CLASSIFICATION OF THE TOCACHE METEORITE, A FALL FROM PERU. G. G. Silva[1], F. F. França[2], L. Martins[2], G. E. Enrich Rojas[2], S. Schuindt[3], J. Garcia[4], D. Galante[5], F. Rodrigues[1], [1]Chemistry Institute, University of São Paulo, Av. Lineu Prestes, 748, CEP: 05508-000, São Paulo - SP, Brazil, (e-mail:gabrielg@iq.usp.br), [2]Geoscience Institute, University of São Paulo, R. do Lago, 562, CEP: 05508-080, São Paulo - SP, Brazil, [3]School of Environment, Geography and Geoscience, University of Portsmouth, UK, [4]Museo Canario de Meteoritos. P.O. Box 3. 35260, Agüimes (Las Palmas, Islas Canarias) Spain, [5]Brazilian Center for Research in Energy and Materials, R. Giuseppe Máximo Scolfaro, 10000, CEP: 13083-100, Campinas - SP, Brazil.

Introduction: The Tocache meteorite fall occurred between 00:00 and 2:00 (local time) of January 1st, 1998, in the Tocache District, Tocache Province, San Martín Department, Peru. Mr. Leodegario Tolentino Laiza and Mrs. Horacia Padilla Herrera witnessed the fall and, in the following week, Mr. Leodegario found one fragment inside of a small crater on his land. The meteorite was kept inside a shed of his property, and was exposed to the high humidity of the Peruvian Amazon. In 2017, the fragment was sold by the couple's son, Mr. Willy Tolentino Padilla and was finally made available for study and classification. This meteorite is the 5th meteorite recorded in Peru and only the 2nd fall of the country. The objective of this work was to perform the petrographic and chemical characterization of the only fragment recovered of the Tocache meteorite.

Methodology: Six thin sections were made from a slice of approximately 10 X 10 cm of the meteorite. The thin sections were used to obtain: (1) petrographic analysis under reflected, plane-polarized and cross-polarized light (Olympus BX40 microscope); (2) mineral compositions using electron microprobe analyser (WDS in a JEOL JXA-8530); (3) compositional maps using scanning electron microscope MEV (SEM-FEG ENV FEI Quanta microscope); (4) μ-XRF elemental analysis (XRF beamline at Brazilian Synchrotron Light Laboratory - LNLS); (5) and mineral identification using RAMAN (Raman Renishaw inVia spectrometer). A small sample of the meteorite was also cut and comminuted (< 200 mesh) for total chemistry characterization using XRF in fused (major and minor elements) and pressed (trace elements) tablets (PANalytical, model AXIOS MAX Advanced spectrometer). A sample was cut in cube of 1 cm^3 to perform an X-ray tomography (SkyScan 1272 X-ray tomograph).

Results: The original fragment weighted 5140 g and about 80% of its surface was covered in a dark-reddish fusion crust showing different degrees of oxidation (Fig. 1A and 1B). The exposed inner parts of the meteorite present a striated structure of conical shape covering a 3 X 4 cm area (Fig. 1B).

Petrography. The thin sections showed that around 60 to 70% in area was covered by not-well-defined chondrules ranging typically between 0.3 and 0.8 mm of diameter (mean 0.5 mm). The chondrules were mainly porphyritic olivine (PO) and porphyritic olivine-pyroxene (POP). Rare radial pyroxene (RP) chondrules also appeared in lower proportion (Fig. 2). The pyroxene crystals (5:95 CPX/OPX) commonly show both irregular and planar fractures, while the olivine crystals show mostly irregular fractures, planar ones being rare. The meteorite presents several long melt veins (up to 400 μm wide), some of them including metal and troilite veins and pockets. The metal flakes vary in size between 0.1 and 1 mm in diameter (mean 0.3 mm), often showing some degree of connection between them. It makes up 11% of the meteorite volume (tomography), of which 7 to 8% is kamacite/taenite, 3% is troilite and up to 0.1 to 0.2% is chromite. Neumann lines can be seen on kamacite crystals. Exposition to humidity led to unevenly distributed weathering of the meteorite, and around 10% of the kamacite crystals have been oxidated.

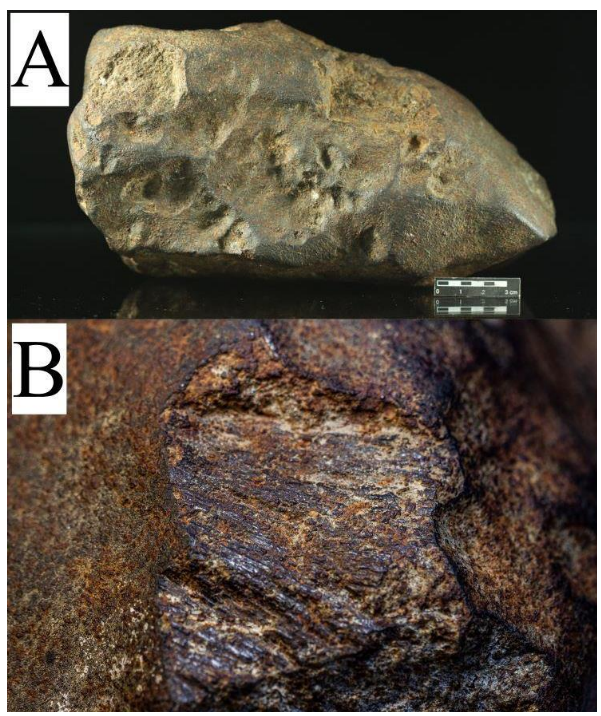

Figure 1: A - Tocache meteorite; B - Close-up of the shatter cone area observed on the surface of the exposed inner part of the fragment.

