

ERC SILVER Kick-Off Meeting, January 21-24, 2018

The Role of Iranian Argentiferous Ore Deposits in Ancient Silver Production

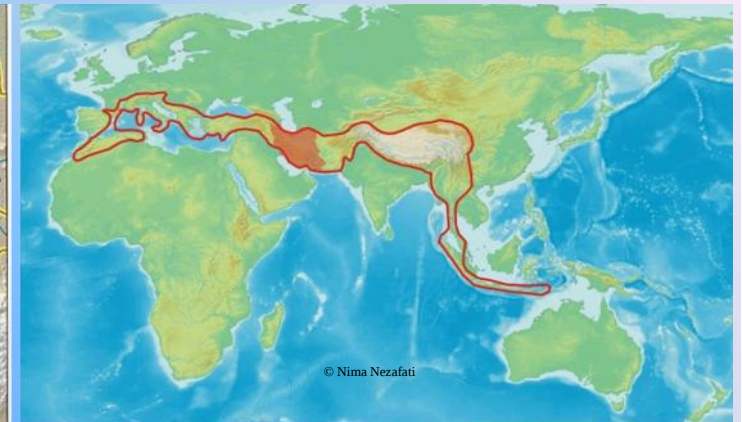
Current Level of Knowledge and Future Perspectives

Nima Nezafati

Head of Department of Geology and Geophysics
Islamic Azad University
Science and Research Branch, Tehran

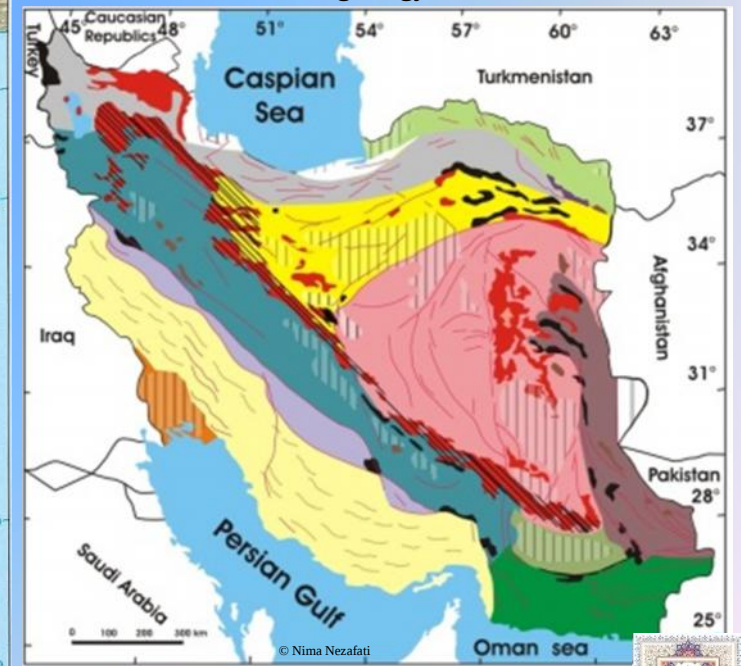
nima.nezafati@gmail.com

Ecole Normale Supérieure (ENS) de Lyon, France



**Tethyan-Eurasian Metallogenic Belt
Alpine-Himalayan Orogenic Belt**

A vast land with diverse geology and natural resources



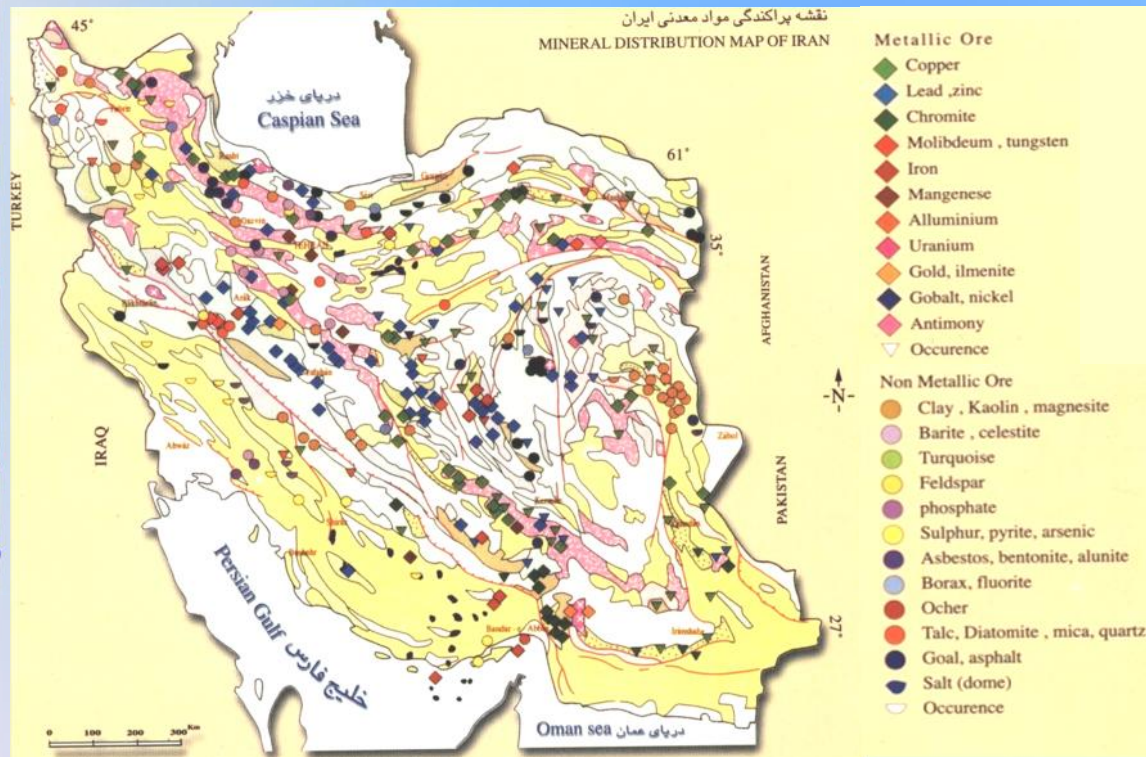
The role of Iranian argentiferous ore deposits in ancient silver production

