The Gold Mine of Sakdrissi: Results and analyses and a calculation of the prehistoric gold-exploitation

Report by
Prof. Dr. Andreas Hauptmann,
Moritz Jansen M.A.
Prof. Dr. Thomas Stöllner,

Deutsches Bergbau-Museum Bochum
Forschungsstelle für Archäologie und Materialwissenschaften
Hernerstraße 45
D- 44787 Bochum
Germany

and

Ruhr-University of Bochum
Institute of Archaeological Studies
Am Bergbaumuseum 31
D-44791 Bochum
Germany

Kachagiani hillock, the prehistoric gold mine of Sakdrissi, in the background the recent mining activities (Foto: M. Schaich, Fa. ArcTron)

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Deutsches Bergbau-Museum Bochum • Am Bergbaumuseum 28 • 44791 Bochum

To whom it may concern

Forschungsbereich
Materialkundliches Labor

Ihr Zeichen
Ihre Nachricht
Unser Zeichen Pra
Durchwahl 0234 968 4043
E-Mail michael.prange@bergbaumuseum.de
Datum 19.07.2013

Certificate of verification

Herewith I confirm that all analyses from the “Sakdrissi-Mine” mentioned in the attached report by Prof Dr Andreas Hauptmann, have been measured at the laboratory of the Deutsches Bergbau-Museum under my supervision.

i. A. Dr. Prange

Dr Michael Prange

Head of laboratory

Deutsches Bergbau-Museum Bochum
Forschungsstelle Archäologie und Materialwissenschaften
Herner Straße 45

D-44787 Bochum

DIN EN ISO 9001:2008 zertifiziert

Deutsches Bergbau-Museum Bochum

DMT-Forschungsinstitut für Montangeschichte
Direktor:
Prof. Dr. Stefan Brüggerhoff

Am Bergbaumuseum 28
44791 Bochum
Telefon (02 34) 58 77-0
Telefax (02 34) 58 77-1 11
http://www.bergbaumuseum.de
Infoline: (01 80 5) 87 72 34

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(Vorsitzender)
Manfred Freitag

Bankverbindung:
Sparkasse Bochum
(BLZ 430 500 01) 13 00 607

RUHR-UNIVERSITÄT BOCHUM | Inst. f. Archäologische Wissenschaften | D-44780 Bochum

FAKULTÄT FÜR GESCHICHTS-WISSENSCHAFT

Institut für Archäologische Wissenschaften
Ur- und Frühgeschichte
Gebäude GA 6/60
Universitätsstraße 150, 44801 Bochum

PROF. DR. THOMAS STÖLLNER
Fon +49 (0)234 32-22546
Fax +49 (0)234 32-14234
thomas.stoellner@rub.de
www.rub.de/archaeologie

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29. Juli 2013

Sadrissi-Gold mine

Dear ladies and gentlemen,

the project „Gold in Georgia" (2004-2011) and the „On Salt, Copper and Gold. The Beginning of Mining in the Caucasus" (ongoing since 2013) is funded by the VW-foundation and by the German Research Foundation (DFG). Both foundations are following strict rules of good scientific practice and control their entire projects by assistance of internationally acknowledged scientists and their reviews.

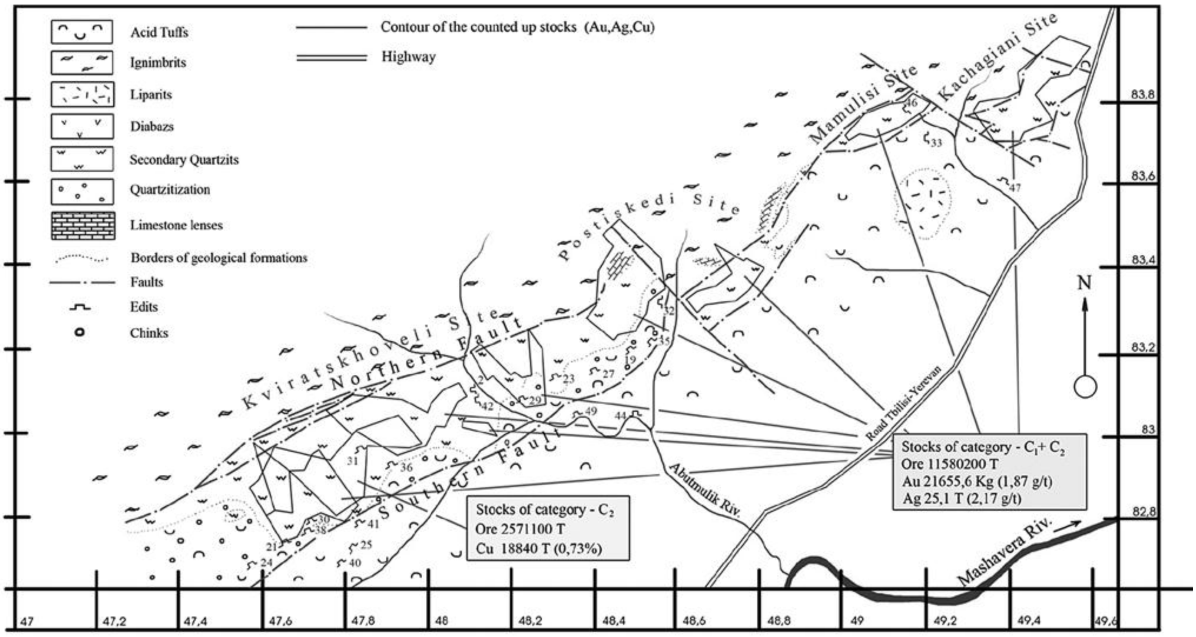
All analyses and investigation presented in this report follow the high standards and criteria of science based work.

