MULTIPLE STAGES OF EARLY EVOLUTION OF HETEROGENEOUS TYPE-7 PIPLIA KALAN EUCRITE. A. Basu Sarbadhikari[1] (amitbs@prl.res.in), R. R. Mahajan[1], M. S. Sisodia[1], E.V.S.S.K. Babu[2], T. Vijaya Kumar[2], M. Shyam Prasad[3] and N. Bhandari[1]. [1] PLANEX, Physical Research Laboratory, Ahmedabad 380009, India; [2] National Geophysical Research Institute, CSIR, Hyderabad 500007, India; [3] National Institute of Oceanography, CSIR, Dona Paula, Goa 403004, India.

Introduction: Eucrites are generally considered as the crustal sample derived from the differentiated asteroid 4-Vesta, either crystallized from a magma ocean [1-3], or generated during partial melting of mantle source [4]. Texturally the eucrites range from igneous non-equilibrated to equilibrated types, the latter of which underwent sub-solidus recrystallization at various metamorphic grades [5-6]. Piplia Kalan eucrite (fall, 1996) contains texturally and compositionally different components in their main masses. Earlier studies reported preliminary petrography and geochemistry [7-8]. We have carried out a more detailed chemical study of texturally distinct clasts to understand the petrogenesis.

Methodology: Major-elements were analyzed using Cameca SX-100 EPMA at PRL, NGRI and NIO. Bulk element concentrations were measured using a quadrupole ICP-MS (Thermo-X series2) at PRL.

Petrography: Piplia Kalan has been interpreted as equilibrated, noncumulate basaltic eucrite constituted of diverse components [7-8]. The eucrite contains two distinct grain-sized igneous clasts; coarse (up to 3 mm) and fine (<0.1-0.5 mm with an average size ~ 0.2 mm). The coarse clast (type-A) displays dominantly ophitic-subophitic texture of blocky grains (Fig. 1). The major silicates are pyroxenes (orthopyroxene, clinopyroxene) and plagioclase (anorthitic) with minor amount of silica phase (quartz/tridymite). Non-silicate phases are spinel, ilmenite, sulfide (troilite), and Fe-metal. Pyroxene has augite exsolution lamellae in pigeonite host. The silica phase occurs at the interstitial spaces of the juxtaposed edge between coarse pyroxene and plagioclase, indicating a subsolidus reaction product.

The finer clast (type-B) also has ophitic to sub-ophitic texture (Fig. 1) and the constituent phases are pyroxene (orthopyroxene, clinopyroxene), plagioclase (anorthitic), quartz, spinel, ilmenite, and sulfide (troilite). Augite exsolution occurs in low-Ca pyroxene host, which is orthopyroxene and was inverted from pigeonite. Few pyroxene grains are partially and totally converted to augite and underwent sub-solidus re-equilibration. Similar to type-A, quartz occurs at the interstitial spaces between pyroxene and plagioclase. Troilite exsolution lamellae from host low-Ca pyroxene are present.

Although rarely present in different sections of this eucrite a third clast (type-C) was also identified (Fig. 1). Larger laths of plagioclase and silica surround the finer granular interlocking grains of granulitic texture (size 30-50 µm). Type-C occurs as pockets in type-A, and at the boundary between type-A and type-B clasts. Silicates are tridymite and quartz, augitic pyroxene and anorthitic plagioclase with minor sulfide (troilite), phosphate (apatite) and oxides, including ilmenite and chrome spinel. Plagioclase and tridymite/quartz occur as laths, contains micro-inclusions of pyroxenes and non-silicates, and are randomly oriented. The plagioclase laths display serrated edges as result of recrystallization, while the finer granulitic grains of silica display replacement texture. Skeletal residue of augite crystals are seemed embedded in coarse plagioclase.

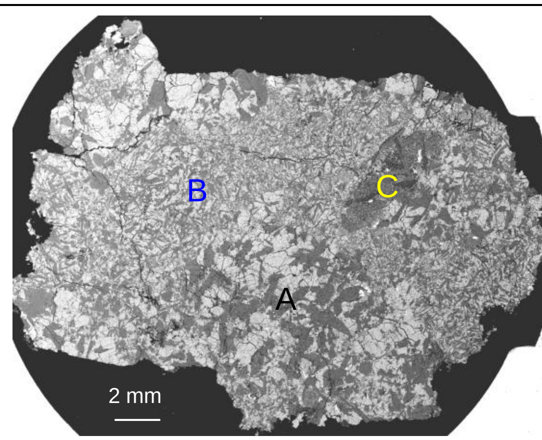

Fig. 1: Back-scattered electron image of a studied thick-section of Piplia-Kalan. Three well-characterized clasts (type-A, -B and -C) with their distinct but not very sharp margins.

Modal calculations indicate nearly equal proportion of low-Ca pyroxenes (orthopyroxene + pigeonite: 30-31%), high-Ca pyroxenes (augite: 18-19%) and silica-phase (3-4%) in type-A and -B clasts. Mode of plagioclase is 4% higher in type-A (47%) than in type-B. Type-B contains higher proportion of non-silicates (~3%) compared to that (~1%) in type-A. On contrary to other two types, the type-C clast contains high modal abundance of silica (~ 48%). The proportions of augitic pyroxene and plagioclase are ~16% and ~33%, respectively.

