Production and characterisation of heavy minerals concentrates from alluvial sediments

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http://doi.org/10.54499/ERA-MIN/0005/2019
https://mostmeg.rd.ciencias.ulisboa.pt/

ERA-MIN2
RESEARCH & INNOVATION PROGRAMME ON RAW MATERIALS TO FOSTER CIRCULAR ECONOMY

ERA-MIN Joint Call 2019 (EU Horizon 2020 ERA-NET Co-fund Project ERA-MIN2, Grant agreement Nº 730238)

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Production and characterisation of heavy minerals concentrates from alluvial sediments

Heavy Minerals

- Minerals with d ≥ 2,89 g/cm^3 (Morton, 1978);
- Diamagnetic, paramagnetic and magnetic;
- Many have Chemical/physical stability to Persist in different environmental conditions (e.g. weathering and diagenesis).
- Essential, accessory and ore minerals;
- Pathfinder/Indicator minerals of several mineral deposits.

Nonmagnetic minerals	Specific gravity (g/cm^3)
Diamant	3.5 – 3.52
Gold	15.6 - 19.3
*Rutile	4.23 - 5.50
Anatase	3.82 - 3.97
Andalusite	3.13 - 3.16
Apatite	3.10 - 3.35
Cassiterite	6.98 - 7.02
Cinnabar	8.00 - 8.20
Sillimanite	3.23 - 3.27
Topaz	3.49 - 3.57
*Zircon	4.60 - 4.70
Cassiterite	6.8 - 7.1

Magnetic and paramagnetic minerals	Specific gravity (g/cm^3)
Chromite	4.43 - 5.09
Clinopyroxene	2.96 - 3.52
Epidote	3.38 - 3.49
Garnet	3.4 - 4.1
Ilmenite	4.4 - 4.8
Magnetite	4.9 - 5.20
Monazite	5.00 - 5.30
Olivine	3.25 - 3.4
Staurolite	3.65 - 3.83
*Tourmaline	3.03 - 3.15
Xenotime	4.50 - 5.10
Wolframite	7.0 - 7.5

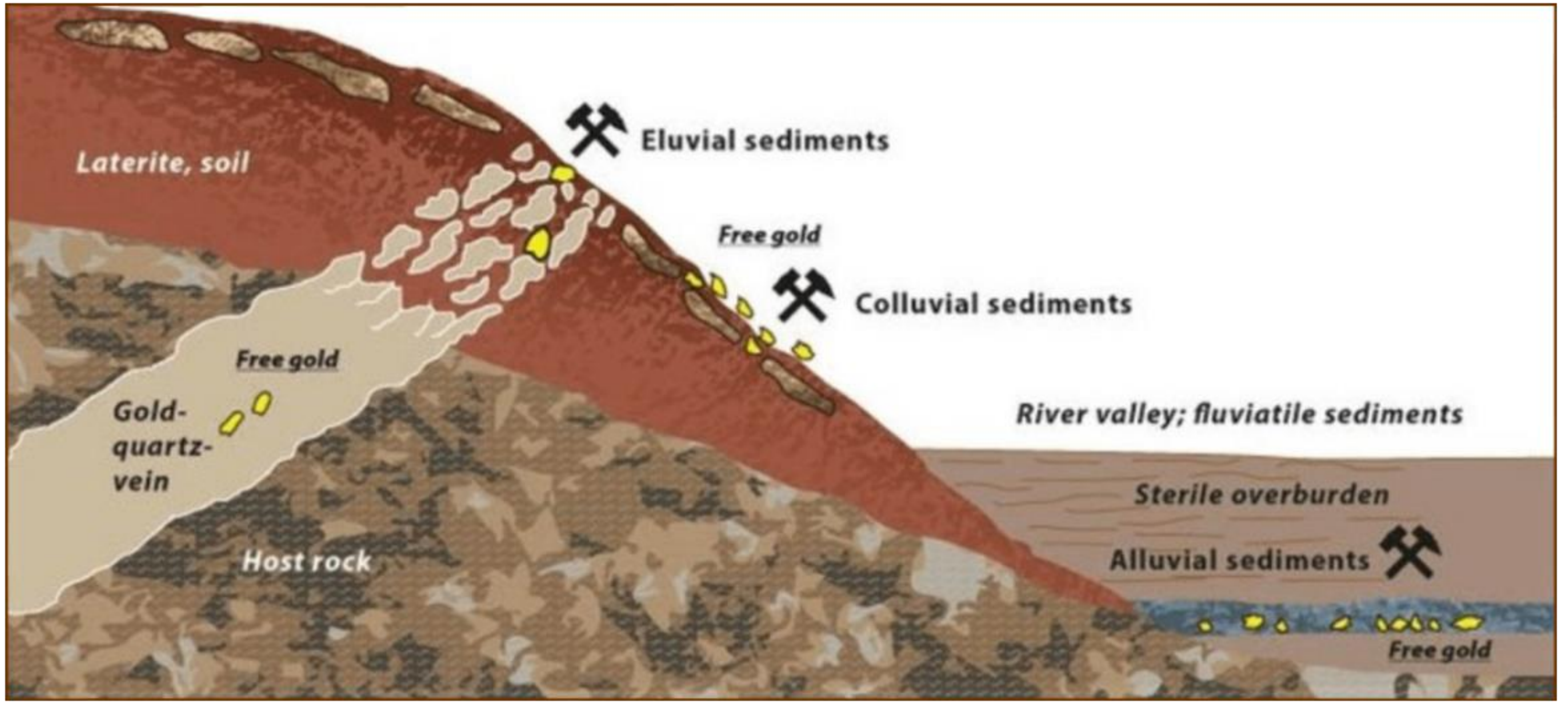
(Modified from http://www.sandatlas.org/heavy-minerals/; * ultra stable minerals)

Examples of ore deposits and their main indicator & pathfinder minerals (adapted from Balaram and Sawant, 2020)

Ore Deposits	Type of Deposit	Main Indicator & Pathfinder Minerals
Gold		Pyrite, chalcopyrite, arsenopyrite, bismuthinite, magnetite, tellurides, tetrahedrite, sphalerite, muscovite, monazite, bastnäsite, quartz, scheelite, wolframite, cassiterite.
REE	Carbonatite rocks	Bastnäsite group, ancylite, monazite, (fluor)apatite, pyrochlore, xenotime, florencite.
	Igneous rocks (including hydrothermal upgrade)	Bastnäsite group, aegirine, eudialyte, loparite, allanite, monazite, fergusonite, zircon, xenotime, fluorapatite, ancylite, gadolinite, euxenite, mosandrite.
	Placers and palaeoplacers	Monazite, xenotime, allanite, euxenite.
	Laterites	Monazite, apatite, pyrochlore, crandallite group, bastnäsite group, churchite, rhabdophane, plumbogummite, zircon, florencite, xenotime, cerianite.
	Iron oxide-associated (including IOCG) deposits	Bastnäsite, synchysite, monazite, xenotime, florencite, britholite.
	Seafloor deposits, such as manganese nodules, ferromanganese crust, phosphorite.	Vernadite, todorokite, carbonate fluorapatite, francolite.
Cu-Ni-PGE		Pentlandite, chalcopyrite, pyrite, millerite, PGM, chromite, Cr-diopside, enstatite, olivine, Cr-andradite.
Volcanogenic massive sulphide (VMS) deposits (Cu, Pb, Zn, Ag, Au)		Galena, sphalerite, chalcopyrite, pyrrhotite, gold, pyrite, gahnite, staurolite, cassiterite, spessartine, sillimanite, andalusite, beudantite, jarosite, barite, tourmaline, högbomite group, nigerite.
W-Mo-Bi, and Sn-Zn-In deposits		Cassiterite, wolframite, molybdenite, topaz, chalcopyrite, galena, sphalerite, arsenopyrite, pyrite, loellingite, beudantite, anglesite, plumboferrite, plumbogummite.
Li		Spodumene, petalite, amblygonite, quartz, K-feldspar, albite, montebrasite, lepidolite, zinnwaldite, eucryptite, cassiterite, lithiophilite, holmquistite, triphylite, muscovite, apatite, tourmaline tantalite, columbite, beryl.
Kimberlite hosted diamonds		Cr-pyrope, Cr-diopside, eclogitic garnet, Mg-ilmenite,chromite, olivine, diamond.
U		Uraninite (pitchblende), thorianite, tourmaline, sulphides, monazite, allanite, zircon, baddeleyite, niccolite, U-Th anatase, U-Th rutile, brannerite, magnetite.

