The Ipitinga H5 Chondrite: a New Meteorite Found in Pará State, Northern Brazil

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ABSTRACT

The Ipitinga chondrite, found in 1989 in Pará State, Brazil (coordinates 0°21′N, 53°49′W), represents the first meteorite recovered from the thinly populated Brazilian Amazonian region. It consists of a single, polyhedral, crust-covered stone, originally weighing about 7kg, of which a mass of 6.685kg is preserved. Terrestrial weathering is evident from its light brown external surface and the presence of limonite pervading its inner portion. Optical investigation shows the meteorite has a chondritic texture with chondrules of different types (porphyritic, granular, barred, radiating, chondrule remnants) but poorly delineated outlines set in a fine-grained recrystallized matrix. Mineralogical and microprobe studies reveal that the stone contains chiefly olivine (Fa 18.3) and orthopyroxene (Fs 16.2 Wo 1.3) of fairly uniform compositions, with smaller amounts of Fe-Ni metal (kamacite, taenite, plessite), troilite, Cr-diopside (En 48.1 Fs 5.3 Wo 46.6) and plagioclase (An 13.6 Ab 80.1 Or 6.3). Chromite, magnetite and limonite are accessories, the last two occurring mainly as alteration products of metal. A preliminary bulk chemical analysis indicates Fe/SiO_2 = 0.78 and total Fe = 27.17%. Based on textural features and chemical data the Ipitinga meteorite is classified as an equilibrated H5 chondrite of shock-stage S3.

Key words: meteorite, chondrite, Ipitinga, Pará, Brazil.

INTRODUCTION

A meteorite originally weighing about 7kg was found in March 1989 in Pará State, northern Brazil. The site of recovery is located about 15km southwest of the foothills of the main local mountain range, Serra do Ipitinga, and has approximate coordinates 0°21′N, 53°49′W (Fig. 1).

The name "Ipitinga meteorite" was submitted to the Nomenclature Committee of the Meteoritical Society and the find as well as the classification of the stone as an H5 chondrite were announced in the Meteoritical Bulletin (Wlotzka, 1992).

The purpose of this paper is both to give a detailed description of the find of this new meteorite and to provide data that contributed to its classification. These data include studies of its texture and composition of its main minerals. Preliminary results on its bulk chemistry are also presented.

CIRCUMSTANCES OF FIND AND MACROSCOPIC ASPECT

The discovery site of the meteorite lies within the gold district called Treze de Maio, a mining concession area of the Mineração Transamazônica Ltda. The meteorite was found by one of us (SLM) during routine geologic field work. The stone was recovered from a roadside about 1km north of the Treze de Maio airstrip. The road connects the airstrip to the mining village and runs through typical dense Amazon forest. It is believed that the speci-