With my best regards

Thomas Stöllner
head of the Institute of Archaeological Studies
Ruhr-University of Bochum

ADRESSE Universitätsstraße 150 | 44801 Bochum, Germany
ANFAHRT U-Bahn: U35 | Auto: A43, Abfahrt (19) Bochum Witten

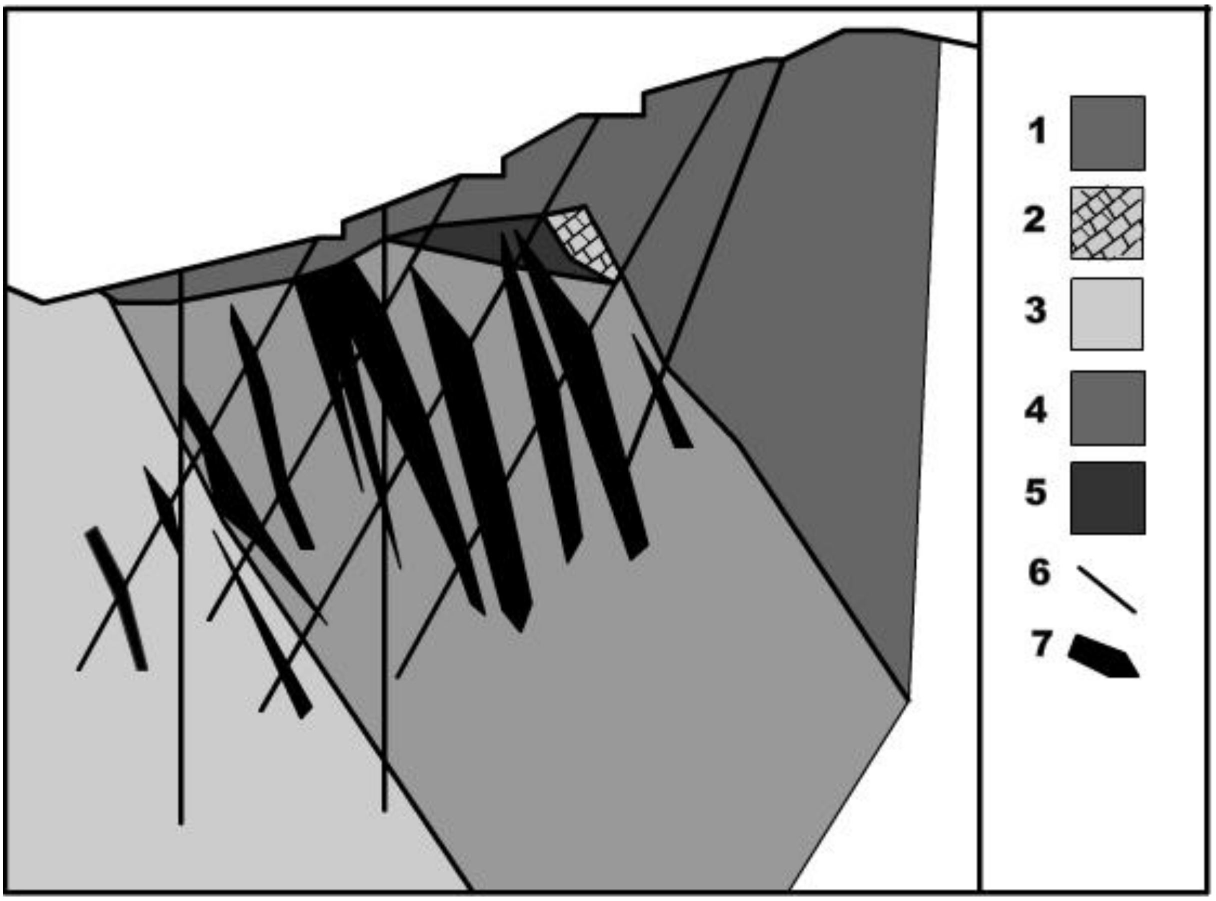
What has been mined in Sakdrissi: the geochemical characterization of the ore-deposit of Sakdrissi



Simplified geologic-tectonic map of the gold deposit of Sakdrisi-Kachagiani. The prehistoric mine of Sakdrissi which is investigated by the Georgian-German team is located in the Kachagiani site in the upper right corner of the map (see Fig. 5). The extent of the entire gold deposit is several kilometres to the southeast (Mamulisi, Postiskedi, Kviratskhoveli). Scale of the map 1 : 10.000 (from Omiadze 2007).