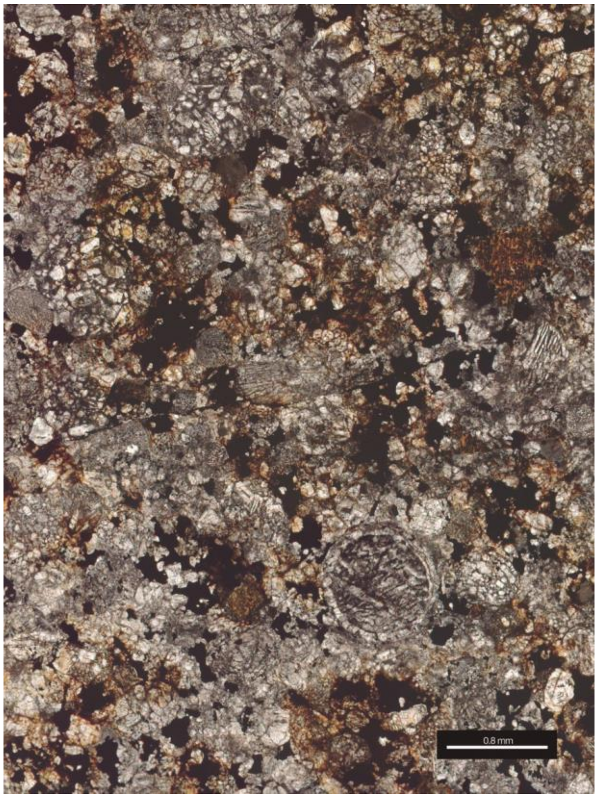

Figure 2: Petrography under plane-polarized light showing the chondritic texture of the Tocache meteorite.

Rock and mineral chemistry. The composition of the major mineral phases includes (Microprobe): olivine ($Fa_{20.1±0.8}$; N=82), low-Ca pyroxene ($Fs_{16.6±0.6}Wo_{1.3±0.7}$; N=60), high-Ca pyroxene ($Fs_{11.2}Wo_{25.7}$; N=1), and feldspar ($Ab_{78.3±4.5}An_{15.7±6.4}Or_{5.9±4.7}$; N=7). Minor and accessory mineral phases comprise of (MEV/EDS and μ-XRF): troilite (Fe = 64.7±0.6 wt%, S = 35.5±0.6 wt%; N=2), kamacite (Ni = 7.2±1.5 wt%; N=2), taenite (Ni = 29.8±3.7 wt%; N=2), tetrataenite (Ni = 46.2±0.6 wt%; N=1), chromite (Cr/(Cr+Al): 0.88±0.06; N=4), zoned Cr-spinel (edge = Cr/(Cr+Al): 0.58±0.05, Mg/(Mg+Fe): 0.22±0.03, Ti: 0.5±0.1 wt%; N=3) (center = Cr/(Cr+Al): 0.29±0.04, Mg/(Mg+Fe): 0.40±0.03; N=3), apatite (Cl: 5.0±0.2 wt%, F: 1.2±0.2 wt%; N=1). The presence of ilmenite and merrillite was observed through RAMAN spectroscopy. The chemical composition of Tocache meteorite is within the range of the average H ordinary chondrite, with slightly lower Si and Mg and higher Fe concentrations.

Discussion: The striated structure with conical shape observed (in opposition to parallel grooves of slickensides) was identified as a shatter cone, being probably associated with melt veins [1]. Mineral chemical analysis, showed that %Fa in olivine, %Fs in pyroxene and albite content in plagioclase agree with those expected for ordinary H-type chondrites. Petrographic evidences, olivine/pyroxene ratio, the large volume of metals and moderate recrystallization allow to classify the Tocache meteorite as an H5 type [2]. The moderate degree of shock indicates a S3 classification [3], while the low oxidation of the metallic phases suggest a W1 classification [4].

Acknowledgments: This research was supported by São Paulo Research Foundation (FAPESP) project 17/16964-0, the Coordination for the Improvement of Higher Education Personnel (CAPES) project 33002010191P0, and Brazilian National Council for Scientific and Technological Development (CNPq) grants 424367/2016-5 and 301263/2017-5. The authors want to thank the Center of Research Support in Astrobiology (NAP/ASTROBIO).

References: [1] Pittarello, L. et al. (2015) *Meteoritics & Planet. Sci., 50*, 1128-1243. [2] Krot A. N. et al. (2014) *Treatise on Geochemistry: Meteorites and Cosmochemical Processes, 1*, 1-63. [3] Grady, M. et al. (2014) Atlas of meteorites. [4] Wlotzka, F. A. (1993) *Meteoritics, 28*, 460-460.