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The garnet placer deposit from SE Spain: industrial recovery and geochemical features

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The only economic deposit of garnets in Spain is located in the Almería province (SE Spain), forming part of the Neogene Volcanic Complex of El Hoyazo. Due to the high quantity and diversity of the almandine garnets, this area is unique. Garnet occurs as isolated euhedral crystals in the volcanic rock, as the principal component of metapelitic xenoliths in dacite, and as a terrigenous deposit formed by the erosion of the volcanic dome. In this work, we provide new mineralogical and geochemical data, which should be taken into account during the processing and recovery of the garnet placer.

Economic importance of the garnet placer

Almandine ($Fe_3Al_2Si_3O_{12}$) is the most common variety of garnet. It is also the variety preferred for industrial purposes because of a combination of superior chemical and physical characteristics such as high resistance to degradation, high specific gravity (4.32) and hardness (7.0–7.5). These characteristics make garnet a high-quality abrasive used in the manufacture of sandpaper, abrasive wheels, polishing/lapping grains, powders, grits, and other industrial products. Other applications deal with water filtration systems, additive in grouting cements for oil-well drilling applications, low- to medium-level radiation shielding, and the cleaning and conditioning of soft metals (Andrews, 1995; Harben and Kuzvart, 1996).

Garnet placer deposit

The garnet-rich sands of El Hoyazo (Almería province, SE Spain) are located to the south of their source area: El Hoyazo Volcanic Complex (Figure 1A). The Complex consists of an erosional remnant of a peraluminous volcanic-subvolcanic dacite dome (a pipe and surrounding block lava) of the high-K calc-alkaline type, which forms a shallow hill. The age of the eruption has been estimated at 11.9 Ma (Munksgaard, 1984). The dacite dome was covered by Messinian reef deposits (Dabrio et al., 1981). Subsequent erosion excavated a large depression through the overlying limestone cover into the softer volcanic rock. The result is a roughly circular crater-like depression, with an area of approximately 0.7 km^2. This is cut by a gorge through which the Rambla de las Granatillas reaches the plain of Cuenca de Níjar.

The Quaternary alluvial fan, which forms the placer deposit, covers an area of 1 km^2 and has a maximum thickness of 40 m (IGME, 1981). Garnets are found loose in layers 5–50 cm thick and up to 50% in volume garnet-rich (Figure 1B). The richest beds lay at 0.5–1.5 m from the base of the sand body. The composition of the El Hoyazo garnet does not differ very much from that found in other typical industrial deposits (Table 1). At the beginning of the twentieth century, garnet exploitation reached an all-time high, which peaked in 1933. From 1996 until very recently, a private company,

***Figure 1** A(left) – General view of El Hoyazo Volcanic Complex. Note that erosion excavated a large depression through the overlying limestone cover into the softer volcanic rock. B(right) – Garnet-rich sands. Garnets are found loose in layers 5–50 cm thick and up to 50% in volume garnet-rich. The richest beds lay at 0.5–1.5 m from the base of the sand body.*

Table 1 Chemical compositions of industrial garnet (wt %) from different world producers. Modified from Harben and Kuzvart, 1996.

	Port Gregory, Australia *Placer deposit*	Tamil Nadu, India *Placer deposit*	Idaho, USA *Placer deposit*	Bohemia, Czech Rep. *Metamorphic*	Níjar, Spain *Placer deposit*
SiO_2	36.10	35.10	39.00	36.92	37.82
Al_2O_3	20.40	21.60	26.00	21.17	19.34
FeO	29.80	32.90*	30.00*	36.70*	37.12*
Fe_2O_3	1.70	—	—	—	—
TiO_2	1.80	0.55	—	0.06	0.05
MnO	1.05	0.53	2.00	0.37	1.55
CaO	1.55	1.84	2.00	0.87	0.99
MgO	6.00	7.40	2.00	3.92	2.80
Total	98.40	99.92	101.00	100.01	99.67

Note: * total Fe.