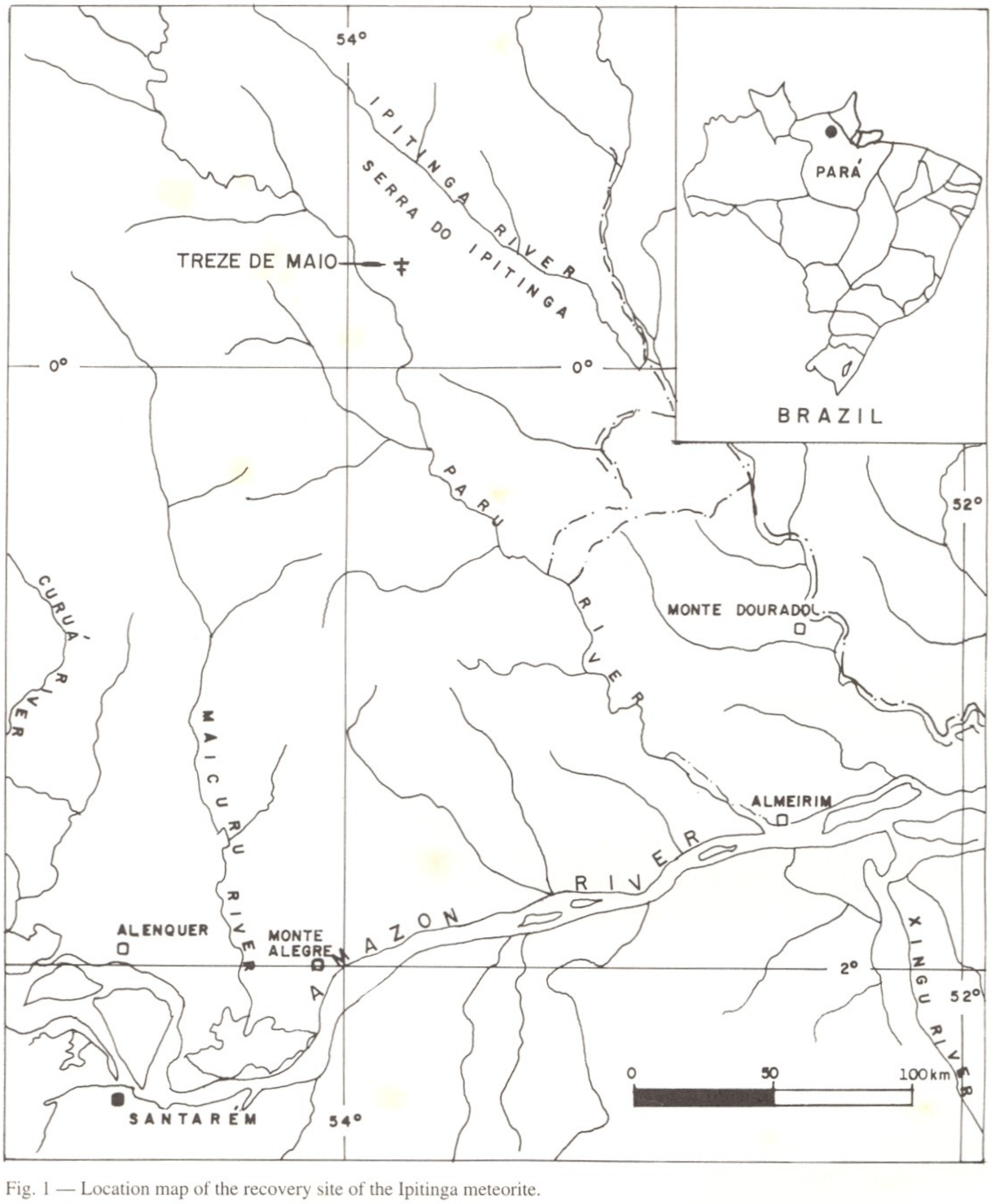


Fig. 1 — Location map of the recovery site of the Ipitinga meteorite.

men was bulldozed out of its original fall point during the implantation of the road.

The stone called attention due to a number of aspects making it quite different from the surrounding, dominantly lateritic materials. It showed a marked polyhedral shape with polished edges, high density and quite strong magnetism. The field classification was as an ultramafic rock but no outcrops or other blocks of similar rocks were found in the nearby slopes and stream beds. It was also noticed that the metallic minerals of the meteorite underwent weathering very rapidly on fresh fractures and sawn surfaces.

The inner portion of the meteorite is fine-grained and greenish brown in colour. This internal mass is entirely coated by an extremely fine-grained, bluish cap about 5mm thick, which was later identified as a fusion crust. The external surface is smooth and light brown in colour, which is indicative that the stone underwent terrestrial weathering for some time.

Samples of the meteorite were obtained by breaking one of its corners. Since then, fractures started to develop all over the stone and an intensive limonitic alteration pervaded its internal, coarser-grained mass.

The original size of the meteorite was approximately 20 × 14 × 14cm and the weight was just over 7kg. A mass of 6.685kg (Fig. 2a) remains preserved and is presently displayed at the Geoscience Museum of the Pará Federal University, in the city of Belém.

The stone was first identified as a meteorite in July 1989 through a thin section described by one of the authors (AMD). It was then decided to postpone the publication of this information until further data from polished sections and chemical analyses were available.

ANALYTICAL PROCEDURES

A pair of thin sections was examined microscopically in transmitted light and one polished thin section was prepared for the study under reflected light. A modal analysis (3900 points) of the latter was performed using a simple point counter. The polished section was further examined by using a scanning electron microscope (SEM; Cambridge Stereoscan 250) at the University of Nancy I, France, to verify the nature of the different minerals and to obtain back-scattered electron images.