Next to placer gold this noble metal occurs in the Bolnissi- district in VMS-deposits and in porphyry copper deposits (Tvalchrelidze 2001). VMS are of major importance. They were formed during the early phase (Jurassic to Cretaceous) of the Alpine metallogenesis. They are parts of the „Tethyan Eurasian Metallogenetic Belt“ (“TEMB”, Jankovic 1997; Moon et al. 2001) which extends from the Alps in the west over the Balkan Mountains, Anatolia, Armenia, Iran to the Himalayas. The Madneuli polymetallic ore deposit is part of the Artvin- Bolnisi unit of the TEMB. It is a hybride between VMS and an epithermal (subvolcanic) gold-silver deposit (Migineishvili 2002). Also the prehistoric copper district of Murgul and at Cerattepe, northeastern Anatolia, belong to this unit (Moon et al. 2001). The ore body of Madneuli is bound to a rhyolithic dome above an intrusion of granodiorite. Kalium-argon-dating of the mineralisation provide an age of 85-93 million years (Moon et al. 2001). Madneuli shows vertical „telescoping“ of a copper-lead/ zinc-baryte-gold mineralisation (Gogishvili et al. 1976). Due to its geochemical stability gold is enriched in the gossan near the surface, where ancient galleries were found (Stöllner et al. 2010). Copper is associated in small amount with gold, but economic valuable amounts occur in a depth of ca. 60 m. Sulfobismuthide and telluride occur occasionally. Copper is exploited in the open cast mine of Madneuli by Joint Stock Co. “GeoProMining“ and gold is mined from secondary quarzite by the Georgian- Russian „Quartzite Co.“. Madneuli and the close by located former open cast mine of David Garedji are in a distance of only a few kilometers from the prehistoric gold mine of Sakdrisi. The area around Sakdrisi itself consists of several prospects. The Kalium-Argon age of this ore deposit is 77,6 - 83,5 millionen years (Gugushvili et al. 2002). The prehistoric mine Sakdrisi-Kachagiani exploited a swarm of vertical to irregularly formed hydrothermal quartz veins with a thickness of only 10 – 30 cm. Gangue is barite and hematite (in parts like a stock- work mineralisations). Hostrocks are ignimbrites and other (pyroclastic) volcanic rocks (tuffs) often intensively affected by tectonic activities and metasomatism. The ore deposit of Sakdrissi was explored and prospected in the 1980ies. The closer context of the prehistoric mine was studied by Omiadze (2007). Down the hill where the ancient mine is located several prospection galleries were opened which cut parts of the ancient mine at a depth of down to 27 m. Channel samples taken by Georgian geologists gave 23 mt of gold bearing rocks with an average of 1.03 g/t gold (Gugushvili et al. 2002). However gold enrichments up to 50 g/t and even 500 g/t were also analysed from boreholes (personal communication Malkhaz Natsvishvili). Such enrichments were much more reasonable loads for ancient exploitation. We do not exclude that such bonanzas of gold could have been available at the originally untouched Pleistocene surface of the Sakrdissi hill and attracted the prehistoric miners. The gold bearing quartz veins accessible today provide only extremely fine grained flower gold hardly visible with the naked eye. It is questionable if the Bronze Age mining was focussed to extract such fine grained gold. No evidence for the application of metallurgical processes such as amalgamation or cupellation exists which could have been used during this time period at Sakdrissi to enhance the yield of gold hidden in the rocks. The Sakdrissi deposit is a hydrothermal ore-deposit.

Vertical hydrothermal veins embedded in volcanic rocks; the veins are mined during the Early Bronze Age (2nd half of 4th mill./beginning 3rd mill. BC) (down to 28 m) and during the Antique period (down to 8 m, as a re-opening and secondary using) (Stöllner et al. 2010; Stöllner & Gambashidze 2011).