Alluvial Heavy Minerals

- AHM are present in sediments, even when sourced from hidden / disseminated mineralisations;
- Alluvial (eluvial and colluvial) sediments: have natural HM concentration, compared to rocks and stream sediments; probable with economic importance!
- From rocks to proximal alluvial deposits: low transport and sorting, preserving original mineral properties.



Fom: AbdelMonem Soltan, Economic geology - Sedimentary ore deposits, Echttps://www.slideshare.net/AbdelMonemSoltan/economic-geology-sedimentary-ore-deposits?next_slideshow=7

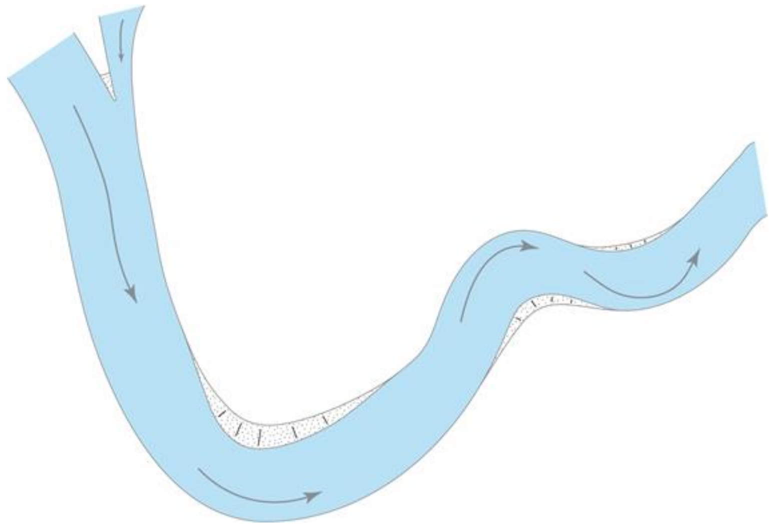
Alluvial Heavy Minerals

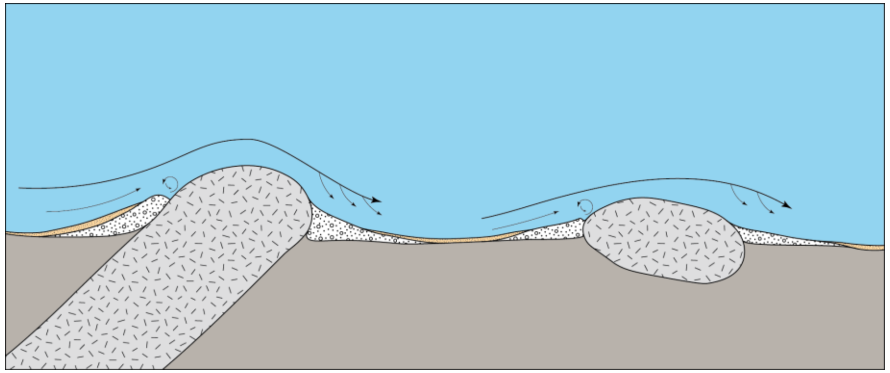
✓ Alluvial deposits

- Alluvial deposits have heterogeneous grain size sediments with hydraulic equivalence: high density fine grains and low-density coarse grains;

- Deposition occur when there is change in the current flow velocity: rock bars, large blocks, gravel areas in river bends…

- There are several dispersion factors: depending on different mineral behavior in different geological, geomorphological, geodynamic settings and environmental conditions.





Adapted from http://www.publicacions.ub.es/refs/pub_dig/pros_aluv.pdf

Alluvial Heavy Minerals Sampling and Preconcentration

- Sampling density is variable, depending on the local or regional exploration target; 1sample/1km^2;
- Collected in 2nd to 4th order streams; **near the source**;
- Alluvial sample: ~ 6 to ~ 20 kg (variable);
- Sieved sample (< 3 mm): ~ 2 to ~ 8 kg (variable);
- Panned sample: ~50 to ~300 g (variable).


Modified photo from Silva Lopes, LNEG

Stream sediments sampling for complementar geochemical survey:

- 3-4 samples/km^2
- 2nd to 4th order streams;
- Sample: 1-2 Kg (variable)

Heavy Minerals Concentrates

- ✓ Heavy Liquids Separation

Oven drying at 70º C

Mineral separation using an heavy liquid (2.89 g/cm^3)

Rejection of light minerals

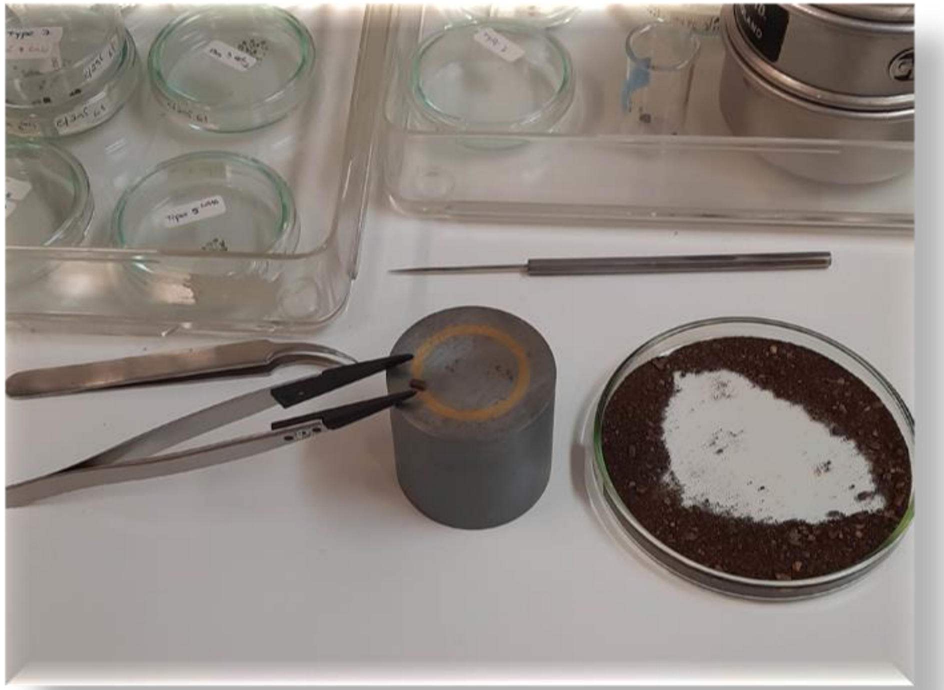
HMC

↓

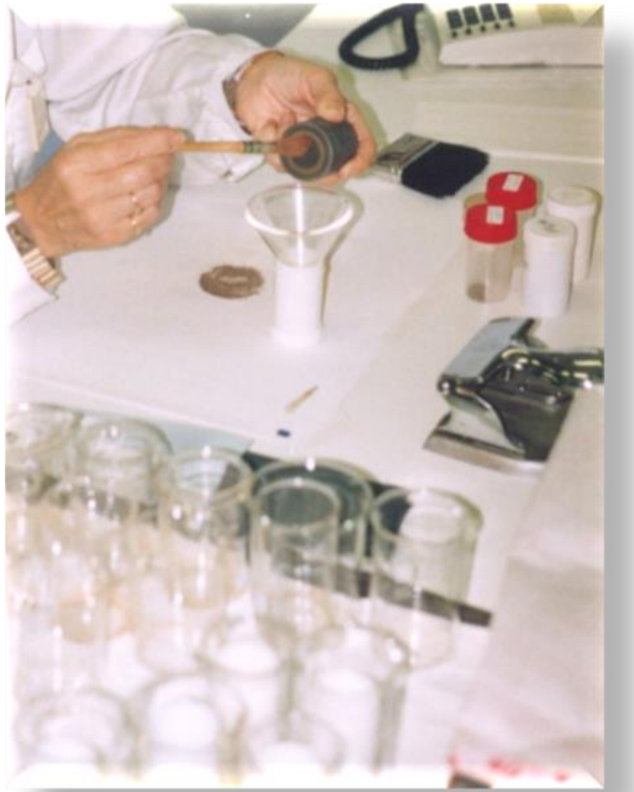
Washing with ethyl alcohol and oven drying