Iran's Contribution to Modern Global Mining

Asia	Mineral Potential			Petroleum Potential	Geological Aid		Geological Survey Capacity	Risk			
	Known Mineral Resources	Existing Mineral Industry	Geological Potential for Mineral Resources		World Bank Funding	Collaborative Projects		Political Risk	Operational Risk	Security Risk	Terrorism Risk
Iran	3	2	1	1	0	3	1	4	4	2	2

0	No or limited data
4	Minor
3	Moderate
2	Large
1	Very large

Assessment of mineral potential, geological survey capacity, risk, and geological aid in Iran, after Kay et al. 2012



Commodity	Unit	Production	World Rank
Metal Resources			
Iron ore	Million tonnes	45	10
Molybdenum	Tonnes	6300	8
Copper	Thousand tonnes	265	13
Gold	Tonnes	0.341	..
Lead	Thousand tonnes	41	11
Zinc	Thousand tonnes	65	16
Silver	Tonnes	15	..
Industrial Mineral Resources			
Pumice	Thousand tonnes	1500	2
Gypsum	Thousand tonnes	13000	3
Cement	Thousand tonnes	75000	4
Barite	Thousand tonnes	270	5
Feldspar	Thousand tonnes	600	7
Fluorspar	Thousand tonnes	70	7
Kaolin	Thousand tonnes	900	8
Mica	Thousand tonnes	7	9
Lime	Thousand tonnes	3000	12

Based on Kay et al. 2010-2012 and USGS 2017

67 types of mineral commodities are reported to have considerable reserves and/or resources in Iran.

Iran is the major or the only producer of **Fe, Mo, U, Cr, Cu, Au, Pb-Zn, Al and coal** in the **Middle East** (based on Mobbs et al. 2012)

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Earliest Silver in the Old World



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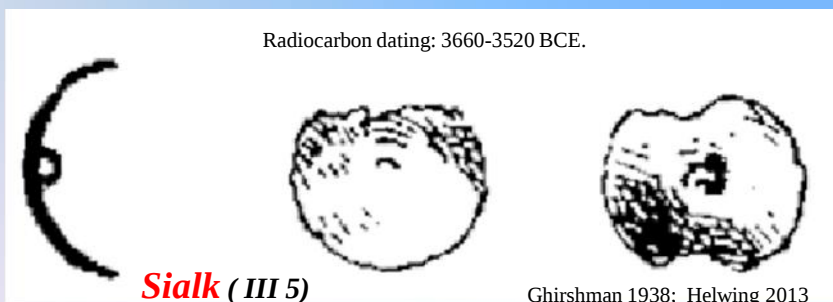
Earliest Silver Objects in Iran



Arisman (Sialk IV, Late4th- Early 3rd Millennium BCE)



Susa II (Late4th- Early 3rd Millennium BCE)



The role of Iranian argentiferous ore deposits in ancient silver production

The Earliest Silver Production Relics



Litharge cake



Lead sheet

Tappeh Shoghali (Late 4th - Early 3rd Millennium BCE)



Twin Litharge cake

© Nima Nezafati

Arisman (Sialk IV, Late 4th - Early 3rd Millennium BCE)



Litharge cake

Nokandeh & Nezafati 2005



Litharge cake

Sialk III-IV (Late 4th - Early 3rd Millennium BCE)

The role of Iranian argentiferous ore deposits in ancient silver production

Silver at Proto-Elamite and Elamite Periods



Proto-Elamite (ca. 3200-2700 BCE) and **Elamite** (ca. 2700-540 BCE) Periods were important time spans for production of silver in the Iranian Plateau.

This is attested by finding several delicate silver artifacts from these periods.



Kneeling bull holding a spouted vessel
Proto-Elamite (ca. 3100–2900 BCE)
16.3 x 6.3 x 10.8cm
Metropolitan Museum of Art



Silver cup with linear-Elamite inscription
Old Elamite (Late 3rd millennium BCE)
National Museum of Iran

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Achaemenid Silverware and Coins



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Later Historic Periods



Silver Coin, Seleucid Empire (330-150 B.C.)
Obverse (left): King Seleucus
Reverse (right): Goddess of Victory with Greek Script



Silver Coin, Parthian Empire of Iran (250 B.C.-226 A.D.)
Obverse (left): King Ardavan (Artabanus) II
Reverse (right): King Arashk (Arsaces) Sitting; King Ardavan Nicknames in Greek Script



Silver Coin, Sassanid Empire of Iran (226-650); Both Sides Contain Middle Persian Script
Obverse (left): King Bahram II, the Queen and the Crown Prince
Reverse (right): Fireplace and Guards