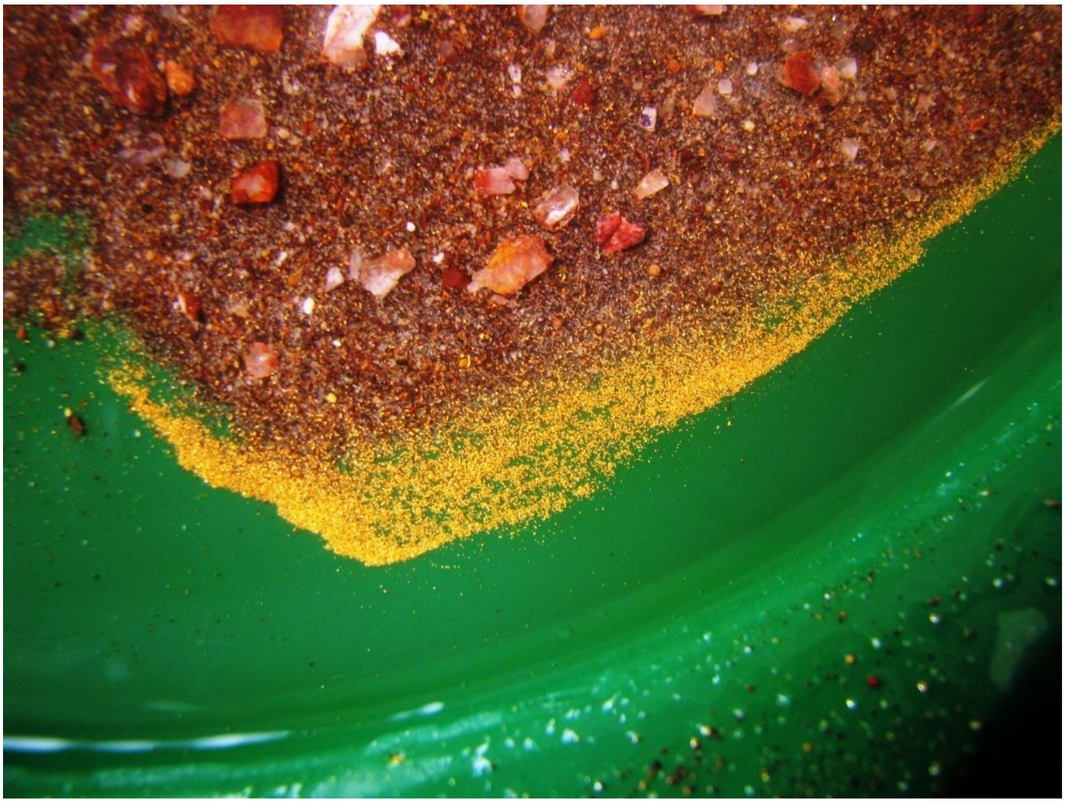


Section through the gold deposit of Sakdrissi, sites 3 und 4 (Gugushvili et al. 2002). Basically, this section can be transferred to the prehistoric mine of Sakdrissi, however there the veins are exposed to surface. 1 Ignimbrite; 2 Limestone, dolomite; 3 Argillaceous tuff and tuffite; 4 Oxidized and silicified tuff; 5 Silicified and pyritizised tuff; 6 Fault; 7 Goldmineralisation

What do we know about the Au-content in the deposit

During the excavation and survey seasons in Georgia we washed numerous gold samples from placers in the districts of Svaneti, Bolnisi and of Tbilisi. Between 500 and 1000 kg of gold bearing gravels were washed using various sized sluice boxes. In addition several hundred of kilograms of channel samples from ore veins and from the backfillings of the prehistoric mine of Sakdrisi were taken. All concentrates obtained were further panned to extract gold grains. In all cases we obtained very fine grained (≤ 0,1 to 1 mm) flower gold.

From these samples native gold grains were collected and prepared for further analytical investigation. They were studied by scanning electron microscopy (SEM), microprobe analyses (EMPA) and mass spectrometry. Further investigations of the ore-deposit were investigated in 2011 by fire-setting experiments which delivered ores with partly evaluated gold contents (Stöllner et al. 2012). In 2013 further sampling of the ore deposit was undertaken: the ores were measured by a portable X-ray spectrometry using a handheld X-ray fluorescence spectrometer (Niton XL.3t, Thermo Scientific) (non-destructive analyses). The XRF is applicable to the determination of main and minor element composition of inorganic materials. In our case this means the (semi-) quantitative analysis of the elements gold, silver, copper, iridium, osmium, ruthenium, arsenic, tin. The method is based on the analysis of small spots (diameter of 3 and 8 mm) rather than of large areas, which gives the chance to detect even small inclusions or heterogeneities.



Gold-flitters washed out from prehistorically mined debris excavated in 4th and early rd mill. BC, Foto: A. Omiadze, Tblissi

Fire Assaying

Gold bearing lead ingot ready for cupellation to extract the gold-content. B After cupellation in a porous MgO-crucible thelead oxide is absorbed by the crucible (which is now of yellowish colour), and a gold prill is left. The gold veins contain 6-7 g/t gold, and the backfillings of Sakdrisi 4-6 g/t, in one case 22 g/t. The fire assay was performed by Dr. W. Homann, Dortmund and Sergo Nadareishvili, Foto: Sergo Nadareishvili, Tbilissi.

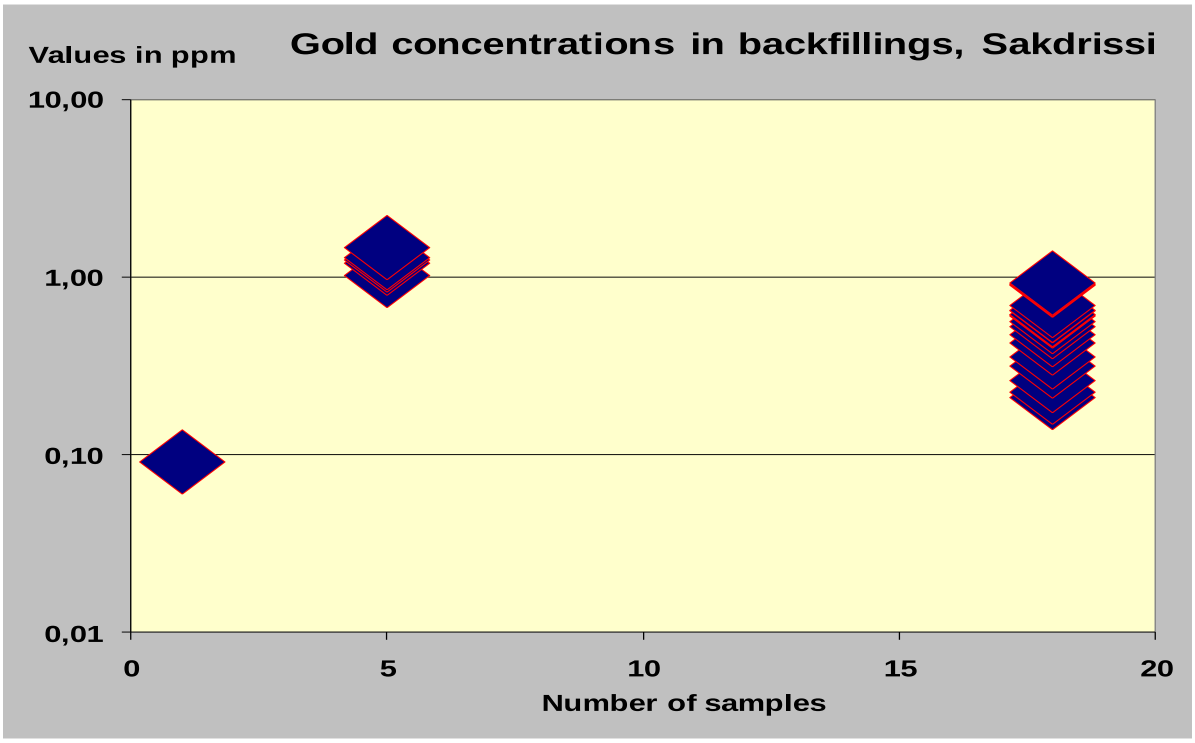
To provide evidence if Sakdrisi actually was a gold mine, and to determine gold concentrations in the ore veins exploited and the gold concentrations left by the ancients we applied one of the oldest analytical processes was applied: fire assaying. This method is still applied even today in a modern version to determine noble metals in large quantities of noble metal containing ores. Fire assaying comprises several steps:

1. Weighing of the original gold or silver bearing sample. Grinding the material, washing a representative aliquot.
2. Roasting of the concentrate to remove sulphide concentrations of ores.
3. Smelting of a concentrate together with lead or lead containing chemical agents and by adding borax ($Na_2B_4O_7 \cdot 10H_2O$). Noble metals will be collected in the lead ingot formed during the smelt (Fig. 9A).
4. The lead ingot will be oxidized by cupellation to lead oxide while the noble metal remains in the metallic state and separates from lead oxide. This will be absorbed by the porous cupel in the liquid state (Fig. 9B).
5. Weighing the noble metal prill. Calculate metal content of the original sample.

We took a channel sample of 175 kg from the gold bearing hydrothermal vein inside the mine of Sakdrisi, and we treated more than 600 kg of backfillings (29 samples) and samples from the nearby Kura-Araxes settlement of Dzedzwebi for fire assaying to get an idea about the yield of the ancient miners. The fire assaying was performed by Dr. Wolfgang Homann, Dortmund

Underground ore deposits have been investigated in the area of the prehistoric mining: according to the prehistoric mining traces it is apparent that most parts of the ore body had been exploited in the late 4th and early 3rd mill.: only small remnants of the original ore body have been reserved: this means that only a minimum of the original ore-content has survived: it must have been originally richer in grade and quality. Therefore we may conclude that Au-contents originally also must have

been higher. One may ask how the prehistoric miners could understand the grade of the ore or the Au-content specifically? During our excavations between 2005 and 2011 we detected installation nearby the ancient entrances that allowed them to test the ores: fine-milling stones were deposite side by side of a water cistern: By easy concentrating of the ores by crushing, milling and washing them enabled them to observe the quality of the ore: although the ore of Sakdrissi is fine grained it can be easily be seen after sieving and washing the ore-concentrate (experimental archaeology did prove the technical steps in much detail!).
By comparing the averages of the Au-contents of the prehistoric backfillings and the average values of Au in prehistorically mined ore-veins it is possible to calculate a minimum average of Au that had been mined in the 4th and early 3rd millennium BC. The original content could easily have been larger as the highest grades never left insid; recent explorations did even prove ore contents between 50 and 500 g/t! Geochemical characterization of the ore-veins from the prehistorically mined ore-veins 1/1, ½ and 1/3 underground (Stöllner et al. 2010). The average of Au shows a content of 15 g/t which is the lowest value one can expect! (Tab. 4). In the backfillings the fire-assying did produce Au-contents of around 1g/t: this can be regarded as a minimum that had been left by the prehistoric miners within the deposit. Our investigations did prove a minimum average of 15g/t, so 14 g/t once had been taken out: But this only is a minimum! According to the whole deposit an average yield of 25g/t a ton seems reasonable. By calculating the mined space and the volume of the ore body we are able to give an average of tons once had been mined: conservatively speaking a minimum of 6000 t can be estimated: this would give 90 kg of gold mined in prehistory as a minimum, 150 kg seems reasonable. Taking into account that the mine was operated around 300 to 400 years a yearly amount of 0,5 kg of pure gold can be argued. When comparing a yearly yield of 3 to 4 g of gold that a gold panner had in the gold-rivers in Europe in the 18th century this seems a lot!