Heavy Minerals Concentrates

- ✓ Magnetic Susceptibility Separation

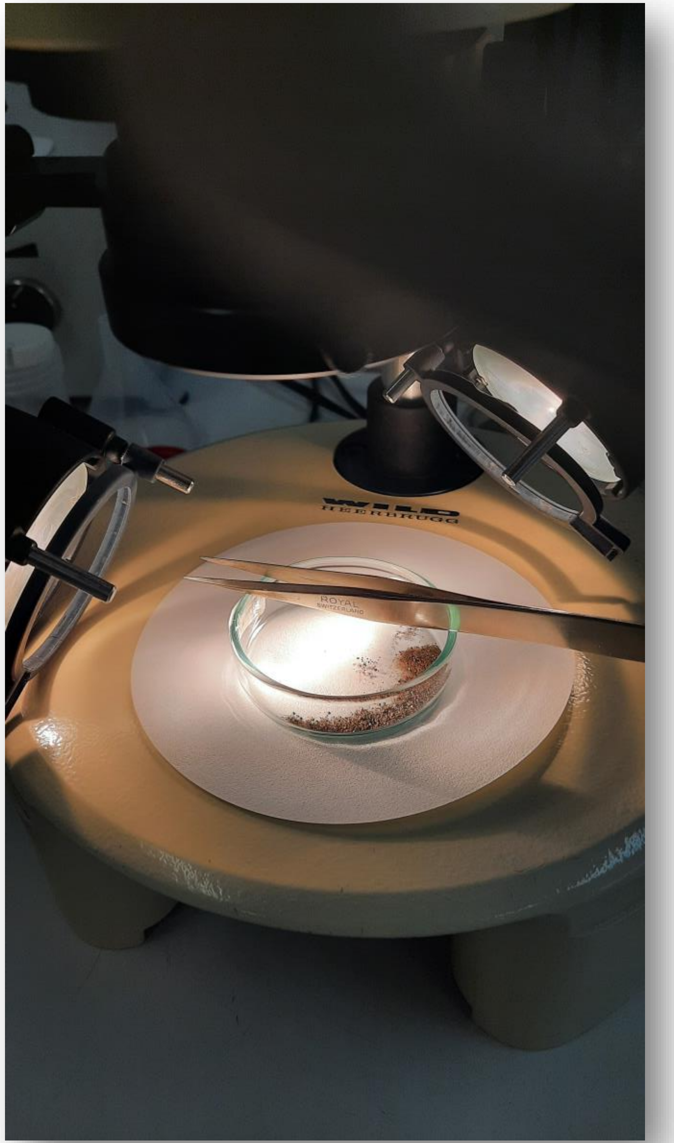


Magnetic separation (hand magnet: minerals with magnetic susceptibility ≥ 10x10-6 C.G.S.M.E)



Magnetic & Nonmagnetic Mineral fraction

Identification _ Semi-quantification _ Characterisation of Heavy Minerals

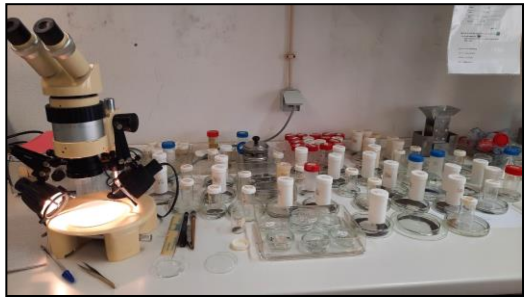


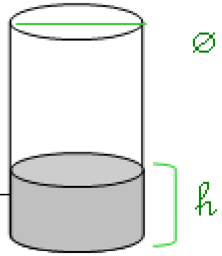
- ✓ Under binocular microscope

- V: (0,01- 1 %); R: (1 - 5 %); P: (5 – 25 %); Md: (25 – 50 %); A: (50 - 75%); M: (75 - 100 %); (adapted from Parfenoff et al., 1970).

- For the calculations: Minimum, <u>Average</u> and Maximun Value;

Example: Md: Minimum= 25 %; <u>Average= 37.5 %;</u> Maximum= 50 %).





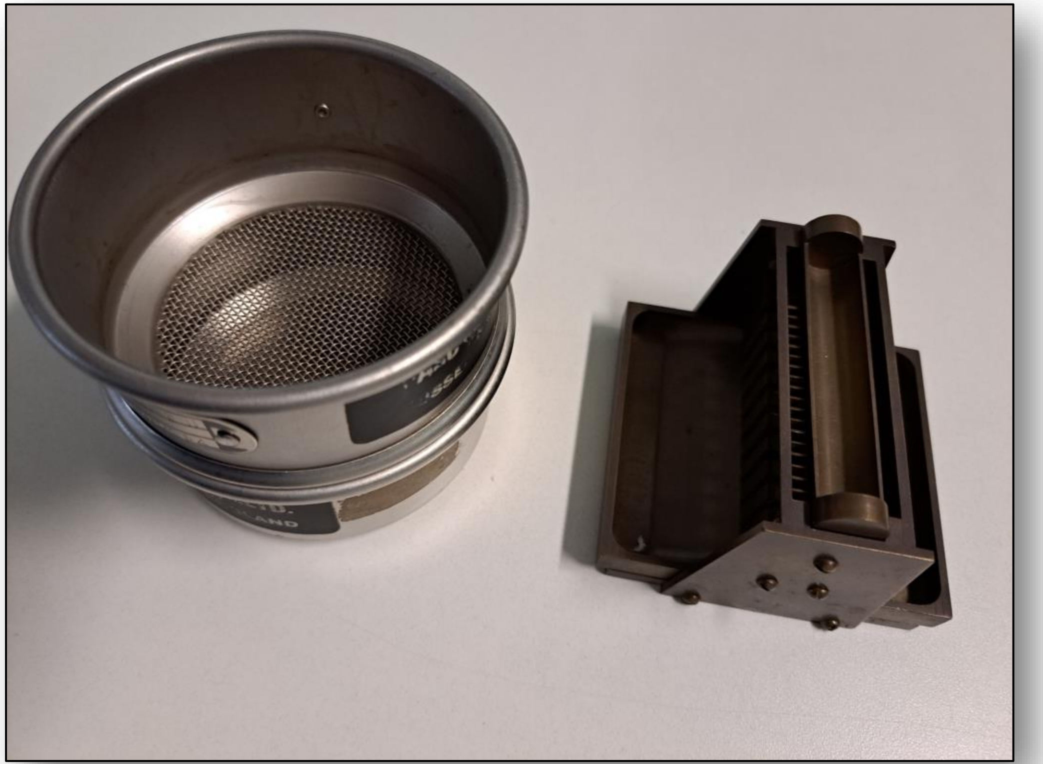
Identification _ Semi-quantification _ Characterisation of Heavy Minerals

- **Gold, cassiterite, wolframite, scheelite and cinnabar**:

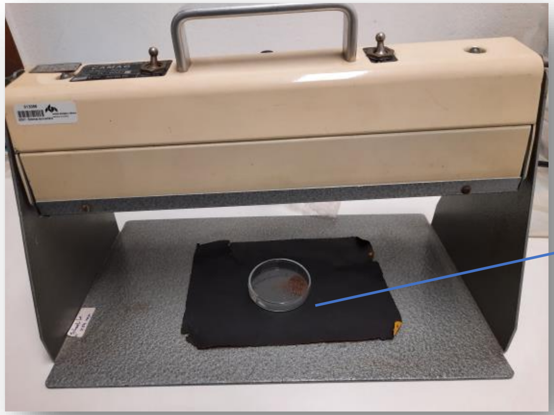
- Total number of grains counted/estimated using a splitter (if needed);

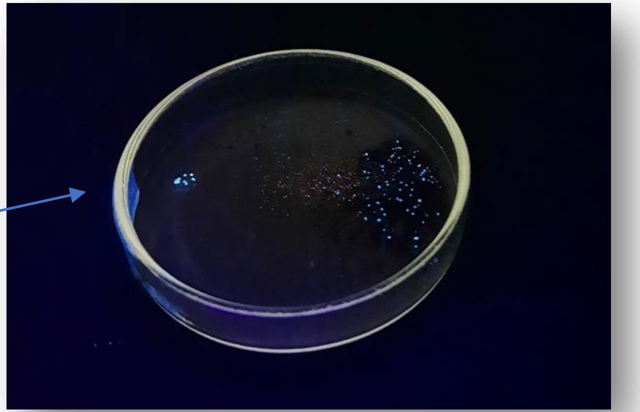
- Grain size (standard lab: very coarse, coarse, medium, fine, very fine);

Sieve can be used during these tasks.

