SILICATE INCLUSIONS IN THE KODAIKANAL IIE IRON METEORITE. Kurat G[1]; Varela M. E.[2] and Zinner E.[3] [1]Institut für Geologische Wissenschaften, Universität Wien, Althanstrasse 14, A-1090 Vienna, Austria, gero.kurat@univie.ac.at , [2]CONICET, UNS Dpto Geologia, San Juan 670, 8000 B. Blanca, Argentina, [3]Laboratory for Space Sciences and Physics Department, Washington University, St. Louis, MO 63130, USA..

Introduction: Silicate inclusions in iron meteorites display an astonishing chemical and mineralogical variety, ranging from chondritic to highly fractionated, silica- and alkali-rich assemblages [e.g., 1]. In spite of this, their origin is commonly considered to be a simple one: mixing of silicates, fractionated or unfractionated, with metal [1-4]. The latter had to be liquid in order to accommodate the former in a pore-free way which all models accomplish by assuming shock-melting.

II-E iron meteorites are particularly interesting because they contain an exotic zoo of silicate inclusions, including some chemically strongly fractionated ones [e.g., 1, 5-9]. They also pose a formidable conundrum: young silicates are enclosed by very old metal [e.g., 4, 10-13]. This and many other incompatibilities between models and reality forced the formulation of an alternative genetic model for irons [14]. Here we present preliminary findings in our study of Kodaikanal silicate inclusions.

Results: The Kodaikanal sample containing the three silicate inclusions studied (GI-1, GI-2 and GI-3, Fig. 1)) belongs to the 4 mm thick slide (H988, NHM Vienna) shown in [15] and comes from the left lower corner.

Inclusion GI-1 is round and consists exclusively of glass, decorated by small schreibersite crystals (see detail of BSE image in Fig 1). Inclusions GI-2 and GI-3 are multiphase inclusions consisting of glass, clinopyroxene (cpx) and low-Ca pyroxene (from here on opx) with minor chromite, apatite and whitlockite. Inclusion GI-2 (~ 9 mm in size) has pyroxenes - ranging in size from 500 to more than 2000 μm - located in the center. The anhedral cpxs are mantled by opxs forming euhedral to subhedral skeletal crystals. Chromite is mainly associated with the opx. Needle-like crystals of apatite and whitlockite are restricted to one area near the surface.

The mineralogy of GI-3 is similar to that of GI-2, however, as GI-3 is only a small part of a bigger inclusion we have decided to perform trace element analyses in inclusions GI-1 and GI-2 only. The major element chemical compositions of the main phases in both inclusions are given in the Table.

Glass in GI-1 (Ko-glass1) is enriched in the heavy REE over the light REE and has distinct negative Eu and Yb abundance anomalies (Fig.2). The glass has high contents of Nb (200 x CI), Be, B (~110 x CI) and Rb (>200 x CI) and low contents of Cr (~0.015 x CI) and Co (0.006 x CI). In inclusion GI-2, glasses in contact with pyroxenes (Ko-glass3) show similar patterns, different from that in glass adjacent to apatite (Ko-glass5). All three glasses have fractionated LREE and slightly fractionated HREE, with Ko-glass3 having REE contents close to chondritic abundances and Ko-glass5 around 0.3 x CI.