Chemical analyses on minerals were carried out using a Camebax electron microprobe with wavelength-dispersive spectrometers also at the University of Nancy I. Operating conditions were as follows: counting time on peak = 6s, sample current = 6-8nA, accelerating voltage = 15kV, various silicate and oxide crystals as standards, and ZAF correction procedures. A preliminary whole-rock chemical analysis (for major and some trace elements) was obtained by ICP atomic spectrometry at CPRG, Nancy. Additional data (St, H_2Ot, Corg, Co, Cr and Ni contents) were obtained by wet chemistry procedures, also at CRPG.

TEXTURE

The chondritic texture, although not evident in a simple visual inspection of the meteorite, can be easily recognized under the microscope. Chondrules make up about 30-40% of the meteorite and range from 0.2 to 3mm in size. They are commonly rounded but their outlines are often poorly delineated and intergrown with the matrix, which is an evidence of strong recrystallization (Figs. 2b, 2d and 2e).

Concerning their internal textures, the majority of the chondrules in this meteorite conforms to the types most commonly found in chondrites, namely porphyritic, granular, barred-olivine and radiating-pyroxene chondrules.

The *porphyritic chondrules* contain subhedral to euhedral phenocrysts of olivine and more rarely of pyroxene set in a mesostasis* of very fine silicate and metal-sulphide grains. The phenocrysts typically show different sizes and comprise 50% or more of the chondrules. The silicates in the mesostasis commonly have a saccharoidal or microgranoblastic texture but bundles of fibrous crystals in subparallel arrangements are also present (Fig. 2b).

The *granular chondrules* seem to represent a variant of porphyritic chondrules in which olivine crystals are more abundant and more uniformly-sized, and whose mesostasis is restricted to interstices (Fig. 2c).

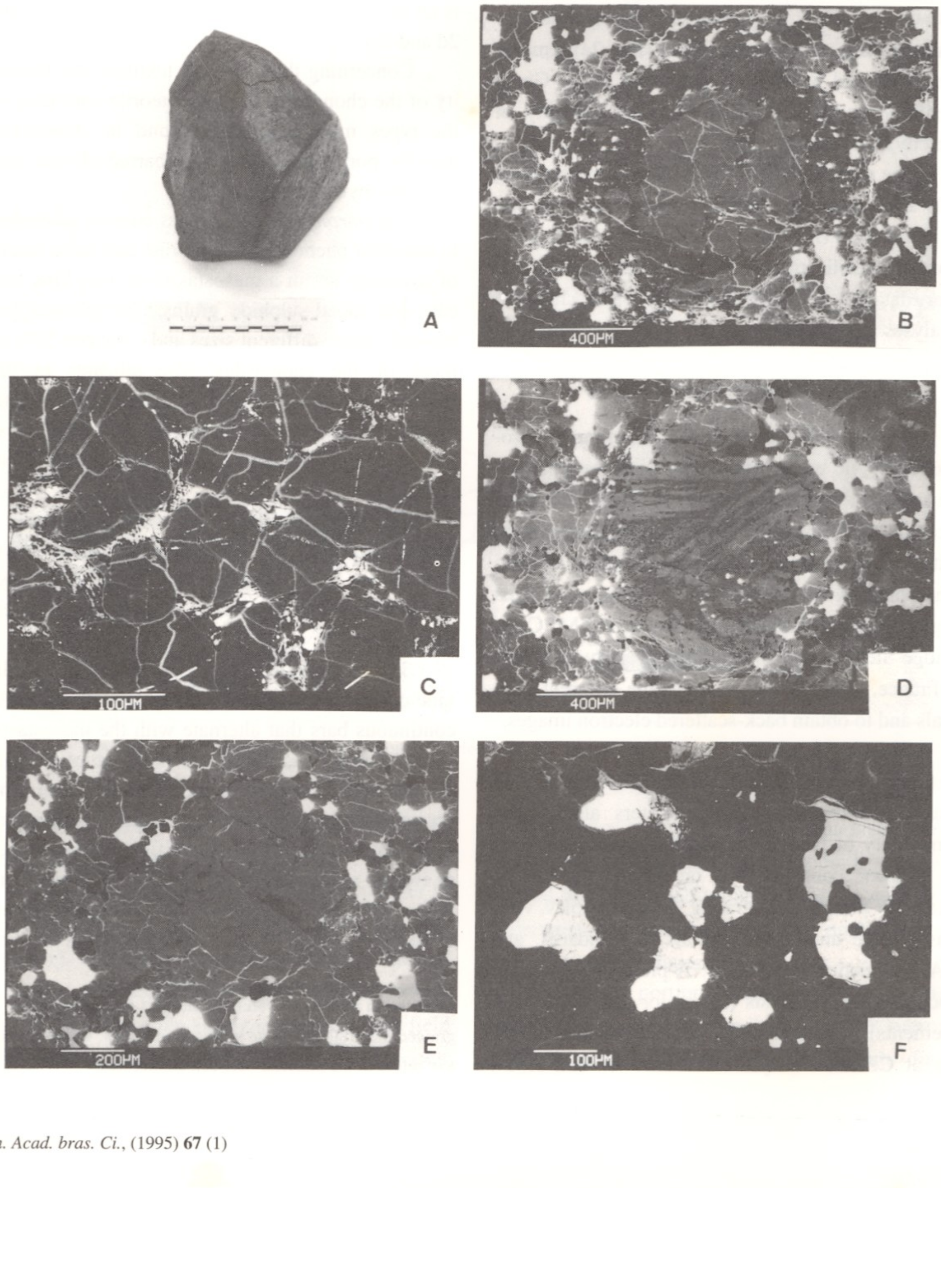
The *barred-olivine chondrules* consist of olivine crystals formed of regularly-spaced, optically continuous bars that alternate with the mesostasis. Many of these chondrules are made up of a single olivine crystal and in some cases an outer rim, crystallographically continuous with the barred interior, is present. Other chondrules are composed of two or more skeletal olivines in different orientations (Fig. 2d). The mesostasis in barred-olivine chondrules varies from a dark, cryptocrystalline