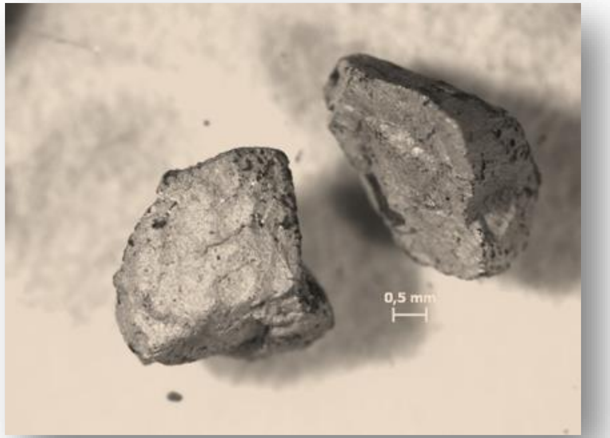


Identification _ Semi-quantification _ Characterisation of Heavy Minerals



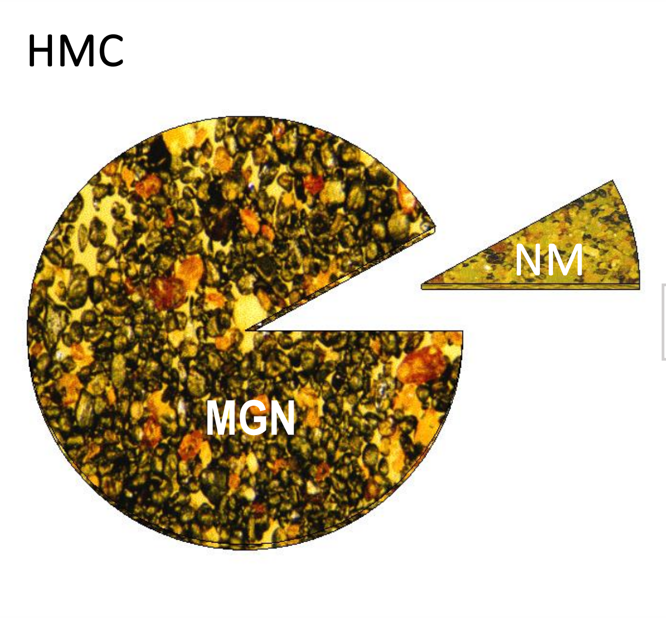


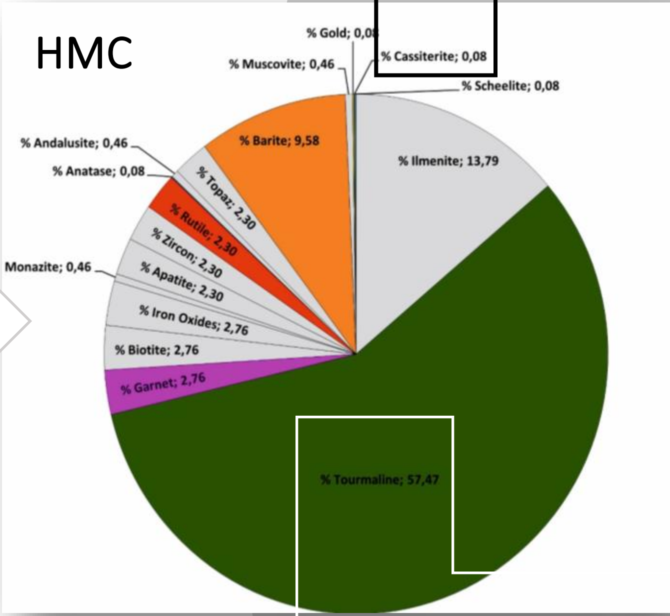
Scheelite identification: under UV light (short wave: 254 nm)



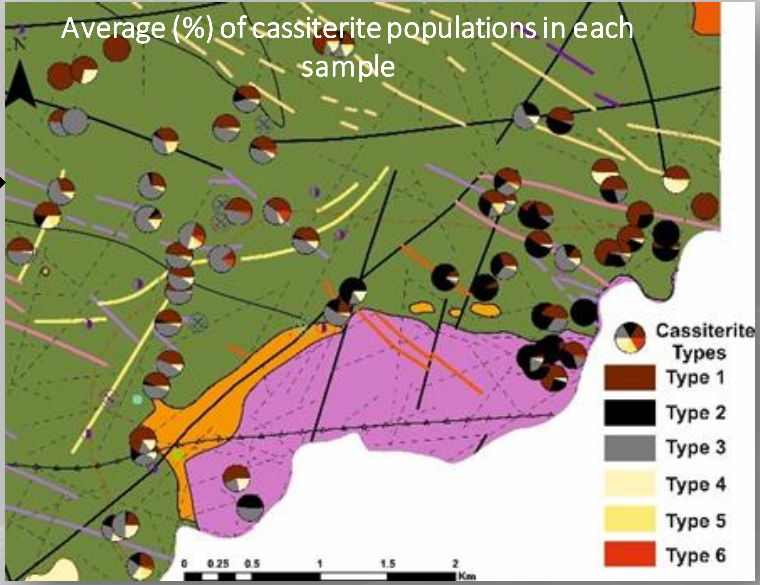
Tinning test: granulated zinc and a glass container with hydrochloric acid. After a few minutes of effervescence, only the cassiterite grains are covered with a metallic grey film (adapted from Parfenoff et al., 1970)

Alluvial Heavy Mineral Average Abundance Distribution

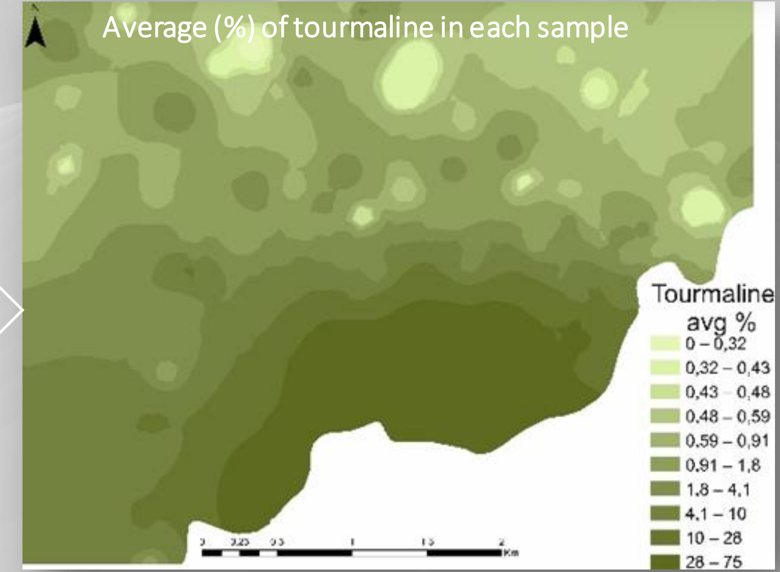




(0,01-1 %); (1 - 5 %); (5 – 25 %);
(25 – 50 %); (50 - 75 %);
(75 – 100 %);



Interpolation method _ IDW
(Inverse Distance Weighted)



Regional Heavy Minerals Assemblage_Segura Region

Segura granite, Li Aplite-pegmatitic veins, Sn-W quartz veins

Grupo das Beiras: Metamorphic halo (Segura/Zebreira granite)