Garnetkao, S.L., had recommenced the exploitation intermittently. Garnet grains are easily recovered from the ore sands for industrial applications, principally as a mineral abrasive. The method of beneficiation is quite simple and inexpensive: the collection of the garnet-rich sands is followed by screening, magnetic separation, washing, jigging and spiral concentration, crushing and finally, classification. The end product is an 80-mesh garnet-rich powder, and the average yield was estimated at 6t/day (Lunar et al., 1997, 1999; Benito et al., 1998).

Source area rocks

El Hoyazo is part of a volcanic and metallogenetic belt that extends from the Cabo de Gata to Mar Menor, in the eastern border of the Betic Ranges (SE Spain). This belt comprises five series of increasingly younger volcanic rocks: calc-alkaline, high-K calk-alkaline, shoshonitic, ultrapotassic and alkali basalts. The volcanic activity began in the late Burdigalian/early Langhian and ended in the Messinian (Bellon and Brousse, 1977; López Ruíz and Rodríguez Badiola, 1980; Bellon et al., 1983; Di Battistini et al., 1987).

The El Hoyazo dacite is porphyritic and has a glassy matrix (50 vol.%), which contains minerals from magmatic crystallization (mainly plagioclase (10–15 vol.%), cordierite (10 vol.%) and biotite (8–10 vol.%), and subrodinately sillimanite, quartz, hornblende, pyroxene, hercynite, apatite, zircon and opaques); xenoliths (60% of metapelitic aluminium-rich restite material and 40% of several types of igneous rocks); and monocrystals derived from the xenoliths (Zeck, 1968, 1970, 1992; Molin, 1980).

The garnet-biotite-sillimanite gneissic xenoliths are the most important type of inclusion, not only because they are the most abundant, but also because they include garnet in their mineralogy. The alternation of biotite and sillimanite (fibrolite) defines a foliation.