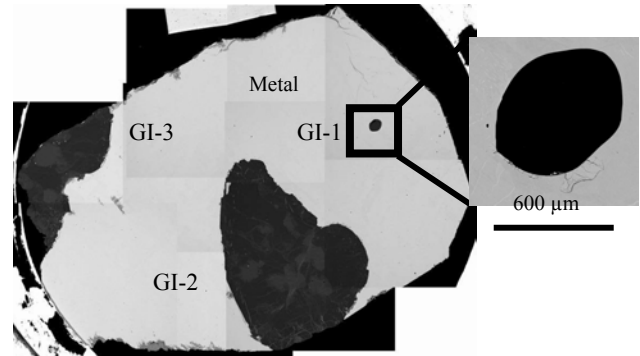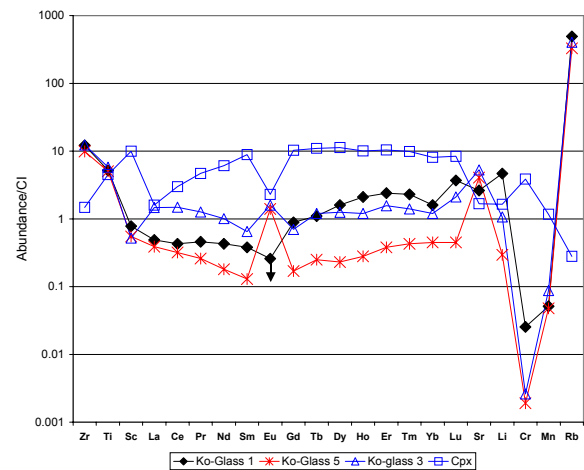The two Gl-2 glasses have a positive Eu anomaly and similar

Fig.1

Fig. 2

Table: Chemical compositions of glasses and minerals in inclusions GI-1 and GI-2 (EMP data in wt%).

Inclusion	Gl-1	Gl-2		
	Glass	Glass	Opx	Cpx
SiO2	67.0	64.3	55.5	53.3
TiO2	0.45	0.50	0.24	0.43
Al2O3	17.3	17.4	0.37	1.24
Cr2O3	<0.02	0.03	0.39	1.23
FeO	0.21	2.87	11.0	5.0
MnO	<0.02	0.05	0.50	0.28
MgO	0.08	0.75	30.8	17.3
CaO	0.07	0.14	1.10	20.0
Na2O	4.5	7.2	0.03	0.54
K2O	7.9	5.0	0.03	<0.02
P2O5	0.27	0.27	0.07	0.03
Total	97.78	98.51	100.03	99.35

abundances of Eu (1.4 x CI), Nb and B (~15 x CI), Be (~45 x CI) and Rb (>300 x CI).

Pyroxenes are rich in trace elements and have negative Eu abundance anomalies.

Discussion: Silicate inclusions in IIE irons are highly diverse in their texture, mineralogy and chemical composition. The Rb-Sr ages are also different, varying from fairly old (e.g., Colomera, 4.51 Ga [16]) to fairly young (e.g., Kodaikanal, 3.5 – 3.7 Ga [10, 11]). This diversity [1] has motivated researcher to formulate several genetic models. However, one feature is common to all silicate inclusions: they kept a memory of a chondritic source, as all have similar oxygen isotopic compositions that are related to those of H chondrites [17]. Because of this property, all genetic models of IIE irons involve collision with or impact into a target of H chondritic composition [7-9, 18].

However, all existing models seem to be grossly ad odds with our data on Kodaikanal inclusions. There are no traces of shock in our silicates but there exists a weak link to H chondrites: the opx in inclusion Gl-2 (Table) has a major and minor element composition similar to opx from H chondrites, however, with TiO_2, Al_2O_3 and Cr_2O_3 contents somewhat high, up to about twice that of H chondrite pyroxenes. The cpx in inclusion Gl-2 has a composition comparable to cpx of ordinary chondrites – similar to L chondrite cpx - but has no similarity with H chondrite cpx. Low-Ca pyroxene and cpx are not in equilibrium with respect to the Fe-Mg distribution, a feature widespread among iron and other meteorites, which is probably due to incomplete metasomatic Fe-Mg exchange between silicates and the environment [e.g., 19]. Considering that opx overgrows cpx, the shift in Fe/Mg ratio is in the wrong direction from an igneous point of view.

