 g, coaxial detector, cooling time — 89 h, measurement time — 40 000 s; **Mt.Tazerzait**: sample mass — 0.206 g, coaxial detector, cooling time — 129 h, measurement time — 6000 s
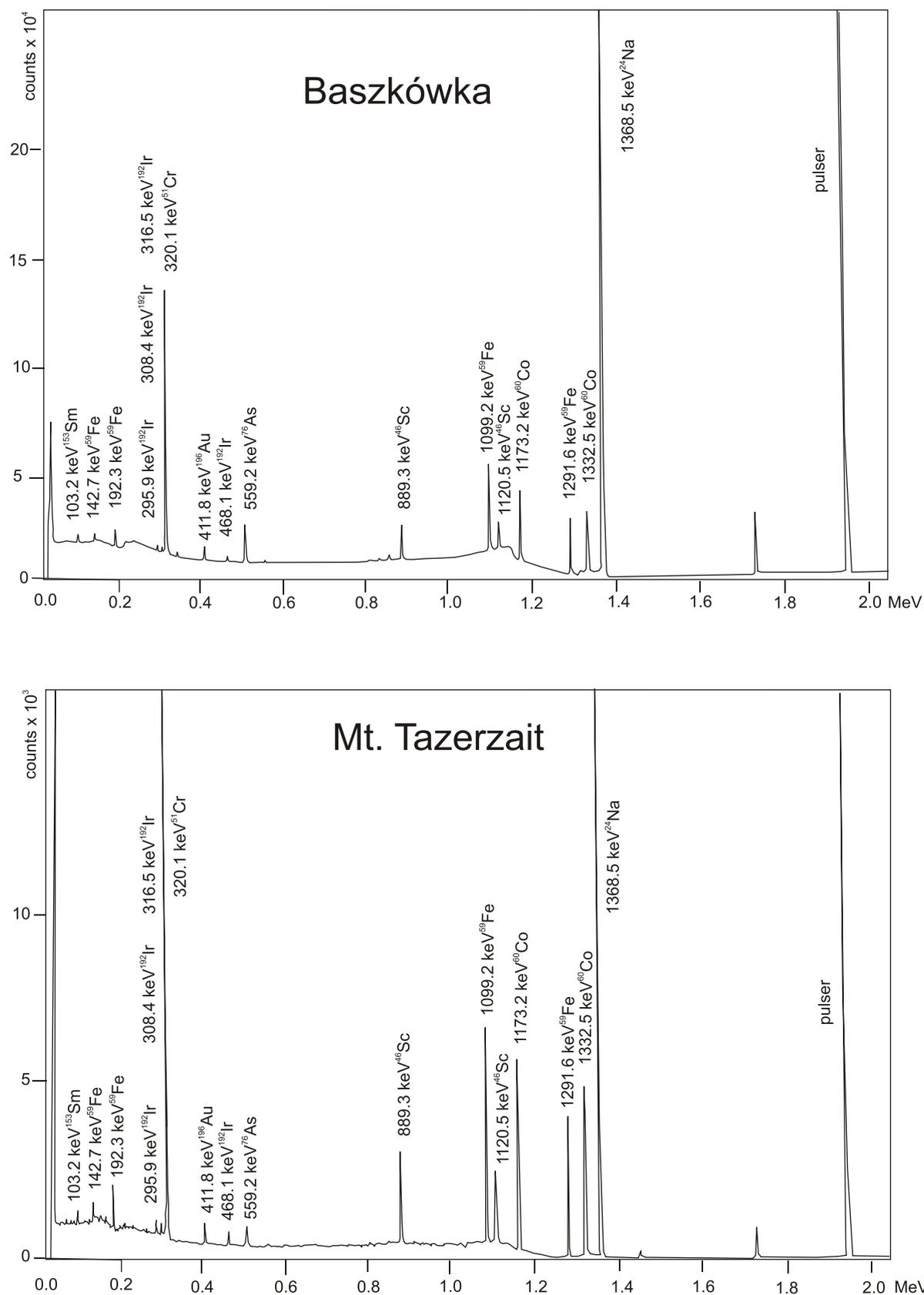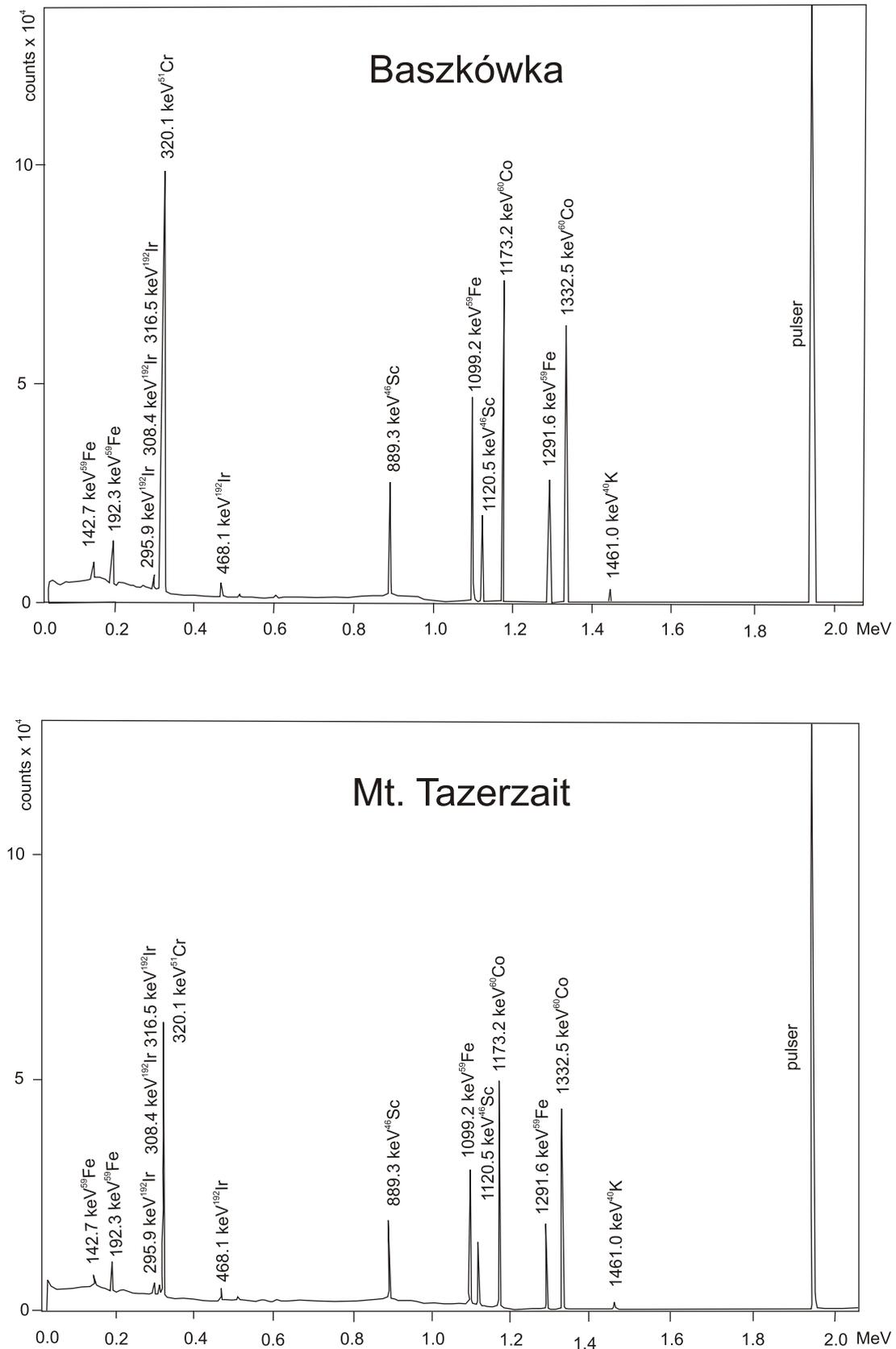
Fig. 2. -ray spectra of Baszkówka and Mt.Tazerzait after 16–17 days of cooling