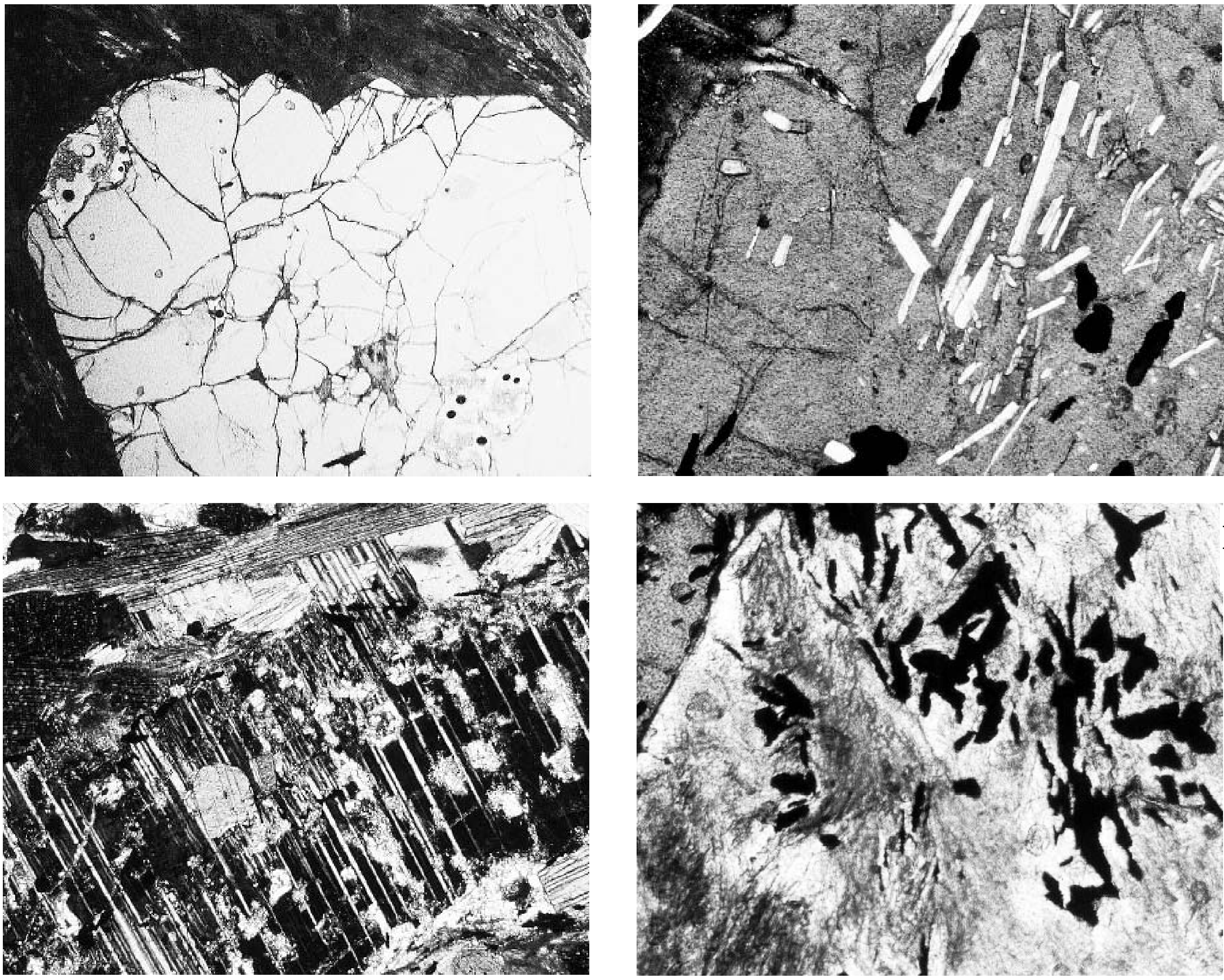

***Figure 2** Some selected features of the main minerals which form part of the paragenesis of the gneissic xenoliths: a) garnet crystals displaying tiny inclusions of quartz, biotite and zircon; b) acicular sillimanite randomly included in a cordierite grain; c) clouded plagioclase associated with biotite, and d) graphite in fibrous sillimanite.*

The mineral assemblage also includes cordierite, plagioclase, potassium feldspar (sanidine), hercynite, apatite, corundum, zircon, quartz, and opaques (graphite, ilmenite and magnetite) (Figure 2). These xenoliths have been interpreted as restites, formed by extraction of 30–60 wt.% rhyolitic melt from a pelitic protolith. The protolith was probably a garnet-biotite phyllite from the surrounding Alpujárride metamorphic complex (Cesare et al., 1997).

Properties of the industrial garnets

We have confirmed the physical and mineralogical properties of the garnets in the dacite and the garnets in the gneissic xenoliths. Both show similar sizes (2–10 mm in size in the lava; up to 1.5 cm in the xenoliths), red colour, euhedral or subhedral habit, unitary cell size (a_o = 11.537 ± 0.01 Å and 11.535 ± 0.01 Å, respectively), refraction index (n = 1.809), mineralogical composition ($Alm_{70\text{-}82}$ $Pir_{6\text{-}16}$ $Gros_{15\text{-}2}$ $Espes_{11\text{-}1}$ and $Alm_{70\text{-}82}$ $Pir_{9\text{-}15}$ $Gros_{15\text{-}2}$ $Espes_{8\text{-}1}$, respectively) and zonation (Fe and Mg increasing, and Ca and Mn decreasing from core to rim). There are, however, differences in the mineral inclusions: garnets from the dacite contain biotite, sillimanite (fibrolite), quartz and zircon; garnets in the gneissic xenoliths also contain amoeboidal to subhedral Ce-rich (32.5 wt.%) monazite, and xenotime, which have not been detected in the garnets from the volcanic rocks (Figure 3) (Benito et al., 1998; Muñoz-Espadas, 1999). Monazites occur as amoeboidal-to-elongated inclusions, from around 10 µm to 120 µm, hosted not only in garnet crystals, but also in the matrix of the xenoliths.