<http://www.banksepah.ir>



<https://metmuseum.org/art/collection/search/325717>
ca. 4th century



<https://www.metmuseum.org/art/collection/search/322973>
ca. A.D. mid-5th–mid-6th century

Metallogenic Epochs of Iran

		Orogeny, Magmatism and/or Tethys Ocean	Iron ($\pm P$ $\pm Mn+REE$)	Copper				Gold ($\pm As \pm Sb \pm Hg \pm W \pm Sn$)	Lead-Zinc ($\pm Ag \pm Cu$)	Barite ($\pm F$)	Manganese $\pm$ Iron	Uranium	Phosphate	Ophiolite-related deposits	Bauxite & Laterite	Salt dome	Coal
Major types of deposits			Sedimentary+Volcanogenic+Magmatic+IOCG	Porphyry ($Cu \pm Mo \pm Au$) + Skarn	Sedimentary (Redbed)	Manto	Other types	Epithermal, Orogenic, Intrusion-Related, IOCG	SEDEX + MVT + VMS	Hydrothermal	Sedimentary+Volcanogenic	Hydrothermal Metasomatic	Sedimentary+Igneous	Alpine Cr, VMS, Listwanite	Weathering	U, Fe, Cu, Sr, etc (Diapirism)	
Metallogenic Epoch	Cenozoic	Alpine (Volcanism + Plutonism)	Sangan	Sarcheshmeh, Sungun	Sorkheh, Nesar	Veshnaveh	$Cu \pm Ni \pm Co$	Agh Darreh, Astaneh				Khoshumi					
	Late Mesozoic	Laramide (V+P)-Late Neotethys												Chromite, Mn, Cu, Magnesite, Jade			
	Mid-Mesozoic	Cimmerian (V+P)-Early Neotethys	Baba Ali, Galali, Shams Abad		Guhjar, Markasheh			Torghabeh, Tareek Darreh	Malayer-Esfahan zone, Mehdi Abad	Mehdi Abad						Alborz-Azərbayjan and central Iran	
	Permo-Triassic	V+P-Late Paleotethys	?				?	Zartorosht	Duna, Elik, Kuh Sormeh	Komshejeh Fasakhod			Jeirud		Jajarm		
	Early-Mid-Paleozoic	Caledonian (V=Volcanism)							Zeber Kuh	?							
	Proterozoic (Cambrian)	Pan-African (Assynitic) (V+P)-Early Paleotethys	Bafgh region deposits		Khungah, Deh Madan			Zarshuran	Angouran, Koushk			Saghand	Esphordi, Gazestan				Hormoz Series

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Major Pb-Zn ($\pm$ Ag) Metallogenic Districts of Iran

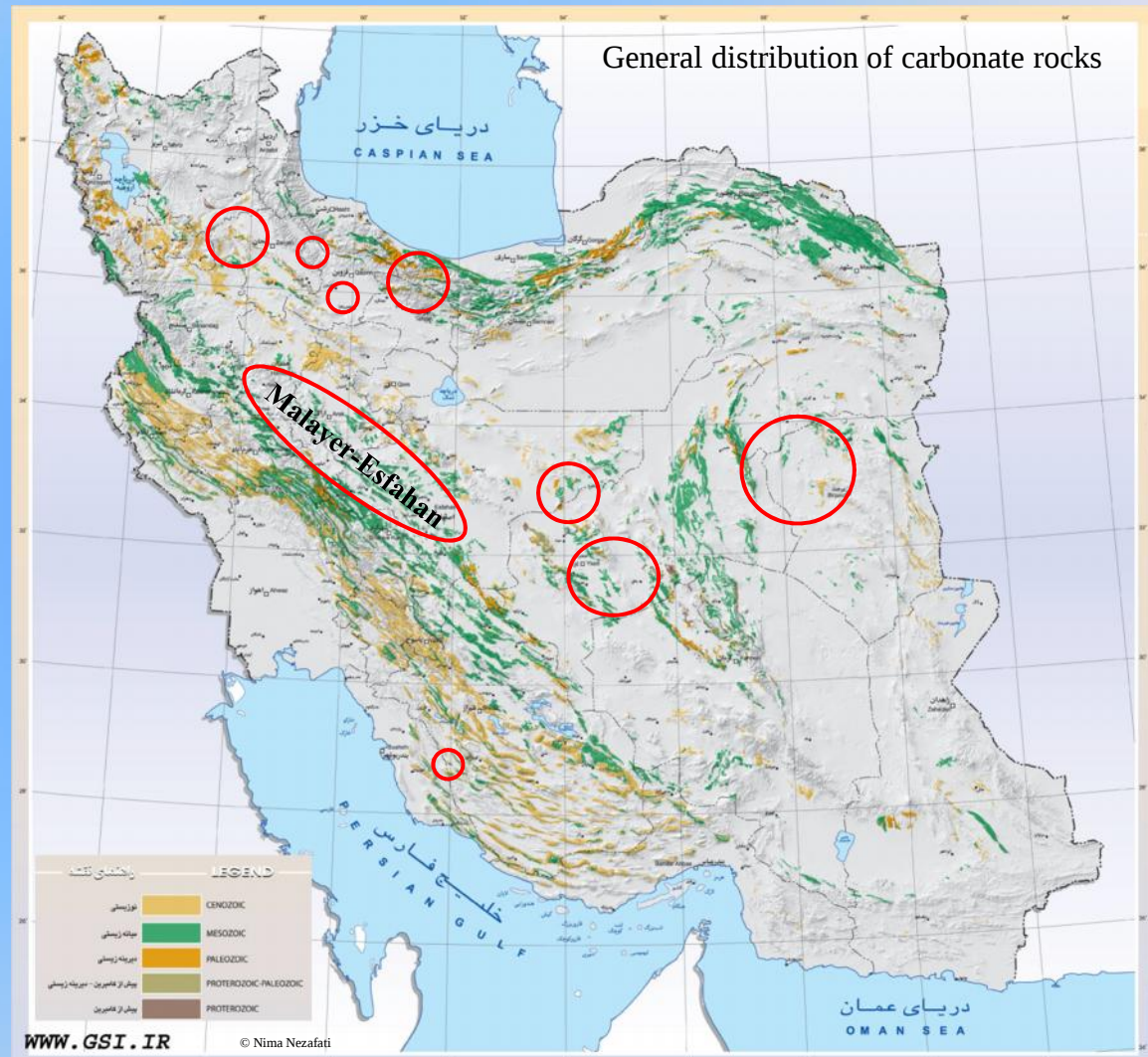
SEDEX type deposits
(Neoproterozoic + Cretaceous)
(Angouran, Kushk)