*The therm mesostasis refers in this text to the very fine-grained material contained within chondrules, whereas matrix refers to the material between chondrules.

material to microgranoblastic or fibrous aggregates mostly composed of silicates.

The *radiating pyroxene chondrules* are less frequent in this meteorite than the foregoing types. They are commonly elongate in section and consist of fans of divergent orthopyroxene needles with minute grains or fibres of other silicates and droplets of metal-sulphide in the interstices. Some of these chondrules display such fine-grained pyroxenes that they look feathery.

The Ipitinga meteorite also contains abundant remnants or fragments of chondrules besides some other textural varieties which cannot be readily related to the above-described types. Among these are, for instance, microcrystalline to fine-skeletal varieties that probably correspond to primitive glassy chondrules. Another example is given by chondrule-like olivine monocrysts (Fig. 2e), which may represent highly recrystallized barred or porphyritic types.



The *matrix* between the chondrules displays a somewhat irregular granularity, average grain size being 100-200 μm (Figs. 2b, 2d and 2e). It is mainly composed of anhedral to subhedral olivine and orthopyroxene crystals as well as of grains and masses of opaque minerals which are commonly moulded around the silicates. Plagioclase is interstitial and occasionally shows diffuse polysynthetic twinning. A slight undulatory extinction is observed in a few grains. Olivine and pyroxene are all fractured and weakly undulose. Planar fractures in addition to nonplanar, irregular fractures, are observed in many olivines from the matrix and also in some chondrule phenocrysts (Fig. 2b). A limonitic alteration material pervades most of the matrix, infilling fractures and constituting thin rims around the metallic phases.

MINERALOGY

The modal analysis of the Ipitinga meteorite indicates (in vol.%) 84.6 silicates, 6.8 metallic Fe-Ni, 5.7 troilite, 1.7 magnetite, 0.9 chromite and 0.3 limonite. Olivine and orthopyroxene represent the main silicates, whereas plagioclase and clinopyroxene are minor components.

Olivine is by far the dominant phase in this meteorite. Microprobe analyses of olivine grains that occur in chondrules and in the matrix show them to be compositionally quite uniform, as expected in strongly recrystallized meteorites. The mean Fa content of 18.3 mol.% (Tab. I) and the range of Fa 16.9-19.5 (Fig. 3a) are very similar to the values listed in Gomes & Keil (1980) (mean Fa = 18.8; range Fa 16.9-20.4) for olivines from ordinary equilibrated H-group chondrites. The low mean CaO content, of 0.01 weight %, also reflects a strong recrystallization, according to Dodd (1972).