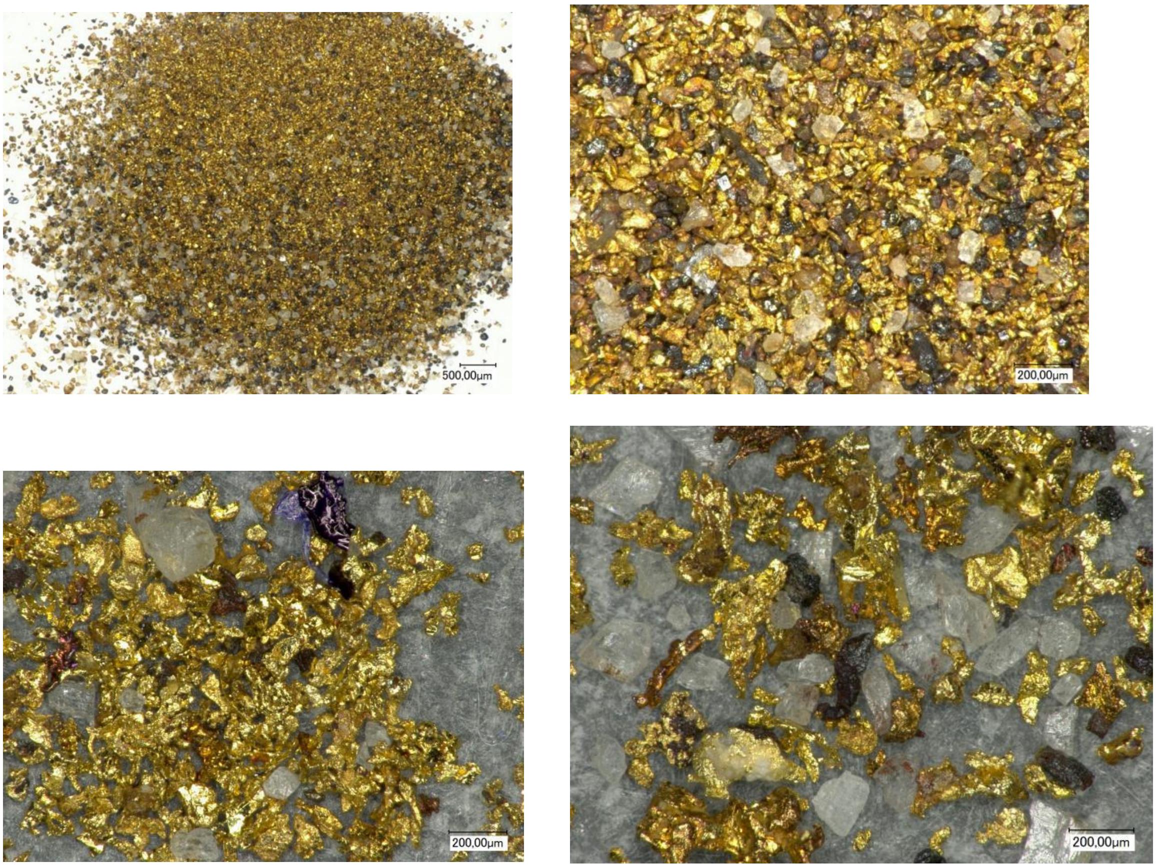


The gold grades of prehistoric backfillings (mining debris) provide an idea what the prehistoric miners left behind. A average grade of 1 g/t is much smaller as the minimum average of the deposit (around 4-5 g/t) and the minimum average measured for the prehistorically exploited ore veins (15 g/t)

Enrichment of Gold flitters by washing of ore-concentrates

In order to win natural gold from Sakdrissi we have washed approximately 250 kg ores that were previously milled. Gold-washing pans and flute-gates/locks were used to enrich and wash the ore. The gold of Sakdrissi is visible as fine grained flitter within the washed ore concentrate. In six samples the ore-flitters were isolated and separated to be investigated geochemically and by SC-ICP-MS-Spectrometry and MC-ICP-MS-Spectrometry (trace elements and lead isotopes).

The gold flitters from the ore-deposits of the prehistoric mine of Sakdrissi can be seen best on sample Geo-28/15.



The gold flitters of Sakdrissi (Geo-28/15); microscopic fotos: M. Jansen, Bochum

Analytical Tables:

Tab. 1: Underground mining debris (4th-early 3rd mill. BC): Gold content (Bochum laboratory)

Underground mining debris (4th-early 3rd mill. BC)	**Au in ppm**
24011	0,64
24011c2	1,26
24011d	0,35
24012	0,09
24017	4,45
24030	0,21
24035	0,52
24040	0,26
24048	0,90
24050	1,24
24051	0,42
24054	0,65
24056	0,91
24057	0,60
24058	6,93
24059	1,28
24062	0,69
24063	0,22
24064	1,02
24065	0,92
24066	0,56
24068	0,61
24069	0,47
24070	1,46
Average	**1,06**

Tab.2: Surface near mining debris (4th-early 3rd mill. BC): Gold content (Bochum laboratory)

mining debris (4th-early 3rd mill. BC) surface near mining area	**Au in ppm**
10080-4, Fd.-Nr. 10193	22,0
10182, Fd.-Nr. 10194	8,75
10196, Fd.-Nr. 10586	0,84

Tab. 3: Underground ore-content (4th-early 3rd mill. BC): Gold content (Bochum laboratory)

Ore near mine 1	**Au in ppm**
GEO-28/15h	6,89
GEO-28/15i	5,78

Tab. 4: Surface near ores (not mined in prehistoric times: too poor?): Gold content (data Prof. Dr. M. Tschochonelidze, Tblissi)

	Sample NN	Au g/t
1	319801	0,1
2	319802	15
3	319803	1,5
4	319804	0,3
5	319805	4,5
6	319806	5,2
7	319807	1,0
8	319808	0,3
9	319809	1,2
10	319810	0,3
11	319811	6,3
12	319812	0,1
13	319813	0,7
14	319814	1,1
15	319815	0,6
16	319816	3,2
17	319817	0,3
18	319818	1,0
19	319819	0,3
20	319820	9,9
21	319821	0,6
22	319822	12
23	319823	1,0
24	319824	2,2
25	319825	4,2
26	319826	0,2
27	319827	3,5
28	319828	7,9
29	319829	53
30	319830	1,0
31	319831	0,4
32	319832	0,7
33	319833	13
Average		4,6