Baszkówka: sample mass — 0.213 g, coaxial detector, cooling time — 422 h, measurement time — 75 000 s; **Mt.Tazerzait**: sample mass — 0.206 g, co-axial detector, cooling time — 399 h, measurement time — 50 000 s

Irradiation and measurement conditions INAA, t_{irr} = 3 min, Φ = 1.6·10^{13} n/cm^{2}s

Element	Indicator radionuclide	Half-life $T_{1/2}$	Analytical γ-ray energies employed [keV]	Cooling time [days]	Measurement time [days]
As	^{76}As	1.097 d	559; 657	1.4–6	0.02–0.5
Au	^{198}Au	2.6935 d	411.8	1.4–12	0.01–1.2
Co	^{60}Co	5.271 y	1173.2; 1332.5	3–60	0.02–1.2
Cr	^{51}Cr	27.7 d	320*	3–60	0.02–1.2
Cu	^{64}Cu	12.7 h	1345.8; 1022**	1.4–2.7	0.02–1.2
Eu	^{152}Eu	13.33 y	121.78***	25–60	0.5–1.2
Fe	^{59}Fe	44.496 d	1099.3; 1291.6	6–60	0.02–1.2
Ga	^{72}Ga	14.1 h	834.09****; 630	1.4–2.5	0.02–0.5
Hf	^{175}Hf	70 d	343.4*****	25–60	0.5–1.2
	^{181}Hf	42.39 d	482.0	7–50	0.5–1.2
Ir	^{192}Ir	73.831 d	468; 296; 784.6	5–60	0.1–1.2
	^{194}Ir	19.15 h	328.46******	1.4–2.5	0.02–0.5
K	^{42}K	12.36 h	1524.6	1.4–2.5	0.02–0.5
La	^{140}La	1.678 d	1596.5	1.4–8	0.1–0.5
Mn	^{56}Mn	2.5785 h	846.8	0.3–1.4	0.06–0.1
Na	^{24}Na	14.9 h	1368.6	1.4–8	0.07–0.5
Ni	^{58}Co	70.916 d	810.8	7–60	0.1–1.2
Os	^{191}Os	15.4 d	129.4	1.5–30	0.03–0.5
Sc	^{46}Sc	83.83 d	118.25; 1120.5	5–60	0.02–1.2
Se	^{75}Se	119.77 d	400	5–60	0.1–1.2
Sm	^{153}Sm	1.946 d	103.2	1.4–9	0.02–0.5
Yb	^{175}Yb	4.19 d	396.3	2.5–8	0.07–0.5
Zn	^{65}Zn	244.1 d	1115.5	25–60	0.5–1.2
	^{69m}Zn	13.76 h	438.6	1.4–3	0.02–0.5

* — corrected for contribution from ^{192}Ir, 316.5 keV line; ** — for well-type detector; *** — corrected for contribution from ^{75}Se, 121.12 keV line; **** — corrected for contribution from ^{54}Mn, 834.8 keV line; ***** — corrected for contribution from ^{152}Eu, 344.29 keV line; ****** — corrected for contribution from ^{140}La, 328.76 keV line; d — day, y — year, h — hour

Preliminary results have been published (Dybczyński *et al.,* 1999; Dybczyński *et al.,* 2001). In this paper the older and new results concerning the bulk composition of the Baszkówka and Mt.Tazerzait chondrites are summarised and discussed together with some results concerning the composition of the magnetic fraction of Baszkówka meteorite.

SAMPLE PREPARATION AND ANALYTICAL METHODS

SAMPLE PREPARATION

A slab was cut from the bottom of the Baszkówka meteorite with a diamond saw. A cylindrical sample was then taken from the interior of the meteorite (to *ca.* 5 cm depth) using the milling cutter. Part of the sample (not adjacent to the cut edge) was comminuted with an agate mortar and pestle which were previously thoroughly washed and also cleaned with quartz.

The cut fragment of the Mt.Tazerzait meteorite used in this study was received from R.W. Bühler, Swiss Meteorite Lab., Glarus, Switzerland. One part was used to make a thin section and the other was comminuted in the same way as Baszkówka.

Investigations with the aid of both optical and scanning electron microscopes showed that in both analysed samples there was a considerable number of fine particles (0.5–23 µm), and also numerous larger particles with diameters of up to 400–500 µm.

INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS (INAA) (DYBCZYŃSKI *ET AL.*, 1999)

Samples, certified reference materials. 100–250 mg samples of meteorite as well as certified reference materials (CRMs): Fine Fly Ash (CTA-FFA-1), Soil-5, SARM-7 and PTC-1 were accurately weighed with the aid of analytical semi-micro balance (Precisa, Switzerland) into high purity polyethylene (PE) snap-cap capsules, 0.22 cm^3 (Faculteit der Biologie, Universiteit, Amsterdam). To avoid any contamination, distribution of the samples into capsules was carried out using a laminar air flow cabinet with HEPA-filter, Holten (Denmark).

The water content of the CRMs was determined in separate subsamples by drying at 105°C to constant weight. Water contents determined this way amounted to 0.26, 1.43, 0.20 and 4.05%, for CTA-FFA-1, Soil-5, SARM-7 and PTC-1, respectively.

Standard preparation. Stock solutions of As, Au, Ca, Ce, Co, Cr, Dy, Eu, Fe, Ga, Ge, Hf, Hg, Ir, K, La, Lu, Mn, Na, Nd, Ni, Os, Pd, Ru, Sc, Se, Sm, Tb, Tm, Yb and Zn were prepared from metals, oxides or salts of spectral purity by dissolving in high purity acids, and diluting with 18 M cm water obtained from Milli-Q RG ultra pure water system (Millipore Co.). Concentrations of stock solutions were usually close to 1 mg/g of solution, sometimes 10 mg/g of solution.

Working standard solutions were made from stock solutions by diluting with 18 M cm water. Concentrations of the standard solutions were determined by weighing.

Multielement standards for INAA were prepared by transferring appropriate masses of standard solutions on to filter paper discs (= 7.7 mm) placed in the same type of PE capsules as those used for the samples. After drying at room temperature, all capsules were closed and wrapped into Al foil similarly as the samples.

The approximate amounts of elements in the standards were as follows:

— standard 1: As (500 µg), Na (50 µg), Sc (2 µg), Co (55 µg), Cr (180 µg),

— standard 2: Cu (400 µg), Sm (10 µg), K (6000 µg), Ni (10 000 µg), Os (100 µg), Yb (5 µg),

— standard 3: Mn (200 µg), La (200 µg), Pt (100 µg), Se (50 µg), Ga (30 µg),

— standard 4: Hg (100 µg), Eu (1 µg), Hf (10 µg), Ru (10 µg),

— standard 5: Fe (50 000 µg), Au (10 µg), Ir (1 µg),

— standard 6: Ca (25 000 µg), Ge (40 µg), Zn (500 µg).