Oxygen isotopic values $\delta^{18}O$ range from +11.5 to +11.7‰ (Martínez-Frías et al., 1998). Radiogenic isotope data yields a µ (${}^{238}U/{}^{204}Pb$) value that is much lower for garnets from the dacite (0.146), than in the ones from the gneissic xenoliths (24.9–33.5). This could be explained by the high amount of ${}^{204}Pb$ in the former (226.8 ppm of total Pb), compared with a maximum of 3.391 ppm in the latter. Other rates using Pb, Sm and Nd isotopes, on the other hand, are very similar for garnets from both sources (Table 2). The Sm-Nd estimated age of the garnets is 313 ± 52 Ma, which coincides with the age of the protolith of the gneissic xenolith from the Alpujárride metamorphic complex (Muñoz-Espadas, 1999).

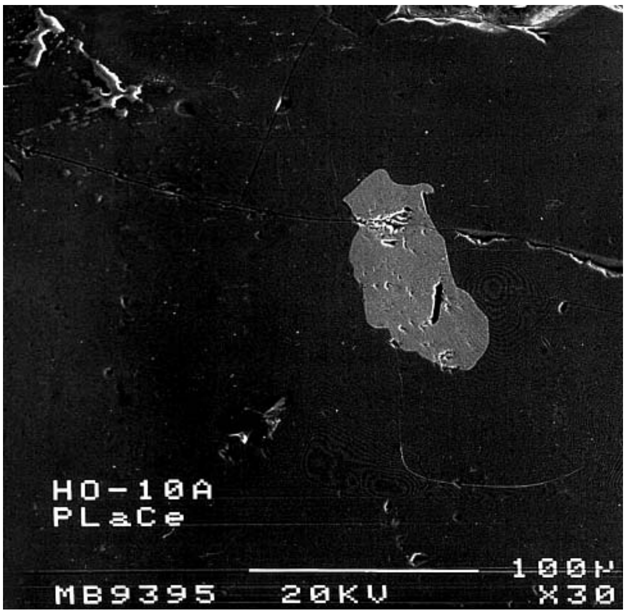

Figure 3 SEM picture (JSM-6400) of an irregular inclusion of monazite hosted in a garnet from the metamorphic xenoliths.

Table 2 Radiogenic isotopes data of the El Hoyazo garnets.

Element/unit	GL (lava)	GE1 (xenolith)	GE2 (xenolith)
[Sm], ppm	2.297	5.224	3.878
[Nd], ppm	9.342	24.64	17.27
[Pb], ppm	226.8	3.391	1.329
[U], ppm	0.5197	1.325	0.6961
${}^{87}Sr/{}^{86}Sr \pm 2\sigma$		0.729132 ± 21	0.715634 ± 17
${}^{147}Sm/{}^{144}Nd$	0.14914	0.12858	0.13622
${}^{143}Nd/{}^{144}Nd \pm 2\sigma$	0.512016 ± 6	0.511974 ± 5	0.511989 ± 6
${}^{206}Pb/{}^{204}Pb$	18.485	18.571	18.564
${}^{207}Pb/{}^{204}Pb$	15.641	15.665	15.661
${}^{208}Pb/{}^{204}Pb$	38.475	38.750	38.753
µ	0.146	24.9	33.5

Note: $\mu = {}^{238}U/{}^{204}$033 Pb; σ = mean weighted deviation.

Controversy on the origin of the garnets

Two different mechanisms have been proposed to explain the origin of garnets in the volcanics of El Hoyazo: direct crystallization from a silicate melt; and derivation as restitic monocrystals from metapelitic xenoliths. The former hypothesis was proposed by López Ruíz et al., 1977, based on the different zonation of the garnets from each source. The latter was initially suggested by Zeck, 1968, 1970, who stressed the similar textural and mineralogical characteristics of the garnets in lava and xenoliths, and regarded the former as monocrystal inclusions. This idea was later supported by Molin, 1980 and Munksgaard, 1985, who found no differences in garnet zoning patterns.

Although our study mostly confirms the mineralogical and textural characteristics of the El Hoyazo garnets, new differences were identified — REE-bearing minerals were detected only in garnets in the gneissic xenoliths. In addition, the different value of µ and total Pb are at odds with the restitic monocrystal hypothesis, suggesting a different origin for the garnets from both sources.

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