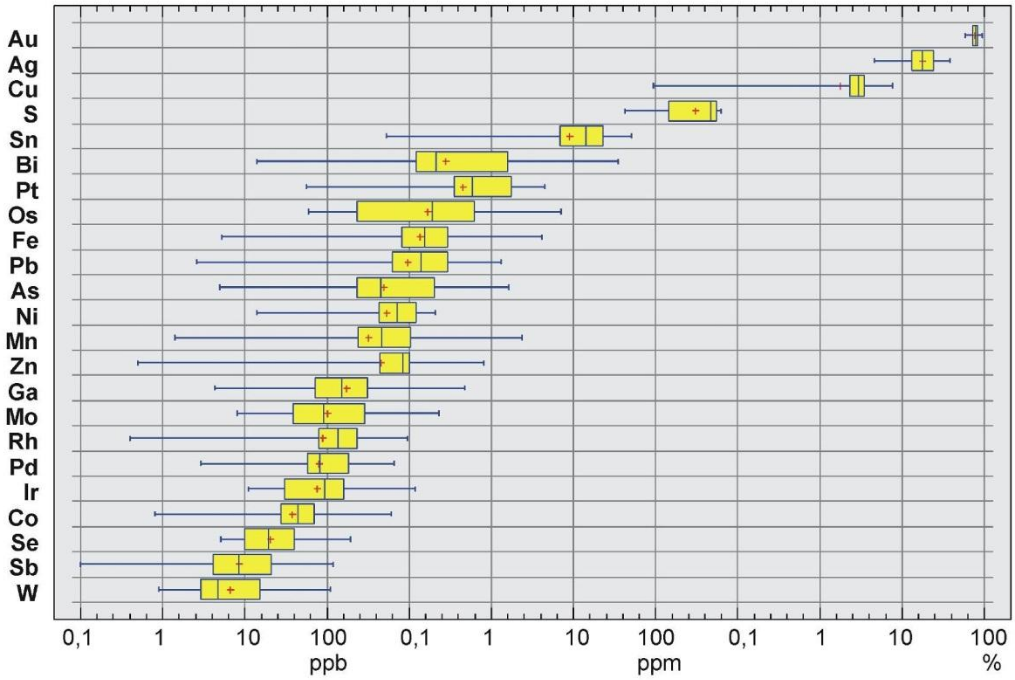
Soil samples Dzedzwebi	Au in ppm
Dzedzwebi II/3, house 2 (2009)	0,61
Dzedzwebi Haus 1	0,31

Tab. 8 Soil samples in Balitshi-Dzedzvebi clearly mark the working of gold containing sands, as there is no gold in soils and in volcanic rocks (basalts)