Element content as determined by NAA and classical methods in the Baszkówka and Mt. Tazerzait meteorites

Element	Baszkówka $\bar{x}\pm$	Mt. Tazerzait $\bar{x}\pm$	Method
Al [wt.%]	1,48±0.11	1.39±0.01	C and S
As [µg/g (ppm)]	1.79±0.48	1.56±0.28	INAA
Au [ng/g (ppb)]	171±31	132±16	INAA
Au [ng/g (ppb)]	146±30	134±15	RNAA
Ca [wt.%]	1.02±0.06	0.95±0.04	TITR
Co [µg/g (ppm)]	601±201	569±75	INAA
Cr [µg/g (ppm)]	3531±54	3535±192	INAA
Cu [µg/g (ppm)]	130±8	121±15	INAA
Eu [ng/g (ppb)]	96±71	63±39	INAA
Fe [wt.%]	21.91±1.71	21.11±1.48	INAA
Fe [wt.%]	23.0±0.96	23.15±0.07	TITR
Ga [µg/g (ppm)]	5.79±0.44	5.98±1.13	INAA
Ir [ng/g (ppb)]	514±37	506±43	INAA
K [µg/g (ppm)]	680±71	732±115	INAA
La [ng/g (ppb)]	520±119	407±40	INAA
Mg [wt.%]	15.60±0.56	16.40±0.28	TITR
Mn [µg/g (ppm)]	2392±402	2590±305	INAA
Na [wt.%]	0.635±0.163	0.678±0.166	INAA
Ni [wt.%]	1.14±0.14	1.07±0.08	INAA
P [wt.%]	0.103±0.006	0.105±0.07	C and S
Pd [µg/g (ppm)]	4.02±1.78	0.763±0.223	RNAA
Pt [µg/g (ppm)]	–	1.95±0.53	RNAA
Pt* [µg/g (ppm)]	1.43±0.88	1.80±0.59	RNAA
Os [µg/g (ppm)]	1.67±0.15	1.34±0.43	INAA
Sc [µg/g (ppm)]	8.67±0.61	9.07±0.65	INAA
Se [µg/g (ppm)]	10.7±1.1	10.4±1.4	INAA
Si [wt.%]	17.47±0.67	18.4±0.14	GRAV
Sm [ng/g (ppb)]	235±54	234±64	INAA
Yb [ng/g (ppb)]	179±22	184±39	INAA
Zn [µg/g (ppm)]	67.7±22.9	59.1±13.7	INAA

$\bar{x}$ — arithmetic mean; — standard deviation; * — *via* [199]Au; INAA — instrumental neutron activation analysis; RNAA — radiochemical neutron activation analysis; C and S — colorimetry and spectrophotometry; GRAV — gravimetry; TITR — titrimetry
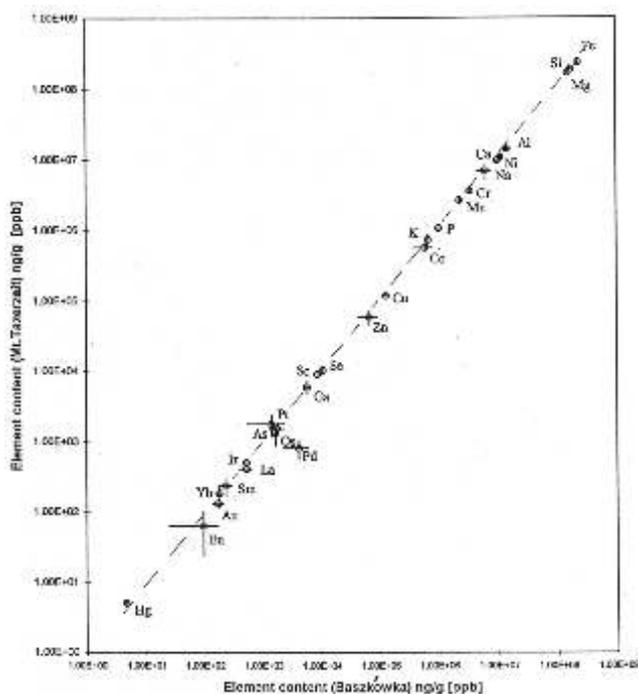

Fig. 3. Linear correlation between concentrations of elements in the Mt.Tazerzait and Baszkówka chondrites, respectively; vertical and horizontal bars associated with points correspond to one standard deviation

Irradiation and counting. The irradiation package consisting of 6–8 samples, 2–3 flux monitors, 2–5 CRMs and 11–12 multielement standards, wrapped in Al foil was irradiated for 3 min in the reactor *Maria* in wierk (Poland) at a thermal neutron flux density of 1.6 10^{13}n/cm^{2}s ($_{fast}$/ $_{th}$ = 0.005) and cooled for at least 4–6 hours.

-ray spectrometric measurements were made with the aid of well type HPGe detector (*Canberra*) 180 cm^3 nominal volume, 30% relative efficiency, well depth 40 mm, well diameter 16 mm, resolution 2.3 keV for 1332.5 keV[60]Co line, coupled *via* an *Ortec* analog line to the multichannel analyser *Tukan* in the form of an ISA card inserted into a typical PC.

Good and reproducible geometry of measurements was assured by placing the samples in the flat-bottomed test tube at the bottom of the well. The results were corrected for the background. Blanks (from the irradiation capsule) were usually negligible for the elements studied in this work.
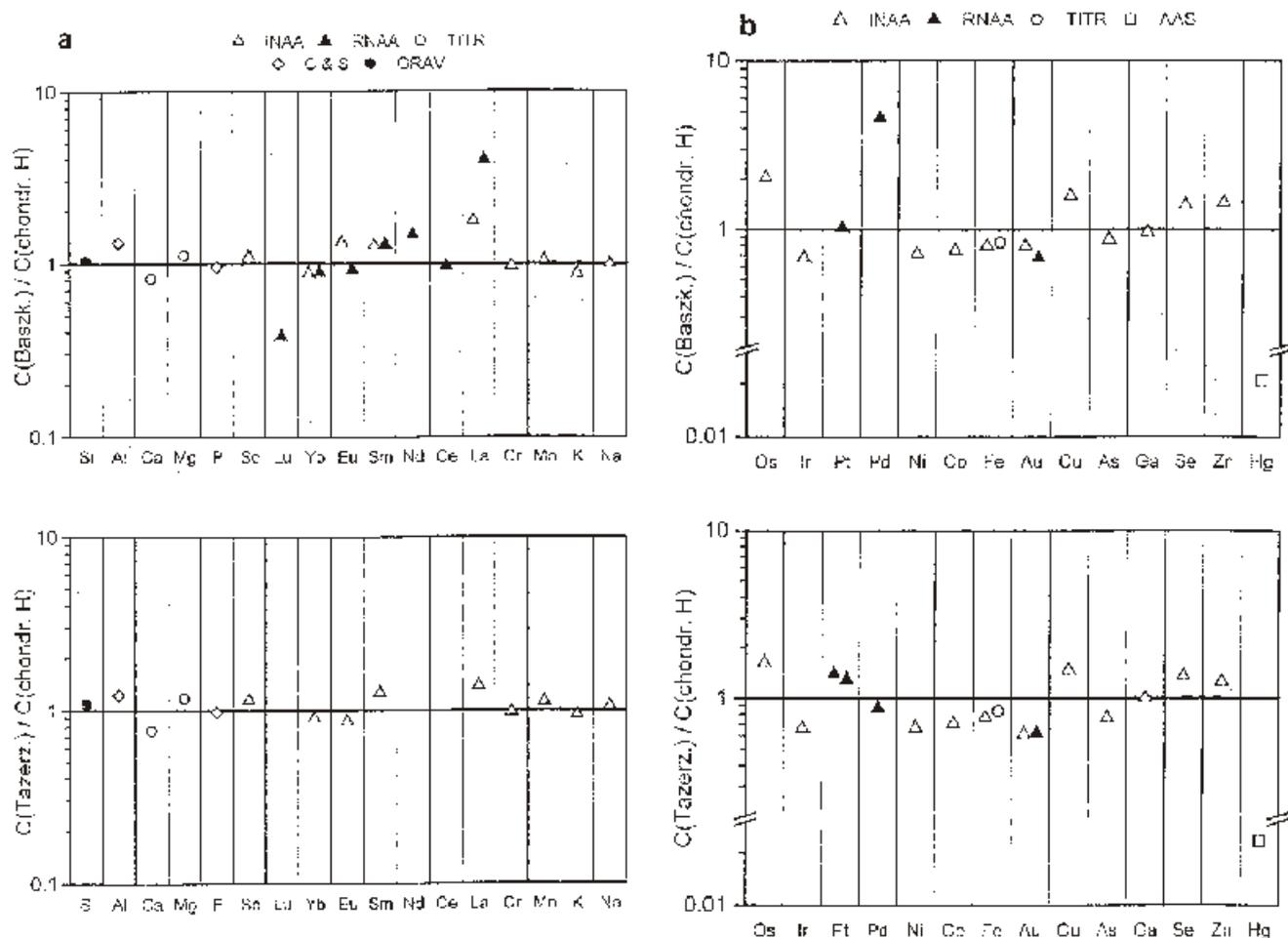
Fig. 4. Elemental contents in Baszkówka and Mt.Tazerzait normalised with respect to the mean composition of H chondrites