MVT deposits
(Cretaceous)
(Malayer-Esfahan axis,
CD, Mehdi Abad,
Nakhlak, Irankuh)

VMS

**Hydrothermal-Vein
(Polymetallic) type**
(Cenozoic)
(Tarom-UD, CD, EI)

Permo-Triassic
(Duna, Shakin, Kuh
Sormeh)



Native Silver has rarely been reported from Iran.

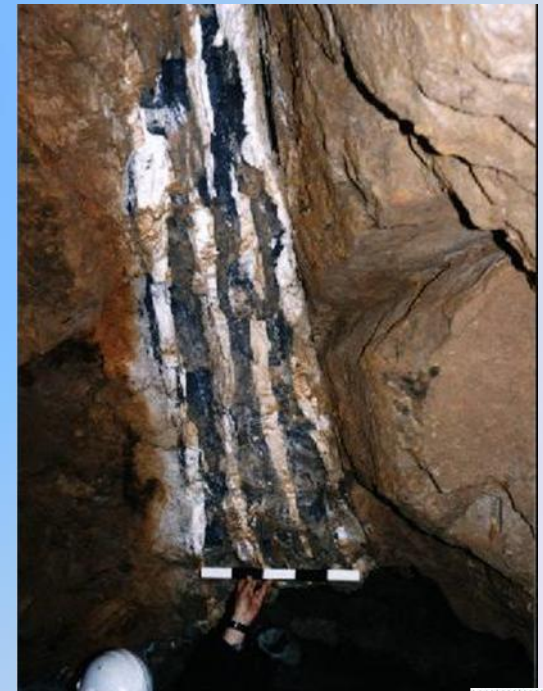
The major part of silver exists in argentiferous lead ores that are mainly hosted by carbonate rocks in Iran!

The role of Iranian argentiferous ore deposits in ancient silver production



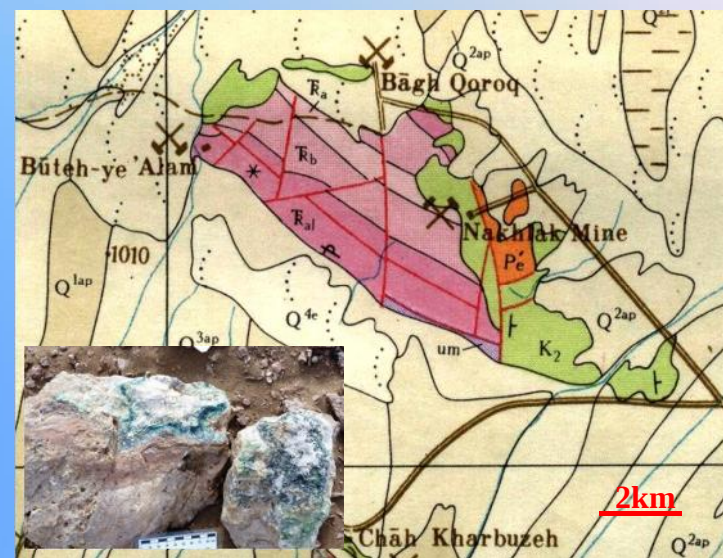
The role of Iranian argentiferous ore deposits in ancient silver production

Nakhlak Mine



The role of Iranian argenteous ore deposits in ancient silver production

Baqoroq Mine



Mineralogy:

Chalcocite, chalcopyrite, fahlore (tennantite), arsenopyrite, magnetite, covellite, cuprite, chrysocolla, malachite, azurite, barite, calcite, and quartz.

Geochemistry:

12.0% **Cu**, 2.07% **As**, 44 ppm **Ag** + high anomalies of Pb, Zn, Sb.

Multi-level underground workings and several old pits including two 75m shafts, a large open pit, and an ad

Komjan Mine

Mineralogy:

Bornite, chalcopyrite, covellite, cuprite, pyrite, malachite, smithsonite, calamine, galena, magnetite, pyromorphite, laurionite, valleriite, hematite, limonite, cerussite, siderite, barite, fluorite, quartz, and calcite.