	Segura /Cabeza de Araya Granitic Massif		**Mineralized quartz breccia veins**	**Aplite-pegmatitic veins**		**Quartz veins**			**Other Veins**				**SGC_Grupo das Beiras**		
LITHOTYPE	**Muscovite granite**	**Two-mica granite**		**Aplites**	**Lithiniferous Aplite-pegmatite**	**(Sn-W) Quatrtz veins**	**(Ba-Pb-Zn) Quartz veins**	**Quartz veins**	**Lamprophyres**	**Tonalitic porphyry**	**Granodioritic porphyry**	**Granitic porphyry**	**Metasediments of Malpica do Tejo Fm. and Rosmaninhal Fm.**		
Geological Setting/Localization/Host structure or lithology	**border**	**core**	**Hosted by metasedimentary rocks**	**Hosted by Segura and Zebreira granite and Grupo das Beiras metasediments (endo/exocontacs)**		**Hosted by metasedimentary rocks to N of Segura granite.** Filling tensile cracks (10 cm; up to max. 50 cm with 1300 m lenght).	**Spatial relationship with muscovitic granite (Segura Massif);** filling ENE-WSW and NNE-SSW faults (up to 3m width and 2500 m lenght)	**SW border of the Zebreira granite**	**Hosted by metasedimentary rocks; N20W associated with shear zones or N10-20E associated with structural alignments to W of Zebreira granite**	**Hosted by metasedimentary rocks; N20-40W** (up to 10 m width)	**Hosted by metasedimentary rocks; associated with shear zones, N50-60E** (with metric thickness)	**Hosted by metasedimentary rocks; N-S to N20W** (up to 10 m width)	**Metamorphic halo-Segura Massif**	**Metamorphic halo-Zebreira Massif**	**Metamorphic halo-Estorninos Pluton**
HEAVY MINERALS ASSEMBLAGE	Muscovite		Muscovite	Apatite		**Cassiterite (unzoned; proximal to Segura granite)**	Barite	Muscovite	Epidote	Biotite	Biotite	Muscovite	**Tourmaline**		
	Apatite (Fluorapatite, Hydroxylapatite: euhedral to subhedral)		Apatite	Zircon		**Wolframite (distal to Segura granite)**	Galena	Pyrite			Horneblende		Zircon (except for Zebreira metamorphic halo)		
	Zircon		Barite	**Rutile**		Muscovite	Sphalerite	Sphalerite			Apatite		Apatite (except for Estorninhos metamorphic halo)		
	Monazite		Cobaltite	Muscovite	Muscovite (with apatite and zircon inclusions)	Zircon (rare)		Arsenopyrite			Pyrite			Biotite	
	Rutile		Pyrite	**Tourmaline (subhedral, 1 mm × 1 mm in size; with inclusions of zircon)**	Topaz (fractured crystals; with inclusions of albite)	Apatite					Cobaltite			Muscovite	
	Ilmenite		Arsenopyrite		Lepidolite (subhedral)	Pyrrotite					Silimanite			Opaque minerals	
	Andalusite		Sphalerite		**Cassiterite (zoned or unzoned; euhedral crystals 6.2 mm × 2.1 mm to 18 mm × 5.6 mm; cassiterite inclusions: muscovite, apatite, subhedral - euhedral zoned tapiolite-(Fe) (40 µm × 30 µm), ixiolite (30 µm × 15 µm) and microlite (80 µm × 30 µm); cassiterite exsolutions (300 µm × 600 µm): subhedral zoned tapiolite-(Fe),columbite-(Fe; Mn,Fe; Mn).**	Arsenopyrite					Muscovite (Zebreira region)		Silimanite	Andalusite	Andalusite
	Garnet (in Cordierite Granite Porphyry dyke associated with Cabeza de Araya batholith)		Chalcopyrite		Columbite-tantalite	Pyrite							Ilmenite	Corundum	
	Muscovite (with zircon and apatite inclusions)	Biotite (with zircon and apatite inclusions)	Galena		Amblygonite-Montebrasite (Subhedral montebrasite: 3 mm × 2 mm in size)	Sphalerite							Pyrite		
	Biotite (rare)	**Tourmaline (subhedral, 4 mm × 2 mmin size)**			Apatite (Hydroxylapatite)	Chalcopyrite							Pyrrotite		
	Souzalite Gormanite (anhedral, 500x100µm)	Silimanite				Stannite Sulfosalts									

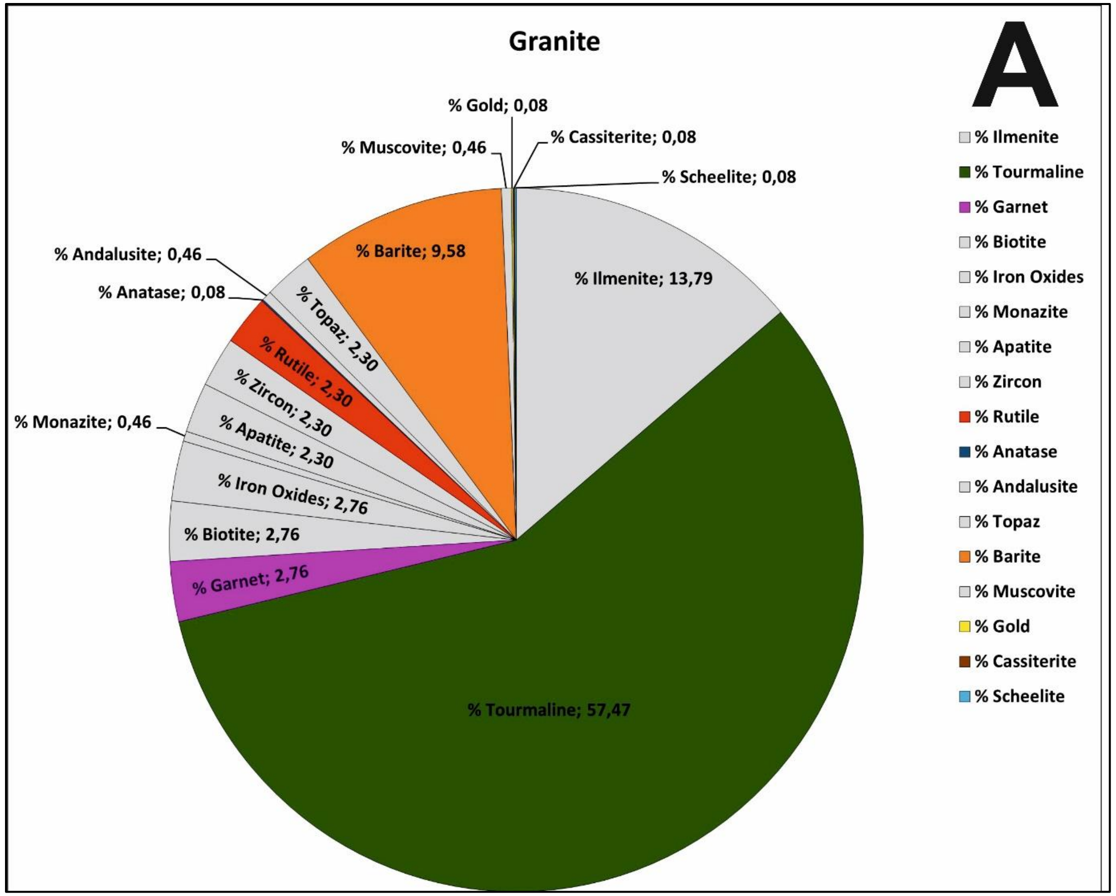
Table A. Heavy minerals assemblage from the different lithotypes and mineralized bodies that outcrops in Segura, Salvaterra do Extremo, Zebreira and Zebreira Sul region. Data compiled from: IGME (1984), Corretgé and Suarez (1994), Sequeira et al., (1999), Neiva et al., (2000), Garcia-Moreno and Corrotge (2000), Carracedo et al. (2005), Antunes et al. (2007, 2010, 2013), Romão et al. (2010) and Garcia-Moreno et al. (2017).

Heavy Minerals Assemblage from Granites and Mineralised veins Segura Region

	Segura /Cabeza de Araya Granitic Massif		Mineralized quartz breccia veins	Aplite-pegmatitic veins		
LITHOTYPE	**Muscovite granite**	**Two-mica granite**		**Aplites**	**Lithiniferous Aplite-pegmatite**	**(Sn-W) Quatrtz veins**
Geological Setting/Localization/Host structure or lithology	**border**	**core**	**Hosted by metasedimentary rocks**	**Hosted by Segura and Zebreira granite and Grupo das Beiras metasediments (endo/exocontacs)**		**Hosted by metasedimentary rocks to N of Segura granite.** Filling tensile cracks (10 cm; up to max. 50 cm with 1300 m lenght).
HEAVY MINERALS ASSEMBLAGE	Muscovite		Muscovite	Apatite		**Cassiterite (unzoned; proximal to Segura granite)**
	Apatite (Fluorapatite, Hydroxylapatite: euhedral to subhedral)		Apatite	Zircon		**Wolframite (distal to Segura granite)**
	Zircon		Barite	**Rutile**		Muscovite
	Monazite		Cobaltite	Muscovite	Muscovite (with apatite and zircon inclusions)	Zircon (rare)
	Rutile		Pyrite	**Tourmaline (subhedral, 1 mm × 1 mm in size; with inclusions of zircon)**	Topaz (fractured crystals; with inclusions of albite)	Apatite
	Ilmenite		Arsenopyrite		Lepidolite (subhedral)	Pyrrotite
	Andalusite		Sphalerite		**Cassiterite (zoned or unzoned; euhedral crystals 6.2 mm × 2.1 mm to 18 mm × 5.6 mm; cassiterite inclusions: muscovite, apatite, subhedral - euhedral zoned tapiolite-(Fe) (40 µm × 30 µm), ixiolite (30 µm × 15 µm) and microlite (80 µm × 30 µm); cassiterite exsolutions (300 µm × 600 µm): subhedral zoned tapiolite-(Fe),columbite-(Fe; Mn,Fe; Mn).**	Arsenopyrite
	Garnet (in Cordierite Granite Porphyry dyke associated with Cabeza de Araya batholith)		Chalcopyrite		Columbite-tantalite	Pyrite
	Muscovite (with zircon and apatite inclusions)	Biotite (with zircon and apatite inclusions)	Galena		Amblygonite-Montebrasite (Subhedral montebrasite: 3 mm × 2 mm in size)	Sphalerite
	Biotite (rare)	**Tourmaline (subhedral, 4 mm × 2 mmin size)**			Apatite (Hydroxylapatite)	Chalcopyrite
	Souzalite Gormanite (anhedral, 500x100µm)	Silimanite				Stannite Sulfosalts