Elements are grouped into lithophile elements (a) as well as siderophile and chalcophile elements (b) and are ordered from left to right in approximate sequence of decreasing condensation temperatures

Several measurements were performed in a live times mode after decay time of approximately 16 h, 2 d, 7 d and 1–2 months after irradiation and the time of measurement varied from 500 to 100 000 s.

The concentration of an element x in a sample, C_x [µg/g], was calculated from the formula:

$$C_x [\text{ppm}] = \frac{A_{o(corr.)(x,s.)} \, m_{st.} [\mu g]}{A_{o(corr.)(x,st.)} \, m_{s.} [g]} \qquad [1]$$

where: A_o — count rate of a radionuclide at the end of irradiation (t_o), $m_{st.}$ — mass of an element x in the standard, $m_{s.}$ — mass of the sample

$$A_o = \frac{A_{n(corr.)} \, \frac{\ln 2}{T} \, t \exp \left[\frac{\ln 2}{T} (t_n - t_o) \right]}{1 - \exp(-\frac{\ln 2}{T} \, t)} \qquad [2]$$

where: $A_{n(corr.)(x,\,s./st.)}$ — count rate of a radionuclide in a sample ($s.$) or standard ($st.$) measured in a live-time mode and corrected (if needed) for spectral interferences, t_n — time of start of measurement, t_o — time at the end of irradiation, t – time of duration of a measurement (clock time).

$$A_{n(corr.)(x,\,s.)} = [N_{(x,\,s.)} - w_k N_{(y,\,main.\,l.)}]/t_{l(s.)} \qquad [3]$$

where: w_k — correction factor used when spectral interference occurred, and calculated from the -ray spectrum of an interfering element (y):

$$w_k = A_{(y,\,interf.\,l.)}/A_{(y,\,main.\,l.)} = N_{(y,\,interf.\,l.)}/N_{(y,\,main.\,l.)} \qquad [4]$$

where: $N_{(x,\,s.)}$ — number of counts in the photopeak of an element x recorded during measurement of a sample, $N_{(y,\,main.\,l.)}$ — number of counts recorded in the same measurement in the undisturbed photopeak of an interfering element (y), $N_{(y,interf.l.)}$ — number of counts for the line of an element (y) interfering with the analytical line of an element x, $t_{l(s.)}$ — live time of measurement of the sample.
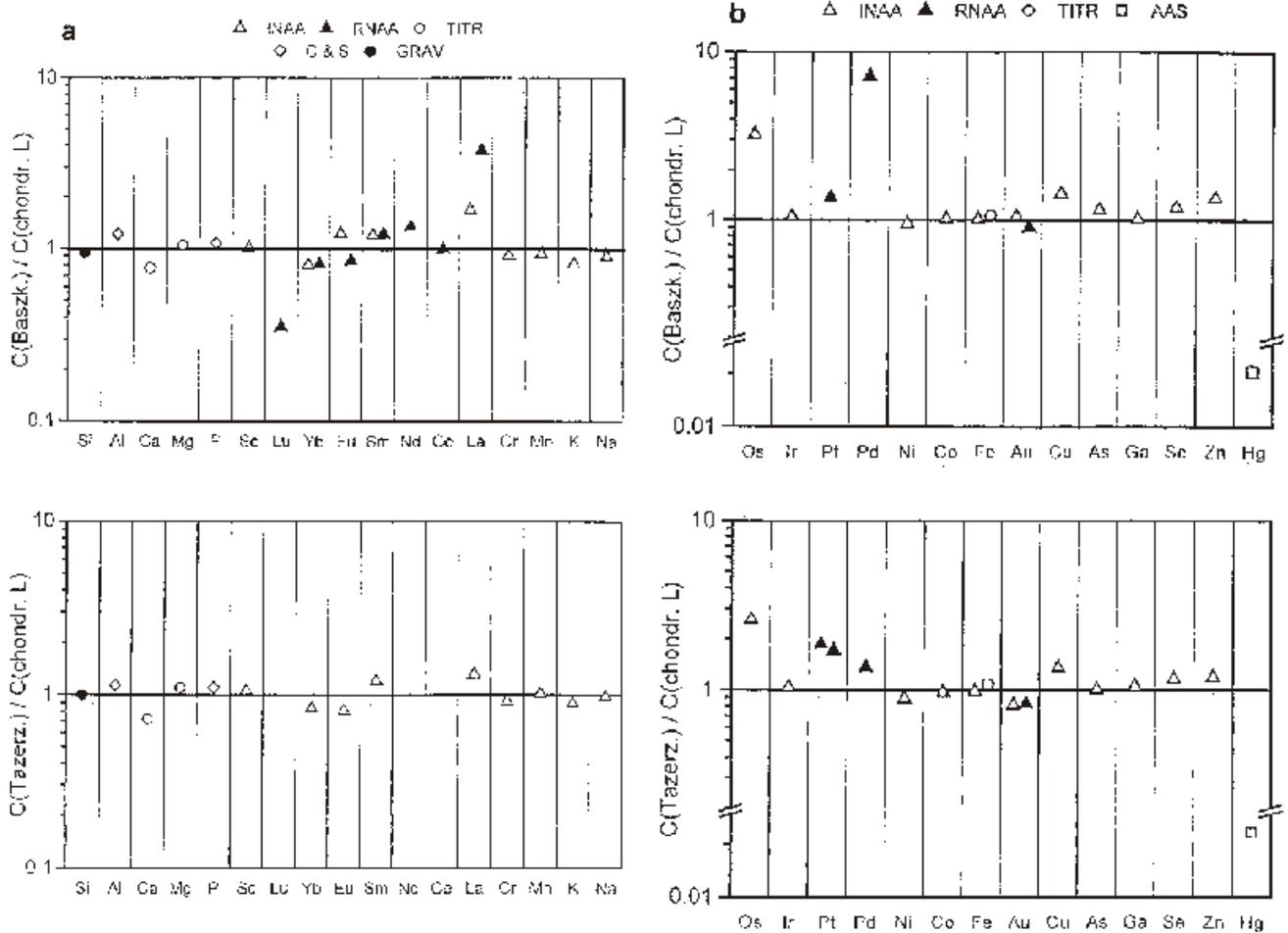
Fig. 5. Elemental contents in Baszkówka and Mt.Tazerzait normalised with respect to the mean composition of L chondrites

Presentation of data as in Figure 4

Usually two different standards were employed to calculate element content according to eqation [1] and the average was taken as a final value of C_x.