Major and Trace Element Composition: Pyroxene compositional range is similar in type-A and -B: $Wo_{1-44}En_{26-36}Fs_{27-68}$, Mg# 31-54. In type-C, pyroxenes are of augite variety, $Wo_{31-43}En_{27-39}Fs_{28-39}$, Mg# 43-51. Plagioclase has rather restricted compositional range of bytownite variety ($An_{82-91}Or_{<1}Ab_{9-17}$) in all the clasts.

Spinels in type-A and -C clasts are of Al-chromite variety (Fig. 2). Type-B spinels are Al-, Ti-rich chromite or Al-titanian chromite. There is no change in the Fe-Mg ratio of the spinels, and therefore does not indicate any fractional crystallization trend within individual and among all the clasts. Ilmenites in type-A and type-C are highly vanadiferous (~ 4.5 wt% V_2O_3), than that in type-B (~0.1 wt%).

Whole-rock major element data indicates Piplia Kalan is in the range of non-cumulate eucrites. Mass-balance calculations involving modal and mineral chemical data indicate different clasts, although having different absolute abundances of elements, retain the Mg/Fe ratio (Mg# 0.34-0.37). Type-A and -B clasts have basaltic composition and show similarity with non-cumulate eucrites. On contrary, type-C clast is siliceous, dacitic in composition in total alkali vs silica plot. Piplia Kalan is characterized by a relatively flat REE pattern, ~10xCI-chondrite with slightly descending trend towards the HREE ~6xCI-chondrite. The Sc, Sm, Yb and La content of Piplia Kalan is in the range of the Main Group - N Laredo eucrites.

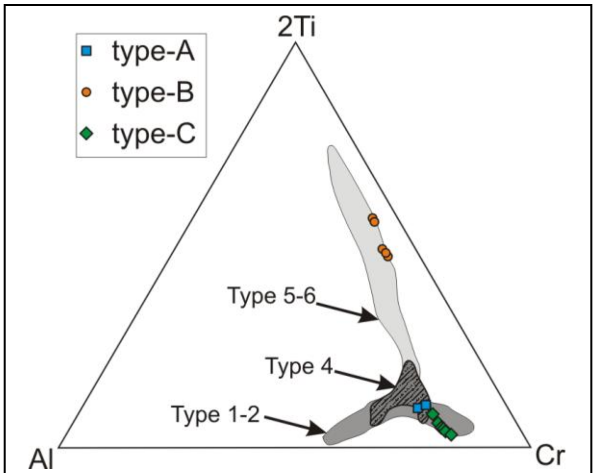

Fig. 2: Plots of spinel composition of Piplia Kalan and comparison with other eucrites from [10].

Discussion: Presence of remnant Ca-zoning in pyroxenes (similar to type-4), partly inverted pigeonite (similar to type-6), ~ 850-900^{o}C equilibration temperature by 2-pyroxene thermometry, heterogeneous texture and extensive shock features indicate Piplia Kalan is a type-7 non-cumulate eucrite, as per the scheme of classification by [5-6]. Type-A and -B clasts show overall similarity in their mineral chemistry. However, some of the key differences in petrography and geochemistry indicate differences in their petrogenesis. The much coarser type-A definitely underwent through different P-T-fO_2 regime than the finer type-B. Type-A cooled slowly at deeper level than the latter, which chilled in a shallow intrusive body. Vanadiferous ilmenite in type-A clast indicates high fO_2 in the range of magnetite-hematite buffer or better, as V^{4+} replaces Ti^{4+} [9]. However, in absence of an independent solution model of V in ilmenite exact oxygen barometric calculation is not possible. Fe-Ti 2-oxide oxygen barometry yielded IW-2 value for type-B. The difference between type-A and -B is also distinct in spinel composition (Fig. 2). The Ti-rich spinels in type-B are in the compositional range of type 5-6 highly metamorphosed eucrites [10]. The type-A spinels are Ti-poor and retain their magmatic composition. The bulk chemistry of type-C clast is different than the other two types, but careful observation indicates type-C was earlier type-A, which underwent hydrous-, silica-melt metasomatism and converted to dacitic composition. Remnant grains of coarse augite in silica-rich matrix, micro-inclusions in coarse grains, and similar spinel and ilmenite compositions are the precursors of type-A. Coarse ridge-like elongated silica-grains, presence of apatite, and granulitic symplectites at the interstitial spaces indicate fluid-induced metamorphism and metasomatism. Type-C clast is not a mesostasis.

This study indicates multiple stages of early evolutionary history of Piplia Kalan. Type-A clast crystallized earliest at highly oxidized condition in the magma chamber in the deep crust, followed by fluid-induced metamorphism and metasomatism at similarly high fO_2 (formation of type-C). Type-B formed from a relatively shallow magmatic flow in much-less fO_2 than the earlier events. The final event was the granulite metamorphism of the whole mass of Piplia Kalan, presumably either by series of magmatism or impact events, which took place in global-scale [11]. Further study based on in-situ trace-element will be attempted to comprehend the petrogenetic processes of Piplia Kalan in comparison to other eucrites.

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