Alluvial Heavy Mineral Average Abundance

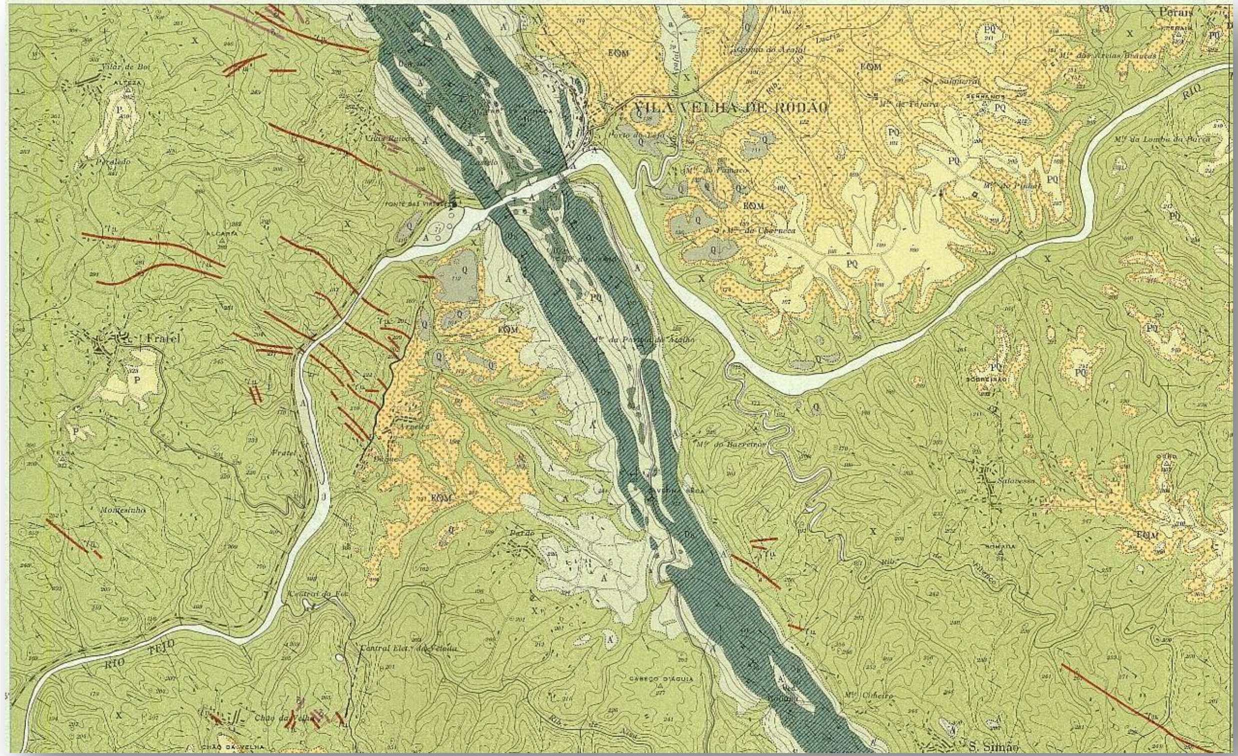
✓ Mineralogical Association _ Original source



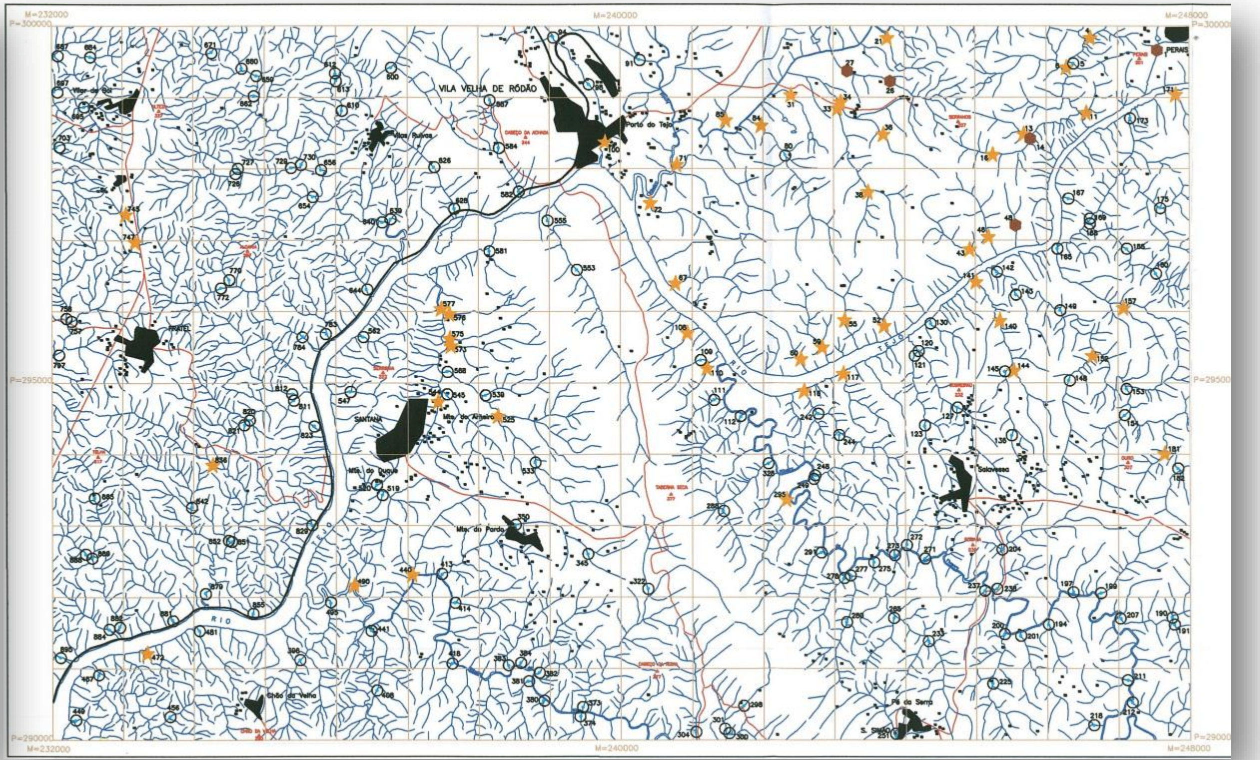
- Deviations to HM assemblage of the main source, can denounce the mix with other sources;
- Representativeness of lithotype source outcrop its relevant;
- Alluvial HM association abundance, in general, reflect the assemblage of lythotypes and mineralisations present in the catchment area;

Alluvial Heavy Mineral Average Distribution

- ✓ Mineralogic Association_ Secondary Source _ Relatively Rare Accessory minerals