Another series of determinations was done with the aid of a 213 cm^3 coaxial HPGe detector (*Ortec*), 40% efficiency, peak to Compton ratio 54:1, resolution 1.9 keV for 1332.5 keV ^{60}Co. The detector was coupled *via* an *Ortec* analog line, which also included a precision pulse generator (*Ortec*) to the multi-channel analyser *Tukan* in the form of an ISA card inserted into a typical PC. The distance of the sample from the detector was adjusted so as to keep the total count rate below 15 000 cps for the very first measurements (i.e. shortly after irradiation) and below 7000 cps later on.

The measurements of -ray spectra were performed in a clock time mode and the "pulser method" was used for dead-time and pile-up correction.

In this case the content of an element in the sample was calculated from the formula:

$$C_x[\text{ppm}] = \frac{A_{o,s.}\, k_{st.}\, m_{st.}\,[\mu\text{g}]}{A_{o,st.}\, k_{s.}\, m_{s.}\,[\text{g}]} \qquad [5]$$

where:

$$A_{o,s./st.} = \frac{N_{corr.}\dfrac{\ln 2}{T}\exp\left[\dfrac{\ln 2}{T}(t_n - t_o)\right]}{1-\exp\left(\dfrac{-\ln 2\; t}{T}\right)}\cdot\frac{A_{puls,o}}{A_{puls,\,s./st.}} \qquad [6]$$

where: $N_{corr.}$ — number of counts in the photopeak of an element x (corrected if needed for the contribution of the interfering element y), $k_{s./st.}$ — normalised activity of a neutron flux monitor for a given position of the sample or standard in the irradiation package, $A_{puls,o}$ — count rate of a pulser in the absence of a sample, $A_{puls,\,s./st.}$ — count rate of a pulser recorded during the measurement of a given sample or standard.

NAA results for certified reference materials (Dybczyński *et al.*, 2000)

Element	Fine fly ash CTA-FFA-1		IAEA Soil-5	
	our results	certified or information value	our results	certified or information value
As	47.9±7.5	53.6±2.7	96.4±18.3	93.9±7.5
Co	37.9±2.2	39.8±1.7	14.0±1.2	148±0.8
Cr	160±11	156±8	30.6±6.1	28.9±2.8
Cu	178±34	158±9	–	–
Eu	2.32±0.14	2.39±0.08	1.28±0.07	1.18±0.08
Fe	4.64±0.22**	4.89±0.14*	4.45±0.19**	4.45±0.19**
Ga	43.5±8.4	(49)	–	–
Hf	5.2±0.1	6.09±0.45	5.41±1.32	6.30±0.30
K	2.10±0.23**	(2.2)**	1.81±0.37**	1.86±0.15**
La	62.9±9.3	60.7±4	28.5±5.1	28.1±1.5
Mn	1009±184	1066±41	829±197	852±37
Na	1.84±0.34**	2.19±0.08**	1.61±0.30**	1.92±0.11**
Sc	24.0±1.3	24.2±1.1	14.8±0.8	14.8±0.7
Sm	9.3±2.2	10.9±0.6	4.51±0.72	5.42±0.39
Yb	4.10±0.90	4.24±0.19	2.07±0.21	2.24±0.20
Zn	633±122	569±58	–	–
Element	Precious-metal ore Sarm-7		Noble-metals-bearing sulphide concentrate PTC-1	
Au	0.300±0.058	0.310±0.015	0.649±0.188	0.65±0.10
Ir	0.069±0.013	0.074±0.012	–	–
Pd	1.50±0.06	1.530±0.032	12.0±0.39	12.7±0.7
Pt	3.74±0.33	3.740±0.045	2.87±0.24	3.0±0.2
Pt*	3.74±0.33	3.740±0.045	2.96±0.19	3.0±0.2

* — *via* ^{199}Au; results for all elements are presented as: mean±standard deviation in µg/g [ppm] except of these marked ** which are in wt.%; certified values are given with their confidence intervals; information values are given as numbers only

Other symbols are the same as defined in earlier formulae.

The summary of measurement conditions for individual elements is given in Table 1.

RADIOCHEMICAL NEUTRON ACTIVATION ANALYSIS (RNAA)

Determination of platinum, palladium and gold with preirradiation preconcentration (Dybczyński *et al.*, 2001). Palladium, platinum and gold were determined by a newly developed procedure in which the sample (*ca.* 0.5 g) is digested in a microwave oven with *aqua regia* and HF. Silica is next removed by evaporation and the solution evaporated with concentrated HCl. The residue is dissolved in 0.5 M HCl and the solution introduced on to the Chelex 100[H$^+$] column. Most of the cations are eluted with 0.5 M HCl while Au, Pd and Pt are retained on the resin. Palladium and platinum are eluted jointly with 8 M HCl, and evaporated to dryness in a quartz ampoule. Gold was eluted with 1 M NH$_3$ + 0.1 M NH$_4$Cl, and afterwards retained on a small Chelex 100 column from 0.5 M HCl solution. The resin is dried and transferred quantitatively to a polyethylene (PE) capsule. The chemical yields assigned on the basis of many experiments with radioactive tracers (with and without real samples) were found to be very reproducible and amounted to: 99.0±1.0% (Pd), 95.3±2.2% (Pt), and 94.5±3.1% (Au). The results were corrected for chemical yield accordingly.

Samples, blank and standards were irradiated for 3 h at a thermal neutron flux density of 1.6 · 10^{13} n/cm^{2}s and cooled for 12–18 h.