From their morphology, the two pyroxenes in Gl-2 appear to have grown from a liquid (skeletal crystals) but that liquid could not have had the chemical composition the co-existing glass now has. The pyroxenes are obviously far out of equilibrium with the glassy mesostasis. REE abundances of a melt in equilibrium with cpx and opx in the inclusion GI-2 would need to be about 40 x CI (except, Eu 10 x CI) and 20 x CI (except, La 100 x CI), respectively. That is very different from what we observe in the glass in contact with the pyroxenes in this inclusion (REE around 1 x CI). Similar disequilibria have been described for silicate inclusions of Miles and Weekeroo Station and promted the proposal that the feldspathic glass could have formed by re-melting of pre-existing feldspar + pyroxene [7] or feldspar + pyroxene + tridymite [8]. Although some match of the REE patterns with those of the glasses can be obtain by these mixtures, two important features cannot be matched: First, the highly fractionated Na_2O/K_2O ratio of the glasses (around 1!) is clearly impossible to achieve by melting of albitic feldspar from H chondrites and needs a fractionation mechanism that involves non-silicates. Something like the sulfide

fractionation process [20] suggested for widespread Na-K fractionation observed in LL chondrites must have been at work. Second, many glasses and also pyroxenes have a negative Yb abundance anomaly [e.g., 8, 9] which cannot be explained by either shock or partial melting. This anomaly is also present in our sample and is accompanied by a negative Eu anomaly in glassy inclusion Gl-1 (as it is also in pyroxenes in Colomera [9]). In addition, the LREE are depleted with respect to HREE (as they are in a similar manner in pyroxenes of Colomera [9]). This pattern clearly resembles that of an ultra-refractory component [e.g., 21-23] and suggests that condensation could have played a role. If this is correct, then also the alkali fractionation could have a nebular origin – similar to that of chondrules and other chondritic constituents [e.g., 19, 20].

Conclusions: Phases in glass-bearing multiphase silicate inclusions in the Kodaikanal IIE iron are chemically far out of equilibrium and strongly fractionated, as previously observed in several IIE irons. Our data suggest that nebular condensation and sub-solidus nebular processing are responsible for this situation. Surprisingly, the REE abundance pattern in glassy inclusion GI-1 suggests that ultra-refractory condensates could have been involved in the formation of silicate inclusions in IIE irons. We take this as yet another hint for a nebular origin of meteoritic irons [e.g., 14].

References: [1] Bunch et al. (1970) Contr. Mineral. Petrol. 25, 297-340. [2] Wasson (1974) Meteorites. Springer, 316 pp. [3] Scott (1979) in: Asteroids, Gehrels (ed.), Univ. Arizona Press, p892-925. [4] Snyder et al (2001) EPSL 186, 311-324. [5] Prinz et al. (1983) LPSC 14, 618-619. [6] Rubin et al. (1986) EPSL 76, 209-226. [7] Ruzicka et al. (1999) GCA 63, 2123-2143. [8] Hsu (2003) GCA 67, 4807-4821. [9] Takeda et al. (2003) GCA 67, 2269-2288. [10] Burnett and Wasserburg (1967) EPSL 2, 137-147. [11] Bogard et al. (1967) EPSL 3, 275-283. [12] Birck and Allegre (1998) MAPS 33, 647-653. [13] Bogard et al. (2000) GCA 64, 2133-2154. [14] Kurat (2003) Conf. Evol. Solar System Materials, NIPR, Tokyo, 65-66. [15] Buchwald (1975) Handbook of Iron Meteorites. Univ. Calif. Press. [16] Sanz et al. (1970) GCA 34, 1227-1239. [17] Clayton et al. (1983) EPSL 65, 229-232. [18] Wasson and Wang (1986) GCA 50, 725-732. [19] Kurat (1988) Phil. Trans. R. Soc. Lond. A325, 459-482. [20] Kurat et al. (1984) EPSL 68, 43-56. [21] Boynton (1975) GCA 39, 569-584. [22] Ireland (1988) GCA 52, 2827-2839. [23] Fahey et al. (1994) GCA 58, 4779-4793.