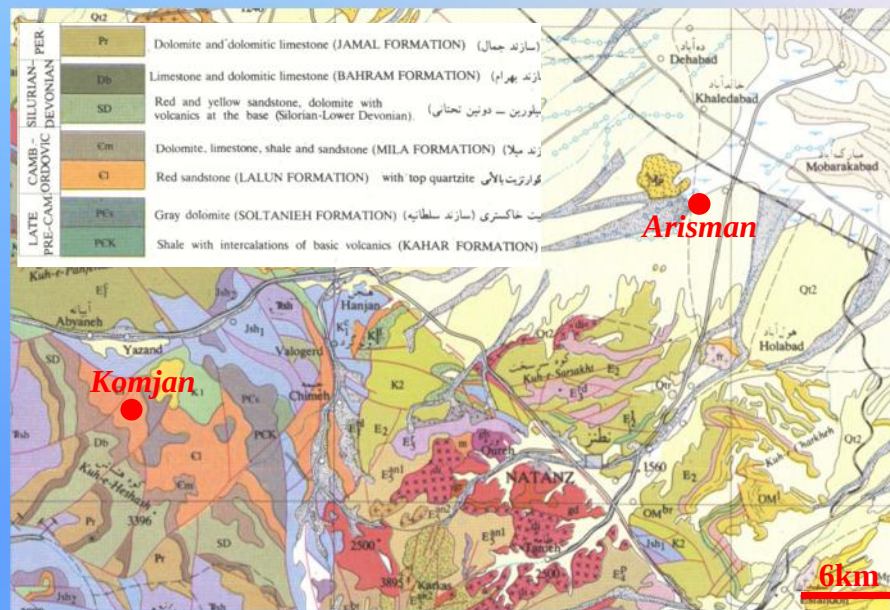
Geochemistry:

50% **Cu**, 79% **Pb**, 1.3% **As**, 23 ppm **Ag**, 6.4% **Zn** + high anomalies of **Sb**.

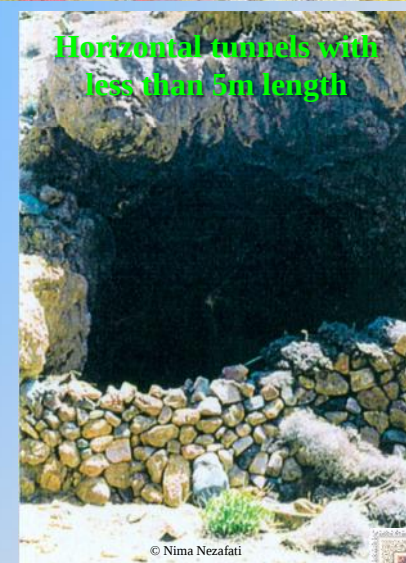
Two major forms of diggings



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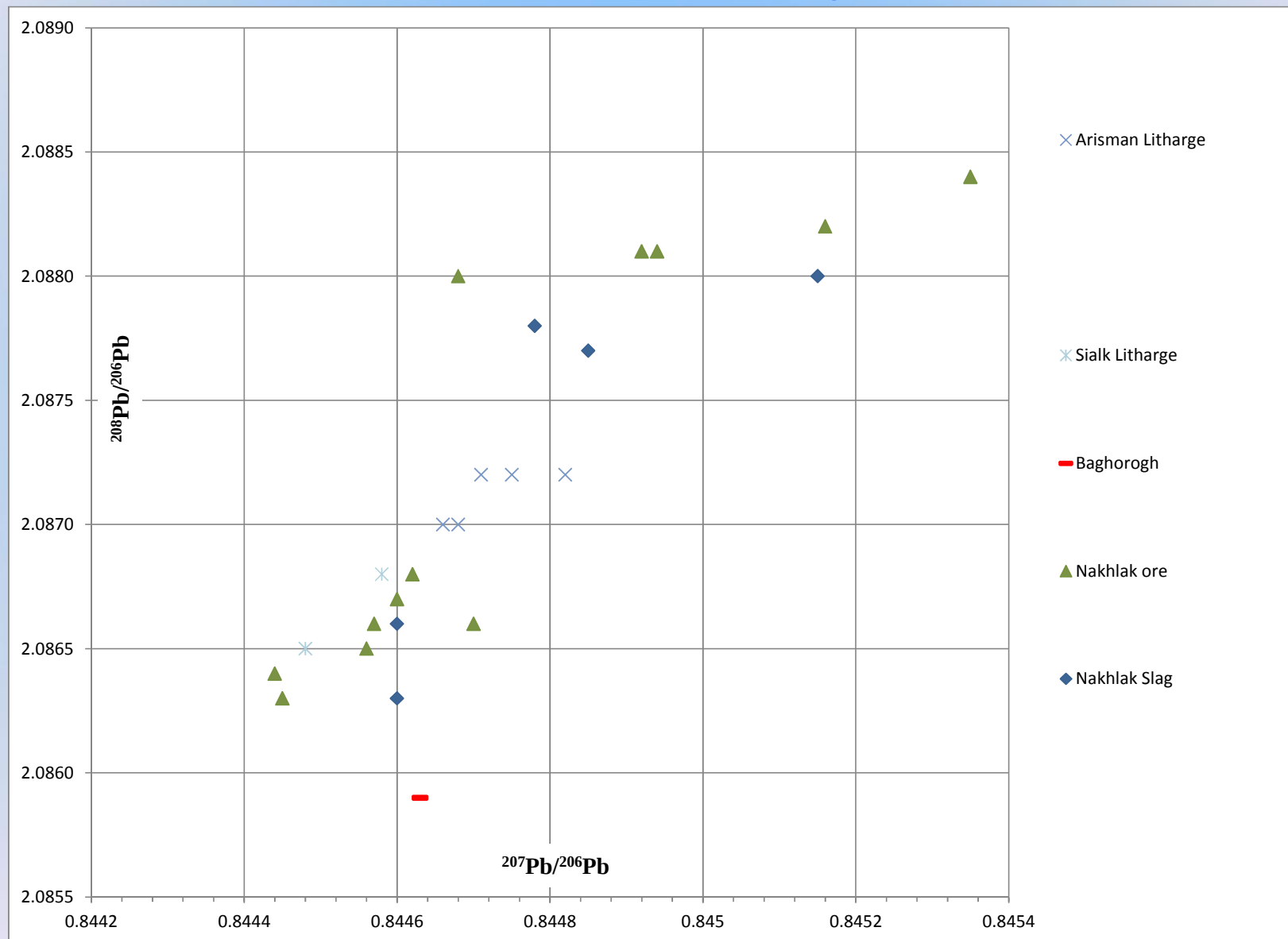