Orthopyroxene is the second most important mineral in the meteorite and is untwinned. The analysed orthopyroxene grains belong to the matrix and to the mesostasis of certain chondrules and, like for olivine, they show a marked compositional uniformity. They are characterized by having a mean Fs content of 16.2 mol.% and a mean Wo of 1.3 mol.% (Tab. I). Both the mean Fs value and the grain-to-grain range of Fs 15.4-16.9 (Fig. 3b) are very close to the composition of orthopyroxenes from equilibrated H-group chondrites, as defined by Gomes & Keil (1980) (mean Fs = 17.2; range Fs 15.7-18.1). The mean Fa content of olivine and Fs of orthopyroxene plotted on the diagram of Figure 4 illustrate how well these silicates fit into the field for equilibrated H-chondrites.

Clinopyroxene is usually very fine-grained and may be distinguished from orthopyroxene by its higher birrefringence. The two clinopyroxene grains analysed in this meteorite are from the mesostasis of chondrules shown in Figure 2b and 2d, where they occur associated with orthopyroxene and plagioclase. Chemically they correspond to chromium-bearing diopsides, having a

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Fig. 2(a) — The Ipitinga meteorite found in Pará State, northern Brazil, now weighing 6.685kg. It shows a marked polyhedral shape and is completely coated by a fusion crust. Its outer surface is pale brown due to terrestrial weathering. Scale is 10cm long. Fig. 2(b) — Porphyritic chondrule containing a large olivine phenocryst (grey) set in a mesostasis made up mostly of fibrous pyroxene (dark grey) and plagioclase (black). The chondrule has a poorly-defined outline and is embedded in an irregularly-grained matrix with silicates (grey to black) and metal-sulphide phases (white). Fractures infilled with limonite (also in white). The olivine phenocryst displays irregular and planar fractures. Back-scattered electron image (BSEI). Fig. 2(c) — Part of the interior of a granular chondrule consisting of closely packed olivine crystals (dark grey) and an interstitial mesostasis made up of silicates (black) and metal-sulphide minerals (white). Fractures in olivine infilled with limonite (also white). BSEI. Fig. 2(d) — Poorly delineated chondrule composed of two barred-olivine crystals (light grey) in different orientations set in a mesostasis of pyroxenes (grey), plagioclase blebs (black) and scarce metal droplets (white). The matrix around the chondrule contains olivine, pyroxene (both in grey), metal and sulphide (both in white) and plagioclase (black, in the upper border of the chondrule). Note that these plagioclase grains are distinctly coarser-grained than the ones contained in the mesostasis within the chondrule. BSEI. Fig. 2(e) — Chondrule-like olivine monocryst (grey) surrounded by a recrystallized matrix of olivine, orthopyroxene (both in grey), sulphide, Fe-Ni metal (both in white) and some plagioclase (black). The monocryst contains minute inclusions, possibly of a relictic mesostasis, and may represent a strongly recrystallized porphyritic or barred-olivine chondrule. Fractures mostly infilled with limonite (white). Some holes in the section appear in black. BSEI. Fig. 2(f) — Anhedral, fractured chromite (grey), metallic Fe-Ni (white) and troilite (light grey, with a network of fractures) situated among silicates (black) in the matrix of the Ipitinga meteorite. Most of the metallic minerals are associated with troilite. The metal grain (kamacite) in the upper left quadrant is coated by an alteration rim of limonite. BSEI.

TABLE I
Electron microprobe analysis (in weight %) of minerals in the Ipitinga meteorite.

	Olivine (N=19)		Ortho-pyroxene (N=12)		Clino-pyroxene (N=2)		Feldspar (N=6)		Chromite (*) (N=7)	
SiO_2	39.89		56.62		54.60		64.25		—	
TiO_2	0.01		0.15		0.36		0.02		2.07	
Al_2O_3	0.02		0.17		0.57		21.76		7.05	
Cr_2O_3	0.01		0.11		0.64		—		57.87	
FeO	17.12		10.78		3.32		0.78		28.58	
MnO	0.46		0.41		0.14		0.04		0.80	
NiO	0.05		0.01		0.03		0.03		—	
MgO	42.96		30.79		16.79		0.03		3.40	
CaO	0.01		0.68		22.63		2.82		—	
Na_2O	0.01		0.01		0.56		9.17		—	
K_2O	—		—		—		1.10		—	
Total	100.54		99.73		99.64		100.00		99.77	
Number of ions on the basis of 4(O) for olivine, 6(O) for ortho- and clinopyroxene, 16(O) for feldspar and 32(O) for chromite										
Si	1.006		2.000		1.995		5.699		—	
Ti	—		0.004		0.010		0.001		0.437	
Al	0.001		0.007		0.025		2.276		2.336	
Cr	—		0.003		0.018		—		12.858	
Fe	0.361		0.318		0.101		0.058		6.719	
Mn	0.010		0.012		0.004		0.003		0.191	
Ni	0.001		—		0.001		0.002		—	
Mg	1.614		1.621		0.914		0.004		1.424	
Ca	—		0.026		0.886		0.268		—	
Na	0.001		0.001		0.040		1.577		—	
K	—		—		—		0.125		—	
Molecular end members										
	Fa	18.3	Fs	16.2	Fs	5.3	Ab	80.1	Fe	80.6
	Fo	81.7	En	82.5	En	48.1	An	13.6	Mn	2.3
			Wo	1.3	Wo	46.6	Or	6.3	Mg	17.1