^{198}Au was measured directly on the resin by γ-ray spectrometry. Pd and Pt after addition of 20 mg carriers were washed out of the quartz ampoule with *aqua regia,* evaporated with concd. HCl, and retained on the Chelex 100 column from 0.5 M HCl. Washing the column with 0.5 M HCl removes some trace impurities (^{24}Na *etc.*). ^{197}Pt is eluted by means of an acetate buffer solution (pH = 5) and then ^{109}Pd is stripped with the aid of 8 M HCl. Finally ^{199}Au (originating from the decay of ^{199}Pt), and the residual amounts of Pd and Pt that remained on the resin were stripped with 0.2 M thiourea in 2 M HCl. Count rates of the three fractions were measured by γ-ray spectrometry and compared with those of the standards measured in the same geometrical conditions. The total amount of each analyse can be determined, so in this case no correction for chemical yield is needed. The blank for the whole procedure was checked and was below the detection limit for all three elements.
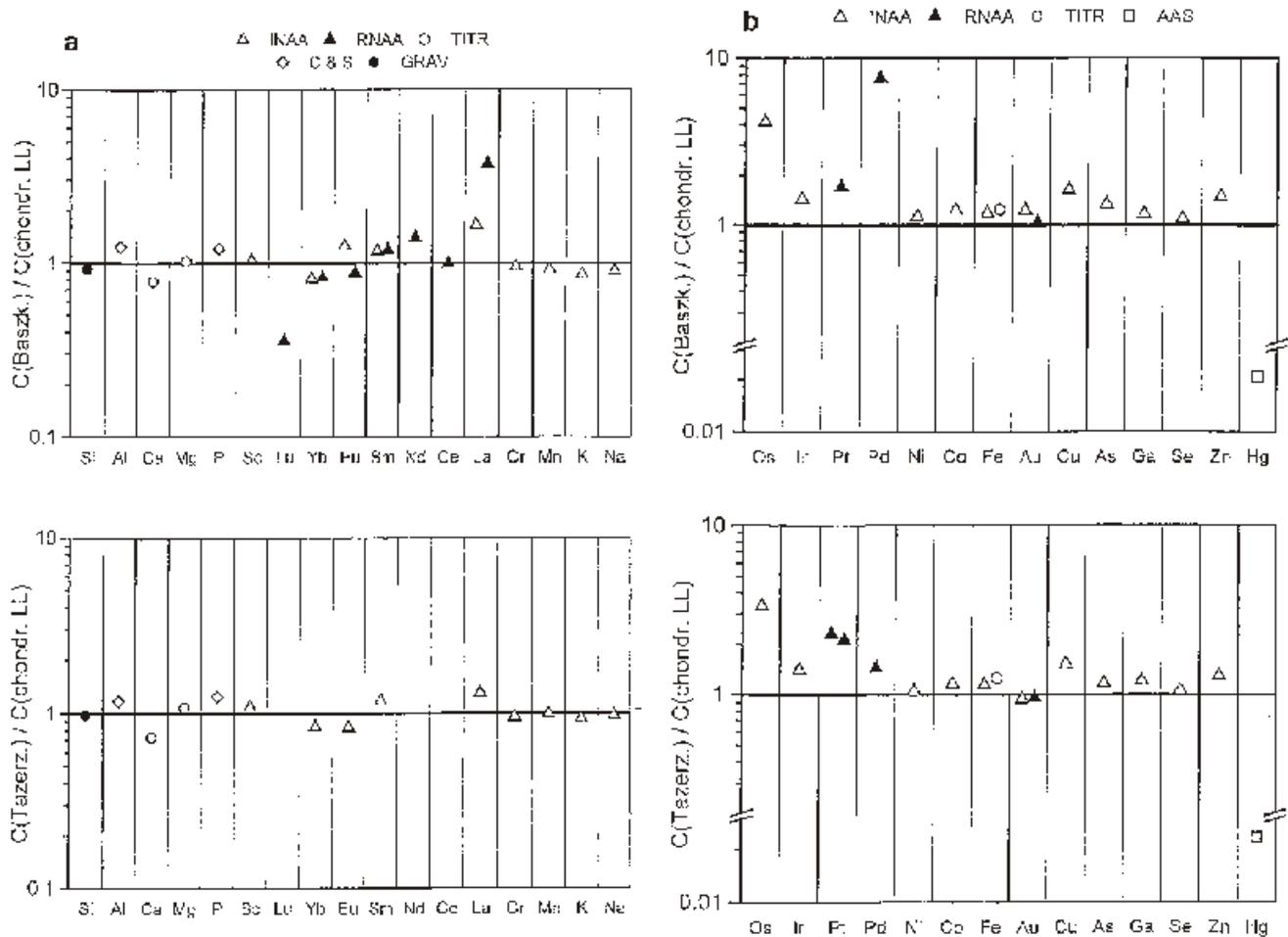
Fig. 6. Elemental contents in Baszkówka and Mt.Tazerzait normalised with respect to the mean composition of LL chondrites

Presentation of data as in Figure 4

Determination of Rare Earth elements in Baszkówka after preirradiation preconcentration (Dybczyński et al., 1999). A 500 mg sample of Baszkówka meteorite was dissolved with the use of a microwave digestion unit (Plazmatronika BM-18) employing an *aqua regia* +HF digestion mixture, the solution was next transferred to a PTFE vessel and evaporated. After treating with HCl, H_3BO_3 and HNO_3 to remove fluorides followed by evaporation with HCl, the residue was dissolved in 1 mol/l HCl and transferred on to a Dowex 50W-X8[H^+] column. Separation of the group of Rare Earth elements (REE) from other elements based on sequential elution from cation exchange column as described earlier (Wasek *et al.*, 1996) was used, supplemented by additional steps: elution of iron with 1.5 mol/l HCl in 80% C_2H_5OH (Wódkiewicz and Dybczyński, 1974) and after elution of the REE fraction with 5 mol/l HCl removal of sodium on the column with composite ion exchanger containing hydrated antimony pentoxide selective for sodium from 8 mol/l HCl (Bilewicz *et al.*, 1987). The effluent containing the REE group was evaporated with HNO_3 transferred quantitatively into a PE capsule, evaporated to dryness and irradiated together with several mixed standards of REE for 2 h at a thermal neutron flux of

$1.6 \cdot 10^{13}$ n/cm^2s. Samples and standards were measured several times by γ-ray spectrometry after cooling times varying from a few hours to two months.