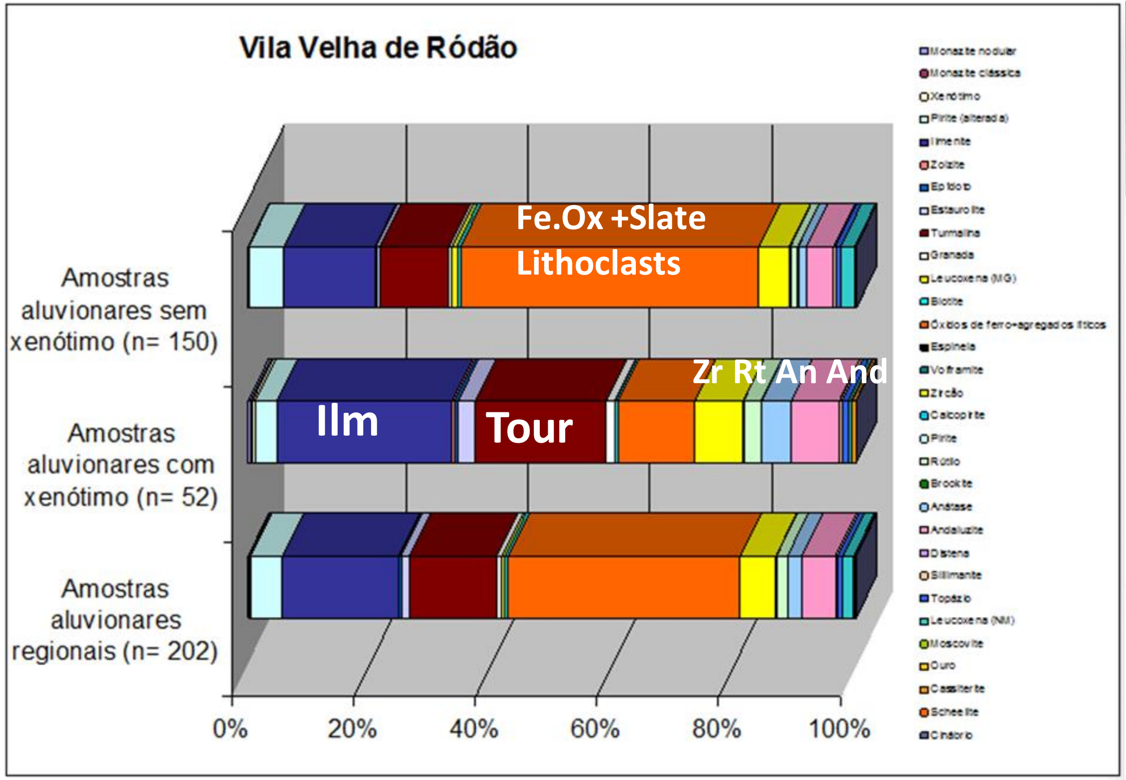
Ribeiro, O., Teixeira, C., de Carvalho, H., Peres., A.M., Fernandes, A.P., 1964, Carta Geológica de Portugal, escala 1: 50 000, Folha 28-B (Nisa): Lisboa, Serviços Geológicos de Portugal.

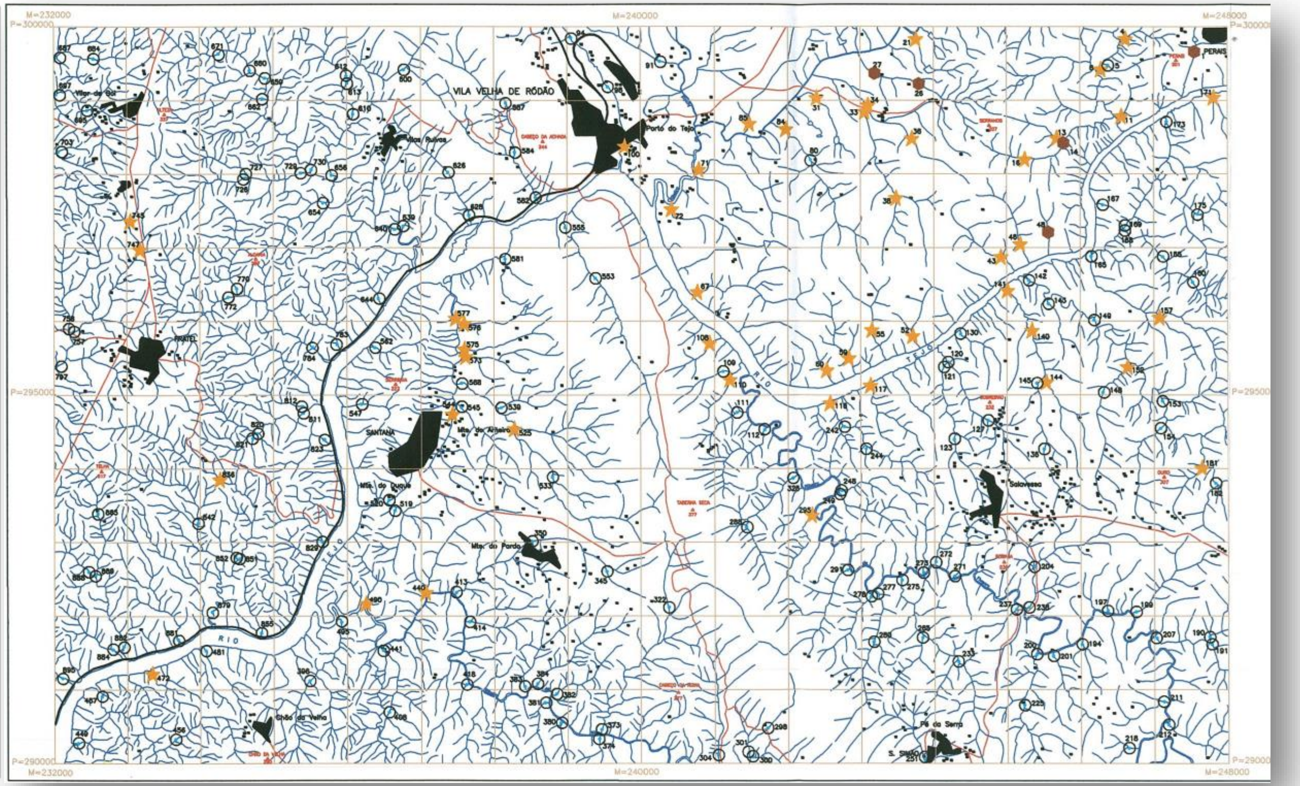


Average (%) of igneous xenotime in each magnetic mineral fraction (up to 1-5 %); Salgueiro (2012); LNEG, Unpublish Report

Alluvial Heavy Mineral Average Distribution

- ✓ Mineralogic Association_ Secondary Source _ Relatively Rare Accessory Minerals



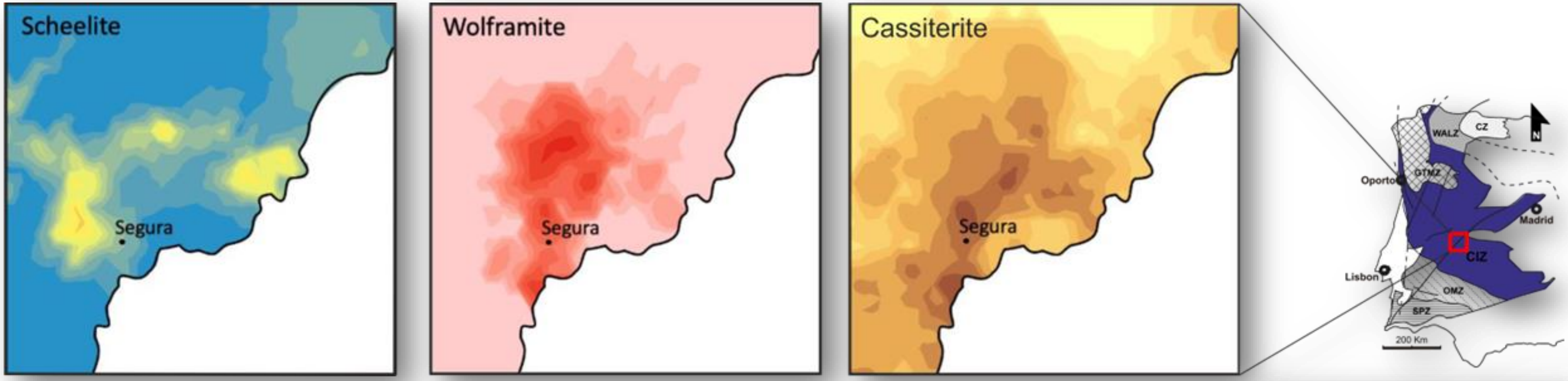


Salgueiro (2012); LNEG, Unpublish Report

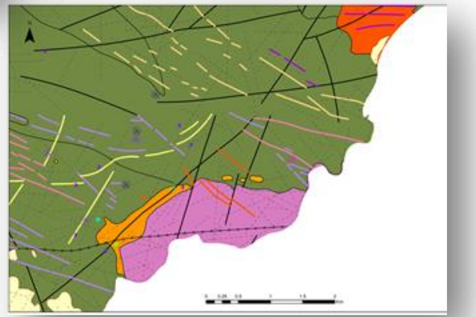
Alluvial Heavy Mineral Grains Distribution

Number of Ore minerals Grains Abundance Mapping

✓ Useful for identification and narrow down the mineral exploration area for different types of ore deposits



Salgueiro et al., 2023: correlation with distinct W-Sn metallogenetic events, and likely locally overlapping, especially to the west. The absence of reported Sch in the mineralized bodies and the well-defined halo around the Segura Massif suggests a metasomatic contact origin by remobilization of W from the metasediments.