All minerals represented by average compositions. N = number of grains analyzed. / (*) = Vanadium was detected in X-ray spectra but not quantified.

mean of En 48.1 Fs 5.3 Wo 46.6, and an average Cr_2O_3 content of 0.64 weight % (Tab. I).

Plagioclase is present in the mesostasis of chondrules as extremely fine grains and also in the matrix in coarser, up to 100 μm, occasionally twinned crystals (Fig. 2d). Chemical data show that the plagioclase is an oligoclase, averaging An 13.6 Ab 80.1 Or 6.3 (Tab. I). This composition is close to the mean feldspar from H-group chondrites (An 12.3 Ab 81.9 Or 5.8), as given by Van Schmus & Ribbe (1968), and falls within the field of the H-chondrites defined in the ternary An-Ab-Or diagram (Fig. 5).

Metallic Fe-Ni minerals are the major opaque phases in this meteorite and occur mainly in the matrix, as anhedral to subhedral particles of up to

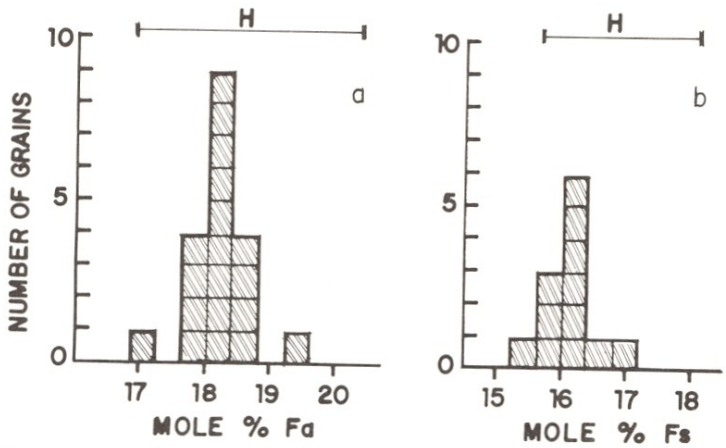

Fig. 3 — Histograms for the Ipitinga meteorite showing the compositions of olivine (a) and orthopyroxene (b) expressed in mole % fayalite (Fa) and ferrosilite (Fs), respectively. Compositional ranges for equilibrated H-group chondrites are from Gomes & Keil (1980).

300 μm in size (Fig. 2f). Both *kamacite* and *taenite* are present, occasionally forming the fine worm-like intergrowths known as *plessite*. Kamacite is the dominant metallic phase and is usually coated by thin, continuous rims of limonite (Fig. 2f). Between the limonite rim and the unaltered kamacite there are commonly patches and cracks infilled with a material that is interpreted as a Ni-bearing magnetite by combined X-ray – reflected light studies. Microprobe analyses made on four kamacite grains indicated Ni contents in the range of 5.5-6.4 weight %, and one taenite analysis resulted

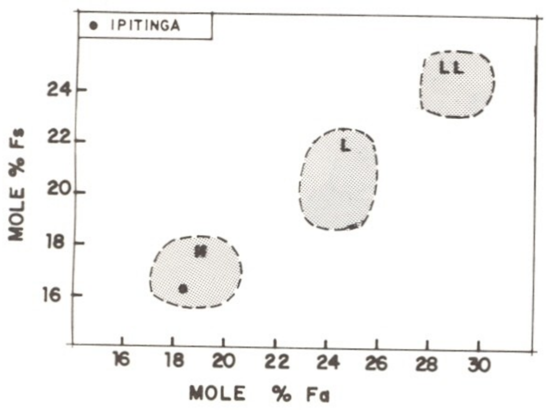

Fig. 4 — Mean fayalite (Fa) content of olivine plotted against mean ferrosilite (Fs) content of orthopyroxene from the Ipitinga meteorite. Compositional fields for H, L and LL equilibrated chondrites are from Gomes & Keil (1980).

in 31.9 weight % Ni. These values, however, ust be considered as approximate, because silicates and oxides were used as standards during probe analyses and Co was not analysed.