DETERMINATION OF SEVERAL ELEMENTS BY WET CHEMICAL METHODS

Determination of silicon, calcium and magnesium. Determination of macroconstituents was performed employing the analytical scheme for aluminosilicates elaborated in this department. Preliminary decomposition of a 1 g sample of the meteorite was achieved using 20 ml of HCl (1+1). Silica was dehydrated by evaporation with 20 ml of concd. $HClO_4$ until dense white fumes appeared (Minczewski and Marczenko, 1976). The precipitate after filtration, ignition, and weighing was brought into contact with a mixture of 2 ml concd. HF and 5 ml concd. HNO_3 and evaporated to remove silica. This operation was repeated three times. The residue was evaporated twice with a small amount of $HClO_4$, ignited and weighed. The silica content was determined from the difference in the mass of the originally isolated precipitate and that after volatilisation of SiO_2.
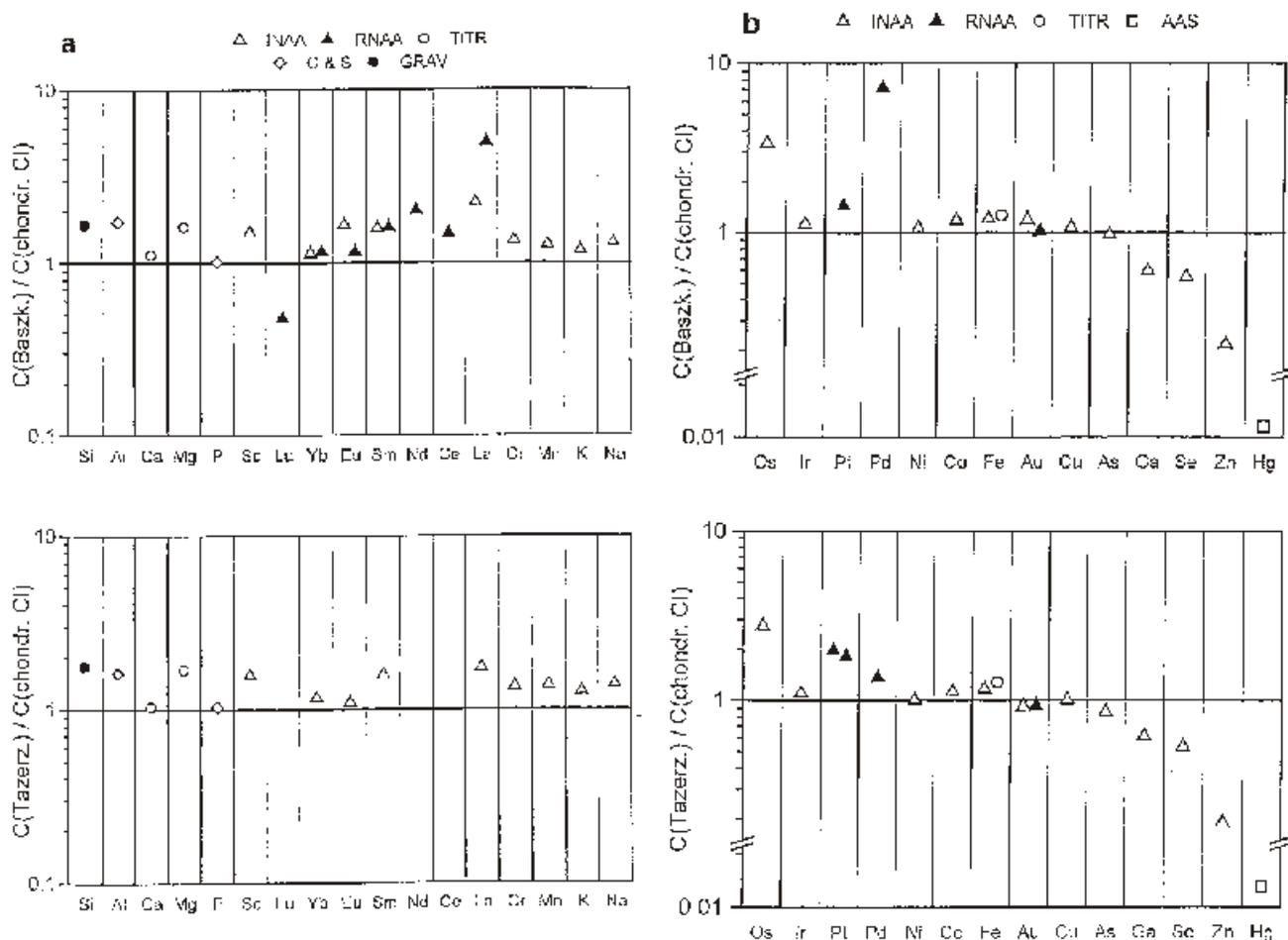
Fig. 7. Elemental contents in Baszkówka and Mt.Tazerzait normalised with respect to the mean composition of CI chondrites

Presentation of data as in Figure 4

The residue was dissolved in HCl and combined with the filtrate obtained during filtration of silica and made up to 200 ml in a volumetric flask. This solution was used for the determination of calcium and magnesium by compleximetric titration (Welcher, 1963).

The sum of Ca and Mg was determined by titration with 0.05 M EDTA in an alkaline medium (buffer pH = 10) using Eriochrome Black as an indicator in the presence of masking agents (ascorbic acid, triethanolamine, potassium cyanide).

Calcium was isolated as an oxalate by precipitation with saturated oxalic acid, pH ~ 4. After ageing for several hours the precipitate was filtered, dissolved in dilute HCl and titrated with 0.05 M EDTA in an alkaline medium (pH ~ 13) in the presence of Murexide as an indicator. The magnesium content was found from the difference of the two titrations.

Determination of aluminum, iron, phosphorus and titanium. A *ca.* 0.3 g sample was treated with $HF + HNO_3$ mixture (three times) to remove silica followed by evaporation with a small amount of sulphuric acid. The residue was fused with potassium pyrosulphate, the melt leached with 10 ml of sulphuric acid (1+1) and the solution transferred into a 100 ml volumetric flask.

Iron was determined by compleximetric titration with 0.05 M EDTA in an acidic medium (pH = 2–3) in the presence of salicylic acid as an indicator (Welcher, 1963).

Aluminum was determined spectrophotometrically as a complex with Chromazurole S (λ_{max} = 610 nm) after adding ascorbic acid to reduce iron (Marczenko, 1979).

Phosphorus was determined spectrophotometrically as a phosphomolybdic heteropolyacid which was reduced to phosphomolybdic blue (λ_{max} = 780 nm) with the aid of hydrazinium sulphate (Marczenko, 1979).

Titanium was determined spectrophotometrically as a complex with hydrogen peroxide (λ_{max} = 404 nm). However the determinations were not sufficiently accurate because of the high self-absorbance of the solution in the vicinity of λ_{max}. The limited amount of the sample available precluded further investigation to eliminate the colour of the solution. Therefore results for titanium are not reported here, and the formerly reported result for Ti in Baszkówka (Dybczyński *et al.,* 1999) may be too high.

T a b l e   4

Comparison of elemental ratios in Baszkówka and Mt. Tazerzait with average values for different classes of meteorites*

Element	Baszkówka	Mt. Tazerzait	Average values for different classes of meteorites			
			H	L	LL	CI
Ca/Al	0.68_8	0.68_3	1.11±0.10	1.12±0.13	1.16±0.07	1.08
Mg/Si	0.89_3	0.89_1	0.82±0.01	0.80±0.01	0.80±0.01	0.90
Al/Si	0.084_9	0.075_5	0.066±0.005	0.064±0.004	0.062±0.003	0.085
Ca/Si	0.058_4	0.051_6	0.073±0.003	0.071±0.004	0.072±0.005	0.092
Fe(t)/Si	1.31_7; 1.25_4**	1.25_8;1.14_7**	1.60±0.06	1.18±0.06	1.03±0.04	1.78
Fe(t)/Ni	20.1_8; 19.2_2**	21.6_4; 19.7_3**	15.84±0.67	17.73±1.37	18.64±2.18	18.12

* — wherever possible data are presented as mean±standard deviation; ** — calculated taking Fe content from INAA measurements

SPECIATION ANALYSIS

A study of the metal phases of Baszkówka was made by a slightly modified method following Kong *et al.* (1995). The magnetic fraction was separated from the Baszkówka chondrite with a hand magnet and was then boiled with concd. HF for 1.5 min, washed with distilled water ultrasonified for 30 min, washed with ethyl alcohol, dried at 60°C and again separated with a hand magnet. In this way, starting from 817.8 mg of meteorite, 136.35 mg of magnetic fraction was isolated. 132.75 mg of this magnetic fraction was transferred into a PE capsule and sent for irradiation together with samples of bulk meteorite and standards as described above.

The irradiated magnetic fraction was measured by -ray spectrometry to determine individual elements in the bulk magnetic fraction. The material was then boiled for 20 min with concd. HF, in PTFE crucible, decanted immediately afterwards, washed 3 times with distilled water, then with ethyl alcohol, dried, placed in a PE capsule, weighed and measured by -ray spectrometry to determine elemental contents in taenite (which could possibly contain also other phase(s) as martensite *etc.*). Element contents in the kamacite phase were found from the difference.

RESULTS AND DISCUSSION

SUMMARY OF DATA ON COMPOSITION, AND SIMILARITY OF THE TWO METEORITES

 -ray spectra of Baszkówka and Mt.Tazerzait meteorites after medium (3–5 d) and longer (16–17 d) cooling times are shown on Figures 1 and 2 respectively. The striking similarity of the spectra of both meteorites is apparent. Considering the differences in measurement and cooling times, the spectra of both meteorites are almost identical.