Alluvial Heavy Mineral Grains Distribution

Mineral Grains Physical Properties

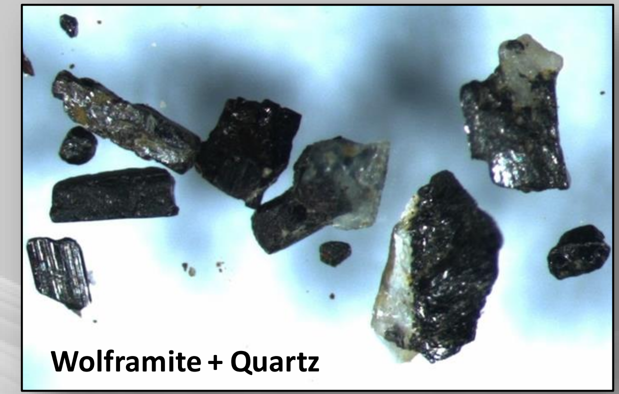
- HM with low mechanical resistance (e.g. wolframite, composite grains, cinnabar) are short distance transported, therefore can indicate proximal mineralisations.

- Despite grain-size is dependent from the original source:

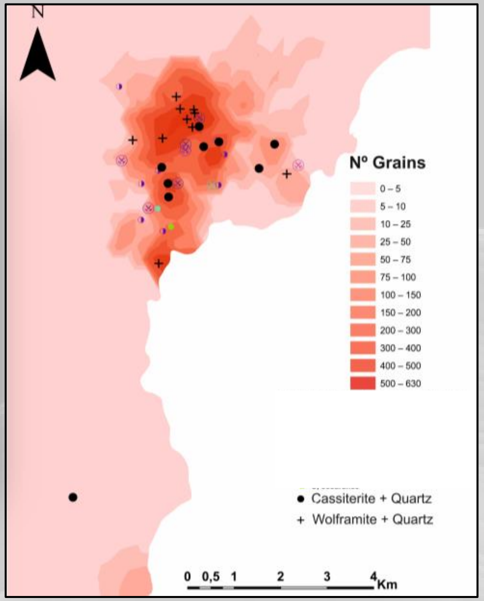
- Grain size variability tends to occur near original/primary sources;

- Less variability in mineral grain size classes, with a clear predominance of fine and rounded grains, reflect the selection and sorting during sedimentary cycles, therefore tends to occur near sedimentary deposits.

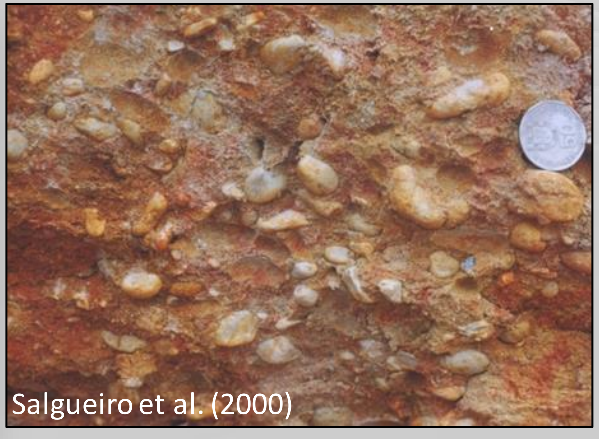
✓ *Proximal/original vs distal/secondary sources*



Wolframite + Quartz



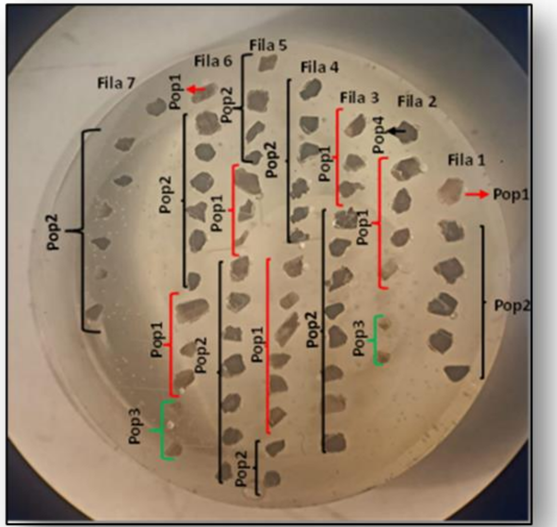
Fine and sorted gold grains 350 µm

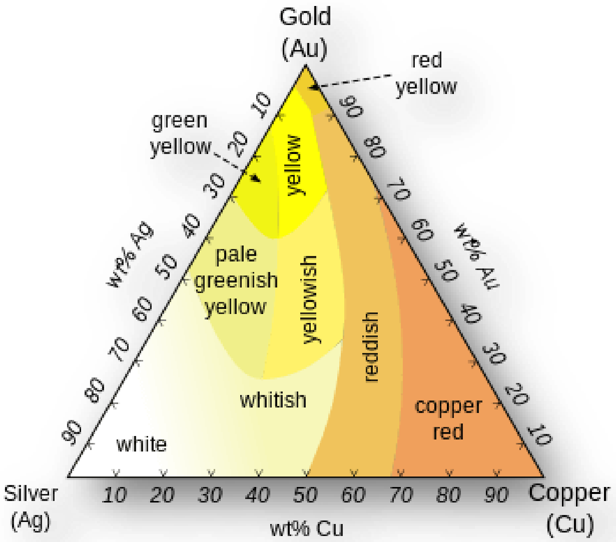


Salgueiro et al. (2000)

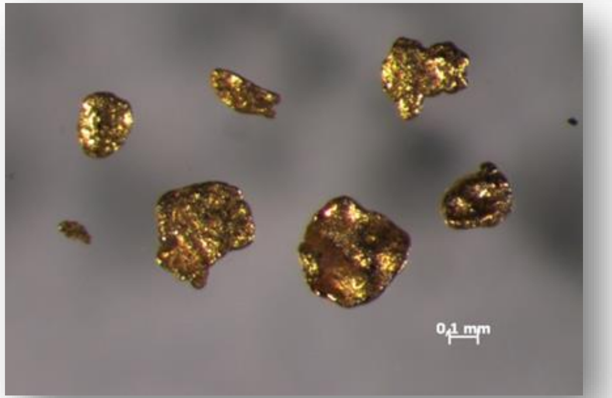
Alluvial Heavy Minerals Physical Properties

- ✓ Different physical properties? Different geochemical properties?
- Visual identification of Pathfinder or Indicator minerals is important for mineral exploration.



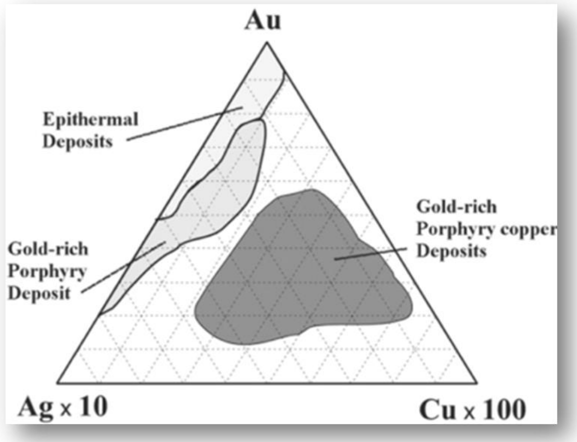


https://www.911metallurgist.com/blog/what-gives-gold-different-colours



Chemical analysis

Mineral Fingerprint



From Townley et al. (2003)

The Production and characterization of AHMC are based on their natural occurrence, physical and chemical properties.

Have higher concentration of indicator and pathfinder minerals than rocks;

Useful for identification and narrow down the mineral exploration area for different types of ore deposits;

Can allow the quick selection of representative mineral grain populations, before chemical analysis;

Chemical fingerprint can confirm / reveal genetic associations with known, inferred or hidden regional mineralisation types / stages;

The results can be profitable when applied to Mineral Research and Exploration.

THANK YOU!