Troilite is almost as abundant as the metallic phases to which it is commonly associated (Fig. 2f). It forms irregular grains that may attain 800 μm in size, and is characterized by possessing a network of fractures infilled with a material comparable to the magnetite derived from kamacite. Microprobe analyses of three troilite particles showed approximate values of 64 to 66 weight % Fe and trace amounts (about 0.02 wt.%) of Ni. Cr was not detected and Co was not analysed.

Chromite is an accessory phase in the meteorite. Most of it is present in the matrix, as fractured, anhedral to subhedral grains, from 50 to 200 μm in size. This matrix chromite belongs to the "coarse chromite" variety of Ramdohr (1967) and occurs either among silicates or associated to metallic Fe-Ni or troilite (Fig. 2f). All chromite grains analysed in this meteorite are of the coarse type and are rather constant in composition (Tab. I). In the correlation diagrams shown in Figure 6 it can be seen that the major oxides of the Ipitinga average chromite fall either very close to or fit into the fields delineated for equilibrated H-group chondrites.

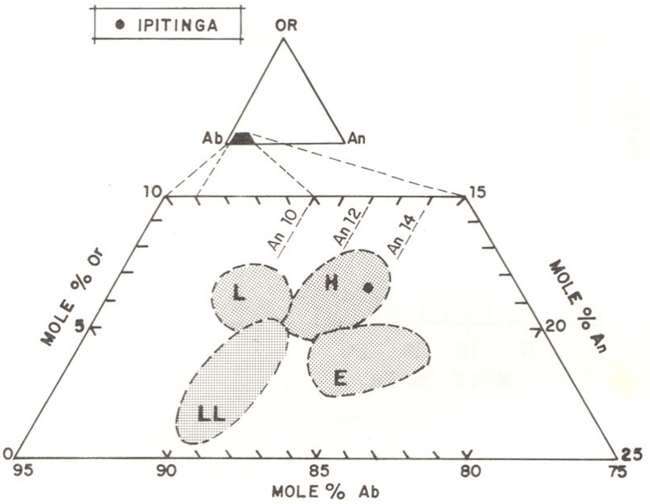

Fig. 5 — Mean plagioclase from the Ipitinga meteorite plotted in the An-Ab-Or ternary diagram for chondritic feldspar compositions. Diagram and fields for H, L, LL and enstatite-chondrites are from Van Schmus & Ribbe (1968).

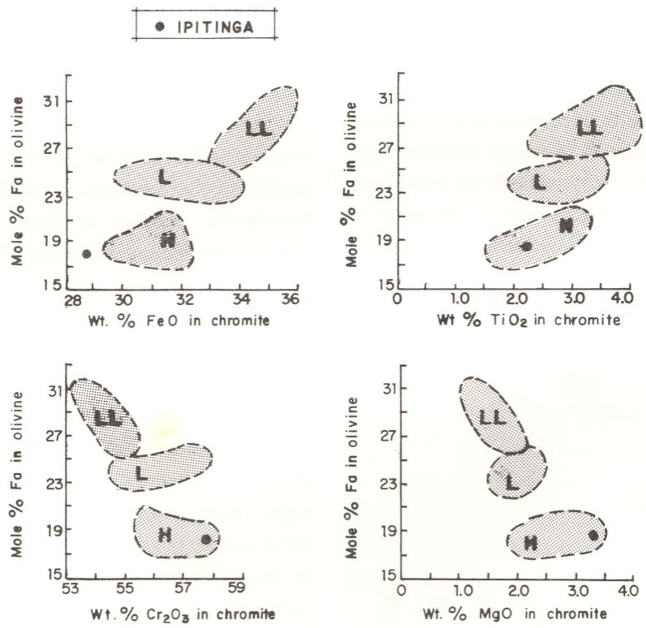

Fig. 6 — Major oxide contents (in weight %) of the average chromite plotted against mean Fa content (in mole %) in the coexisting olivine from the Ipitinga meteorite. Diagrams and fields for H, L and LL equilibrated chondrites are from Bunch *et al.* (1967).