Concentrations of 27 elements in bulk meteorites: Baszkówka and Mt.Tazerzait respectively as determined by INAA, RNAA and wet chemical methods are shown in Table 2. The results are presented as: mean±standard deviation and are based on the analyses of 3–6 samples for each element

in the case of elements determined by NAA. In the case of wet chemical methods, the analyses were made in triplicate (Baszkówka) and duplicate (Mt. Tazerzait) respectively, because of the scarcity of the materials being analysed.

Considering the intrinsic inhomogeneity of the analysed materials, the wide range in particle size and the relatively small masses of the samples being analysed, the precision of determination for most elements can be considered as more than satisfactory.

Analogous data for CRMs are presented in Table 3 demonstrating the reliability of the methods used in this study.

Even preliminary inspection of Table 2 shows that contents of individual elements in both meteorites are almost identical within experimental error. The only exception is palladium, which seems to be more abundant in Baszkówka. This element, however is probably quite inhomogeneously distributed as can be inferred from the high value of standard deviation as compared to analogous data obtained when analysing certified reference materials of similar Pd concentration (*cf.* Table 3).

In Figure 3 elemental contents of elements as determined by us (*cf.* Table 2), supplemented by data for mercury obtained with an automatic mercury analyser, and given in an earlier paper (Dybczy ski *et al.,* 2000) in Mt.Tazerzait (*y*) are plotted *versus* analogous data for Baszkówka (*x*) on a log-log scale. The straight line is described by an equation: $y = 1.01256x - 0.0629$ and the coefficient of correlation amounts to $R = 0.9982$.

If the data for Pd are excluded the equation has the form: $y = 1.006989x - 0.02972$, i.e. represents almost a perfect fit ($y = x$) with a coefficient of correlation $R = 0.9997$.

CONSIDERATIONS CONCERNING THE CLASSIFICATION OF THE BASZKÓWKA AND MT.TAZERZAIT METEORITES

The preliminary classification of Baszkówka and Mt. Tazerzait as L chondrites was based on the study of olivine and orthopyroxene grains by electron microprobe analysis (Wlotzka *et al.,* 1997; St pniewski *et al.,* 1998*a*). The classification of Baszkówka as an L chondrite was later confirmed by its oxygen isotope composition: $^{17}O = 3.66$ and $^{18}O = 4.88$ (St pniewski *et al.,* 1998*a*, quoted after I. Franchi, The Open

Concentration of elements [mg/kg (ppm)] in magnetic fraction of Baszkówka meteorite and their distribution among individual phases (results from single experiments)

Element	Bulk magnetic fraction	Kamacite	Taenite (plus possibly other phases)
Co	3353	4928	1479
Cr	2384	811	4240
Fe	418 546	579 906	226 547
Ir	1.094	0.8485	1.385
Ni	41 178	44 250	37 522
Sc	5.95	2.02	10.62

University). In Figures 4–7, elemental contents in Baszkówka and Mt. Tazerzait, normalised with respect to mean composition of H, L, LL and CI chondrites respectively, are shown. The general conclusion that follows from inspection of Figures 4–7 can be summarised as follows:

— regarding the four categories of chondrites discussed here, Baszkówka and Mt. Tazerzait are more similar to the L group than to any other class of chondrites,

— the striking similarity of Baszkówka and Mt. Tazerzait is once more confirmed by this way of presentation of analytical data,

— despite the classification of both new chondrites as L group, some features show a difference from the population of L chondrites known until now. Wherever deviations from the mean composition of L chondrites were observed, the data for Baszkówka and Mt.Tazerzait showed a similar trend, confirming once again the similarity of bulk composition of both meteorites.

Taking a closer look at the data presented in Figure 5 one can note that marked deviations from a ratio equal to unity (i.e. perfect agreement) can be observed in the case of several elements. Osmium, palladium, copper and platinum show elevated, and mercury distinctly lower, concentrations with respect to the mean composition of L chondrites. It seems also that Baszkówka and Mt. Tazerzait are slightly enriched in light Rare Earths and depleted in heavy Rare Earths. These observations, together with other data such as very long cosmic ray exposure times, gas retention ages, extremely low mercury contents (Baszkówka 4.5±0.5 ng/g; Mt.Tazerzait 5.1±0.4 ng/g; Dybczyński et al., 2000) etc., suggested that both meteorites may originate from a common parent body which is different from that typical for most of the other L chondrites (Stępniewski et al.,1998a; Dybczyński et al., 2000).

It is worth noting that the plots of concentrations of siderophile and chalcophile elements in Baszkówka and Mt. Tazerzait normalised with respect to CI chondrites show a fairly regular pattern of decreasing abundance with an increase in element volatility (cf. Fig. 7b).

In Table 4 several elemental ratios for macroconstituents are listed and compared with the average values for four classes

of meteorites, taken from the paper by Jarosevich (1990). One should note that while the Fe(t)/Si ratio for Baszkówka and Mt.Tazerzait is close to that for L chondrites, other ratios are different. The Fe(t)/Ni ratio resembles rather that of LL chondrites, the Ca/Al and Ca/Si ratios are lower than analogous values for all other classes of meteorites and the Mg/Si and Al/Si ratios are closer to those for carbonaceous chondrites than to values typical for any of the classes of ordinary chondrites. This confirms once again the unusual features of the Baszkówka and Mt.Tazerzait meteorites.

Jarosevich (1990) observed that when plotting MgO vs. SiO_2 content for many ordinary chondrites, one gets a straight line with the H group well separated from the L and LL groups, which in turn partially coincide with each other. The data for Baszkówka and Mt.Tazerzait do not lie on the same line, rather they seem to lie on another straight line well above the line plotted by Jarosevich and approximately parallel to the former. This finding seems to provide additional argument for the hypothesis that both meteorites may come from a parent body different to that of the L chondrites known so far.

RESULTS OF SPECIATION ANALYSIS

Concentrations of several elements in the bulk magnetic fraction and in individual metal phases as determined by NAA utilising long-lived radionuclides are shown in Table 5.

It should be remembered that the concentration of cobalt in kamacite is being used for classification purposes (Sears and Dodd, 1988; Kong et al., 1995). According to this classification, three different abundance ranges of Co in kamacite: 4400–5100, 7000–9500 and 14 200–37 000 ppm are considered as typical for H, L and LL chondrites, respectively (Kong et al., 1995). Hence Baszkówka with its 4928 ppm Co in kamacite would belong rather to the H group. However, this result is different from a previous independent experiment where the Co concentration in kamacite was found to be 7561 ppm (Dybczyński et al., 1999). This shows on one hand that the metal phase in Baszkówka seems to be quite inhomogeneous, on the other hand it may indicate again special features of this meteorite different from those of other L chondrites.

As expected, the siderophile element Ir is enriched in the magnetic fraction, the enrichment being greater in the "taenite fraction" (which except of taenite itself may contain also other phases), than in kamacite. It is interesting to note that the taenite fraction apparently may be enriched also in some typical lithophile elements such as Cr and Sc (cf. Table 5).

CONCLUSIONS

Accurate determination of 28 elements in Baszkówka and Mt.Tazerzait meteorites confirmed earlier observations on their unusual similarity. At the same it was shown that both meteorites tentatively classified as L chondrites have some peculiar

features distinguishing them not only from all other L chondrites, but also from all ordinary chondrites. They likely originate from a common parent body which appears different from that characteristic for other chondrites.

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