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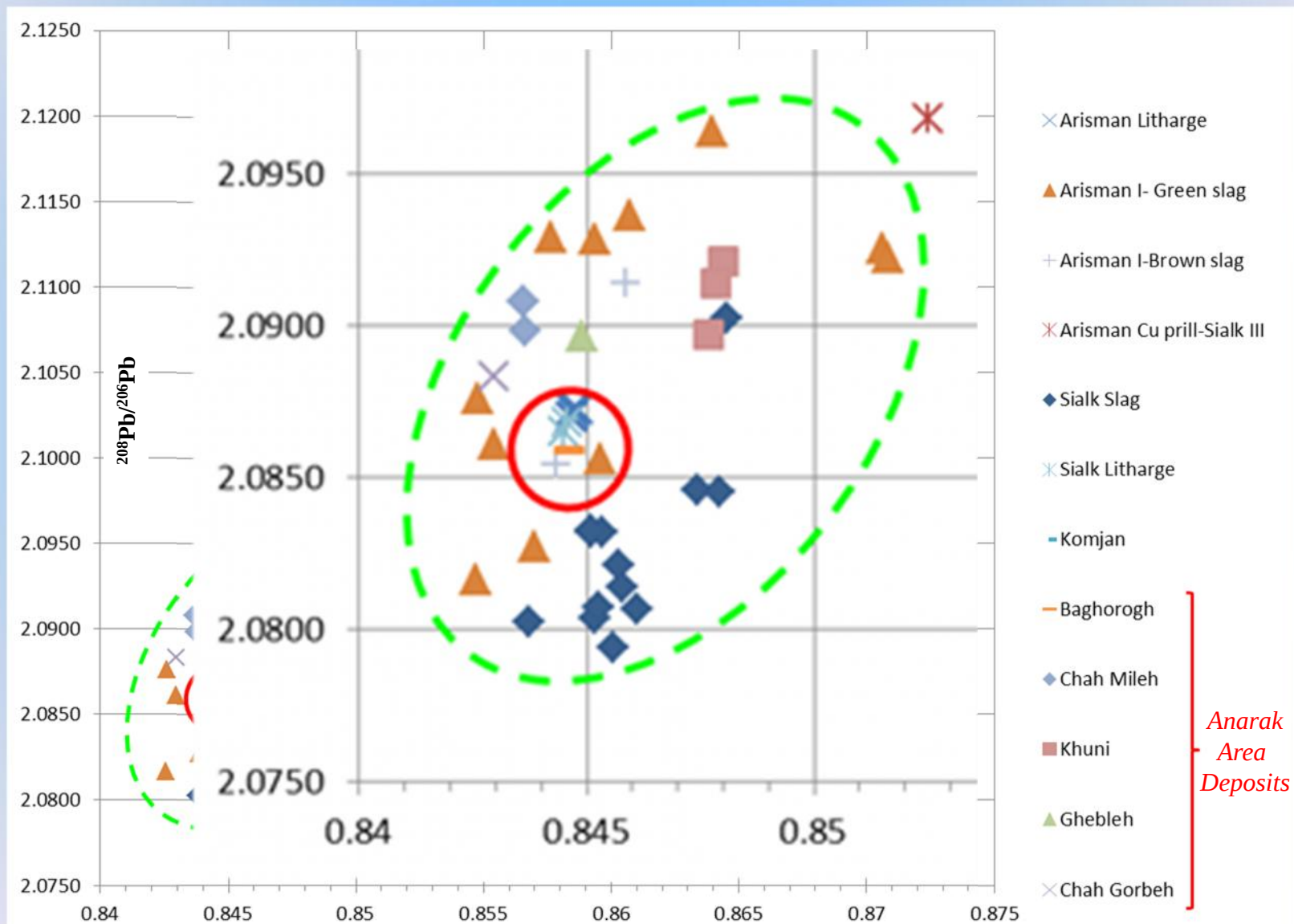
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Lead Isotope Analysis