TABLE II
Bulk chemical analysis (in weight %) of the Ipitinga meteorite together with the average compositions and other chemical parameters of the three main groups of chondrites given by Gomes & Keil (1980).

	Ipitinga	H-group	L-group	LL-group
SiO_2	34.71	36.52	39.88	39.39
TiO_2	0.12	0.13	0.15	0.19
Al_2O_3	2.25	2.43	2.31	2.21
Cr_2O_3	0.54	0.36	0.44	0.30
FeO	30.85(*)	8.87	13.12	17.70
MnO	0.30	0.25	0.27	0.32
MgO	21.86	23.48	24.98	25.40
CaO	1.53	1.82	1.90	1.96
Na_2O	0.68	0.85	0.88	0.87
K_2O	0.06	0.14	0.14	0.21
P_2O_5	0.38	0.23	0.26	0.22
H_2O	1.94	0.33	0.34	0.37
Fe^o	n.d.	17.23	7.70	3.39
Ni	1.22	1.58	1.12	0.95
Co	0.08	0.085	0.059	0.052
FeS	5.02	5.35	6.17	5.87
C	0.03	0.10	0.09	—
Total	101.57			
Total Fe	27.17	27.52 (avg.)	21.82 (avg.)	20.87 (avg.)
Fe/SiO_2	0.78	0.77	0.55	0.49

(*) = Includes all iron present in metal, silicates and oxides, except that combined with S in troilite. / n.d. = not determined.

BULK CHEMISTRY

A bulk chemical analysis of the Ipitinga meteorite is shown in Table II together with the average compositions of the three main groups of chondrites and some important chemical parameters related to them. The bulk chemical data for Ipitinga must be considered only as preliminary ones, because the results of a routine analysis by ICP were coupled with partial wet chemistry data. The amount of Fe^o (metallic Fe) was not determined, and in Table II all iron, except that combined with S in troilite (FeS), is presented as FeO. This FeO includes, consequently, Fe^o of the metallic phases, FeO present in silicates and oxides, and also Fe_2O_3 resulting from weathering oxidation.

Considering the available chemical data the Ipitinga meteorite is more closely comparable to the H-group chondrites (Tab. II), although it shows SiO_2, MgO, FeS and Ni values that appear somewhat low. However, the total Fe value of 27.17 weight % and the Fe/SiO_2 ratio of 0.78 are both in quite good agreement with the average numbers of total Fe = 27.52% and Fe/SiO_2 = 0.77 given for H-group equilibrated chondrites by Gomes & Keil (1980).

CONCLUSIONS

The Ipitinga meteorite is classified as an *H-group* chondrite on the basis of the composition of its minerals, particularly those of olivine (Fa 18.3) and orthopyroxene (Fs 16.2), as well as plagioclase (An 13.6 Ab 80.1 Or 6.3) and chromite. An H-group classification is also indicated by some of the bulk chemical results, especially the Fe/SiO_2 ratio (0.78) and total Fe content (27.17%).

Based on the uniform compositions of olivine and orthopyroxene, the strong recrystallization of the matrix, the microgranoblastic to fibrous texture in many chondrule mesostases and the poorly delineated chondrule outlines, the Ipitinga meteorite is placed into the *petrologic class 5* of Van Schmus & Wood (1967). Also consistent with this classification are the low mean CaO content of olivine (0.01 wt.%), considered typical of equilibrated chondrites by Dodd (1972), and the mean Wo content of orthopyroxene (1.3 mol.%), which is within the range of Wo 1.2-1.6 for petrologic class 5 meteorites given by Scott *et al.* (1986).

Additional features such as the presence of weak undulatory extinction and of planar fractures in olivine, and the occasionally deformed aspect of plagioclase indicate the meteorite is weakly shocked, belonging to *shock-stage S3* of Stöffler *et al.* (1991).

In their study of Brazilian stone meteorites, Gomes & Keil (1980) describe a total of 21 chondrites and achondrites so far known in the country. All of them were recovered from the densely-populated eastern and southeastern regions of Brazil and most of them correspond to observed falls. In this respect, Ipitinga represents a particularly interesting case: it is one of the few new finds and the first meteorite discovered in such a thinly-populated area as the Amazonian region of Brazil.

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