The role of Iranian argentiferous ore deposits in ancient silver production

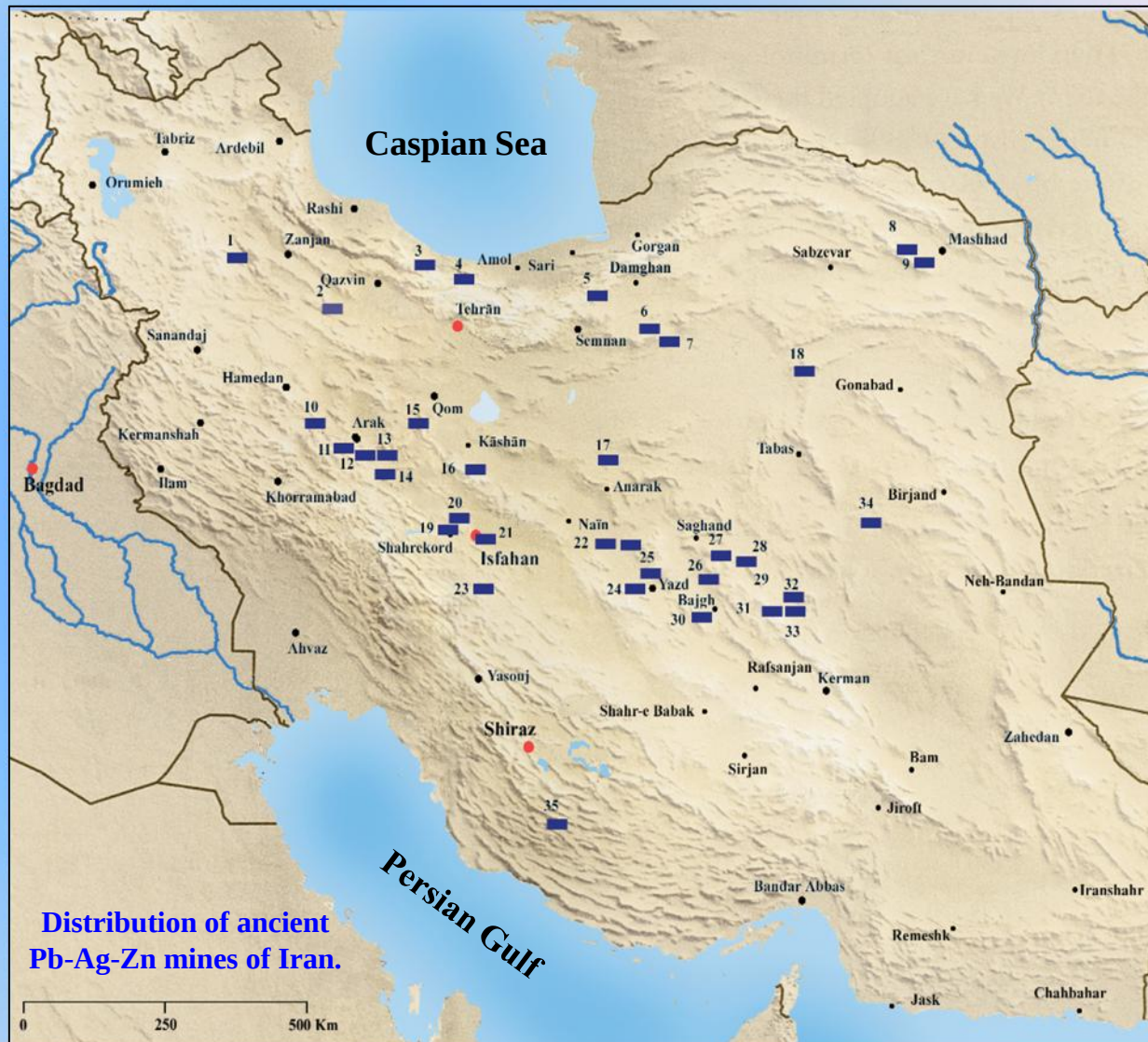
Lead Isotope Analysis



The role of Iranian argentiferous ore deposits in ancient silver production

Ancient $Pb+Zn+Ag$ Mines of Iran

1) ANGURAN, Zn, Pb (Ag), 2) SHAKIN, Pb, Ag, Zn (Ba), 3) KALARDASHT (GROUP), Zn, Pb, Ag (Ba, F), 4) DUNA, Pb, Ag, Zn (Ba), 5) TUYEH-DARVAR (GROUP), Pb, Ag, Zn (Ba, F), 6) ANARU, Pb, Ag, Zn (Ba), 7) RESHM (KHANJAR), Pb, Ag, Zn, 8) NORTH NEYSHABOUR (GROUP), Pb, Ag, Zn, 9) PIVEZHAN, Pb, Ag, Zn, 10) AHANGARAN, Pb, Ag, Zn, Fe (Au, Ba), 11) EMARAT-SHAMSABAD (GROUP), Pb, Zn, Ag, (Fe), 12) LAKAN, Pb, Zn, Ag (Fe, Ba), 13) KHUGAN, Pb, Zn, Ag (Fe, Ba), 14) DARREH NOGHREH, Pb, Ag, Zn (Ba), 15) RAVANJ, Pb, Ag, Zn (Ba), 16) PINAVAND, Pb, Zn, Ag (Cu, Ba), 17) NAKHLAK, Pb, Zn, Ag (Ba), 18) OZBAKKUH (GROUP), Zn, Pb, Ag, 19) TIRAN (GROUP), Pb, Zn, Ag (Ba), 20) KHAN-E-SORMEH, Pb, Ag, Zn (Ba), 21) IRANKUH (SHAHKU), Zn, Pb, Ag (Ba), 22) HAFTAR (AGHDA), Pb, Zn, Ag, 23) KOHRUYEH, Zn, Pb, Ag, 24) DARREH ZANJIR, Pb, Ag, Zn (Ba), 25) ANJIREH (YAZD), Pb, Ag, Zn (Ba), 26) ZIREKAN (ZARIGAN), Pb, Ag, Zn, 27) PUDANU, Zn, Pb (Ag?), 28) AHMADABAD, Pb, Zn, Ag (Ba, Fe), 29) KUSHK, Zn, Pb (Ag), 30) MEHDIABAD, Zn, Pb, Ag (Fe), 31) TAJKU, Zn, Pb (Ag?), 32) GOWJAR, Zn, Pb (Ag), 33) TARZ, Zn, Pb, Ag, 34) NAYBAND, Pb, Zn, Ag, 35) KUH SORMEH, Zn, Pb, Ag (Ba).



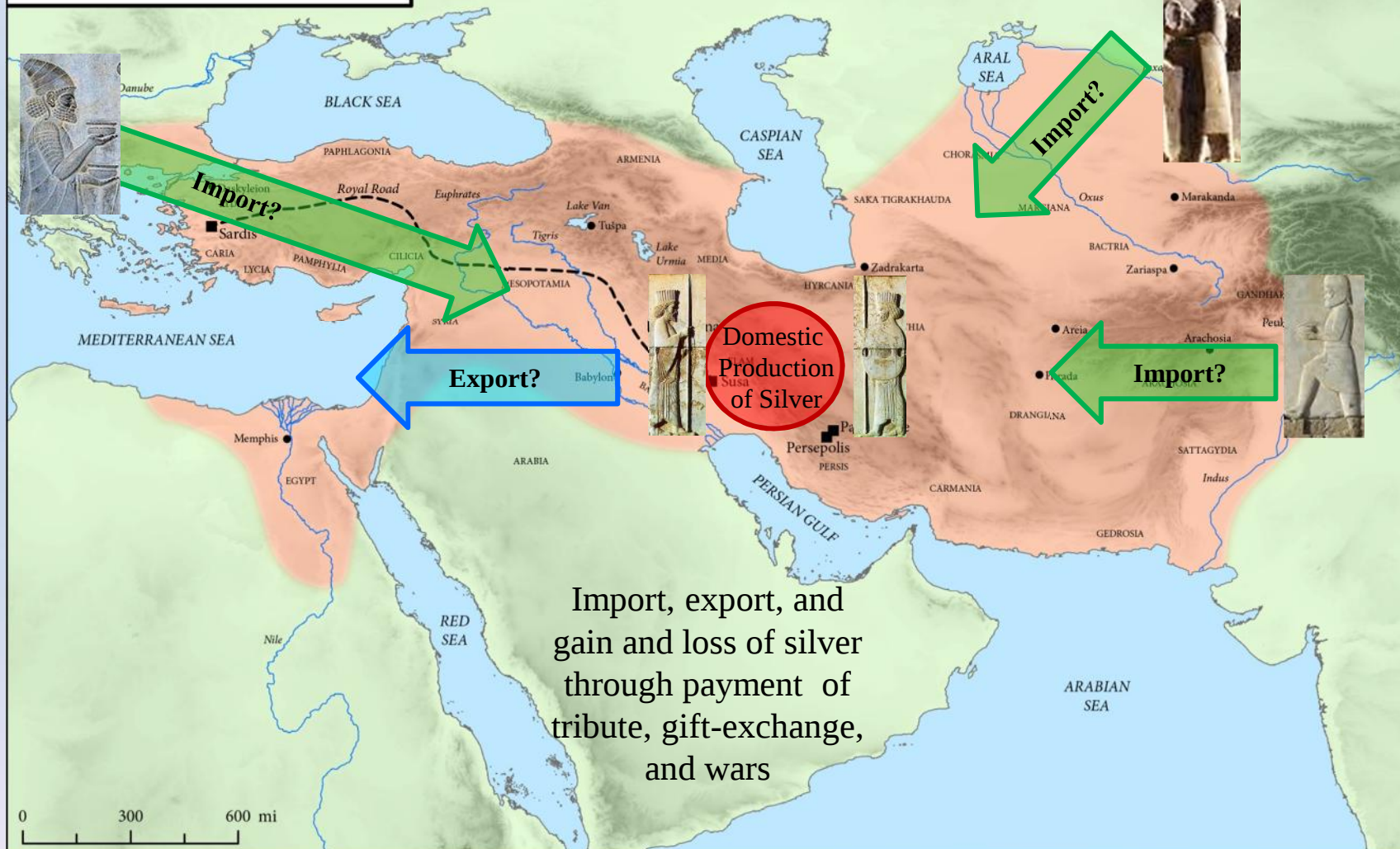
After M. Momenzadeh 2004

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THE ACHAEMENID EMPIRE AT ITS GREATEST EXTENT (C. 500)

- Imperial Residence
- Satrapy Capital

Exchange of Silver Across the Empire



Import, export, and
gain and loss of silver
through payment of
tribute, gift-exchange,
and wars

The role of Iranian argentiferous ore deposits in ancient silver production

Challenges and Concerns

-**Large extent** of Pb-Zn-Ag deposits and ancient mines of Iran with few archaeological and isotopic data, therefore need for large scale survey and sampling.

-**Long history** of silver production and usage in the Iranian Plateau and likeliness of **re-melting** of silver from diverse sources and therefore mixed isotopic signatures and geochemical patterns.

Silver recycling should be considered as a serious challenge.



*Thank you for
your attention!
Merci beaucoup!*