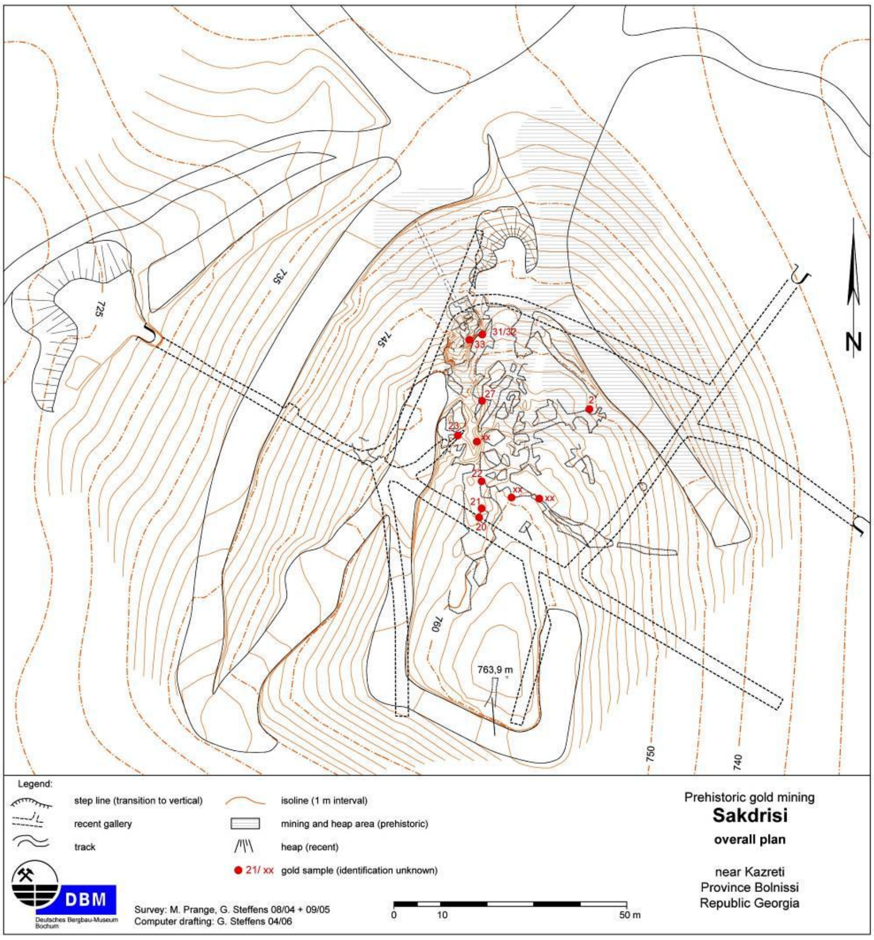
Sample-N	Remarks	LOCATION	Au	Ag	Cu	Ba	Sn	Cd	Pd	Bal	Mo	Nb	Zr	Sr	Rb	Bi	As
24036	prehistoric mining debris	mine Sak 1/2	0,017	< LOD	0,053	< LOD	< LOD	< LOD	< LOD	67,722	0,002	< LOD	< LOD	0,004	< LOD	< LOD	< LOD
1	ore vein, sample crushed/milled	mine Sak 1/3	0,003	0,005	0,047	0,101	< LOD	< LOD	< LOD	50,253	< LOD	< LOD	0,005	0,004	< LOD	< LOD	< LOD
6	ore vein, direct measuring	mine Sak 1/3	0,051	< LOD	0,052	0,05	< LOD	< LOD	< LOD	66,187	< LOD	< LOD	< LOD	< LOD	< LOD	0,005	< LOD
6	ore vein, direct measuring	mine Sak 1/3	0,041	< LOD	0,011	0,008	< LOD	< LOD	< LOD	68,59	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
9	ore vein, direct measuring	mine Sak 1/2	0,017	0,022	0,284	< LOD	< LOD	< LOD	< LOD	53,27	0,016	< LOD	< LOD	0,007	< LOD	0,007	0,007
9	ore vein, direct measuring	mine Sak 1/2	0,023	0,008	0,113	0,075	< LOD	< LOD	< LOD	44,883	0,004	< LOD	0,005	0,005	< LOD	0,003	< LOD
9	ore vein, sample crushed/milled	mine Sak 1/2	0,014	0,01	0,109	0,074	< LOD	< LOD	< LOD	42,09	0,004	< LOD	0,006	0,006	< LOD	0,003	0,002
9	ore vein, sample crushed/milled	mine Sak 1/2	0,018	0,007	0,107	0,055	< LOD	< LOD	< LOD	48,026	0,003	< LOD	0,005	0,005	< LOD	0,003	0,003
10	ore vein, direct measuring	working edge, western vein	0,013	< LOD	0,061	< LOD	< LOD	< LOD	< LOD	66,758	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
10	ore vein, direct measuring	working edge, western vein	0,008	< LOD	0,082	< LOD	< LOD	< LOD	< LOD	70,133	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
12	ore vein, direct measuring	mine 1_2, N-extension,	0,021	< LOD	0,124	< LOD	< LOD	< LOD	< LOD	62,402	< LOD	< LOD	< LOD	0,003	< LOD	0,009	< LOD
12	ore vein, sample crushed/milled	mine 1_2, N-extension,	0,012	0,012	0,157	0,026	< LOD	< LOD	< LOD	41,149	< LOD	< LOD	< LOD	0,003	< LOD	0,005	< LOD
12	ore vein, sample crushed/milled	mine 1_2, N-extension,	0,015	0,017	0,19	0,046	< LOD	< LOD	< LOD	33,805	0,003	< LOD	< LOD	0,004	< LOD	0,008	< LOD
12	ore vein, sample crushed/milled	mine 1_2, N-extension,	0,014	0,017	0,182	0,048	< LOD	< LOD	< LOD	37,905	0,002	< LOD	< LOD	0,003	< LOD	0,007	< LOD
10	ore vein, sample crushed/milled	working edge, western vein	0,009	0,008	0,078	0,055	< LOD	< LOD	< LOD	45,341	0,002	< LOD	< LOD	0,003	< LOD	0,003	< LOD
10	ore vein, sample crushed/milled	working edge, western vein	0,014	0,004	0,071	0,05	< LOD	< LOD	< LOD	54,089	< LOD	< LOD	< LOD	0,003	< LOD	< LOD	< LOD
10	ore vein, sample crushed/milled	working edge, western vein	0,011	0,008	0,077	0,044	< LOD	< LOD	< LOD	47,102	0,002	< LOD	< LOD	0,003	< LOD	0,002	< LOD
15	ore vein, direct measuring	5th vein east of mine 1_7	0,012	< LOD	0,032	0,018	< LOD	< LOD	< LOD	73,135	0,002	< LOD	< LOD	0,003	< LOD	< LOD	0,006
16	ore vein, direct measuring	mine 1_1_abovo middle	0,013	< LOD	0,076	0,011	< LOD	< LOD	< LOD	66,993	0,003	< LOD	< LOD	0,003	< LOD	0,002	< LOD
16	ore vein, sample crushed/milled	mine 1_1_abovo middle	0,008	0,013	0,103	0,064	0,005	< LOD	< LOD	52,615	0,003	< LOD	0,003	0,008	< LOD	0,005	0,003
16	ore vein, sample crushed/milled	mine 1_1_abovo middle	0,005	0,012	0,114	0,073	< LOD	< LOD	< LOD	51,788	0,004	< LOD	0,003	0,008	< LOD	0,006	< LOD
16	ore vein, sample crushed/milled	mine 1_1_abovo middle	0,007	< LOD	0,11	0,054	< LOD	< LOD	< LOD	54,528	0,004	< LOD	0,003	0,008	< LOD	0,006	0,003
6_2	ore vein, sample crushed/milled	mine 1_3, eastern vein	0,006	0,006	0,049	0,194	< LOD	< LOD	< LOD	49,23	< LOD	< LOD	< LOD	0,005	< LOD	0,002	0,003
			0,015	0,006	0,095												

Se	Pb	W	Zn	Ni	Co	Fe	Mn	Cr	V	Ti	Ca	K	Sb	Cl	S	Al	P	Si	Mg
< LOD	0,004	< LOD	0,003	< LOD	< LOD	5,14	0,027	0,004	< LOD	0,021	1,505	0,271	< LOD	0,042	0,059	0,917	0,081	24,038	< LOD
< LOD	0,002	< LOD	0,003	< LOD	< LOD	6,607	< LOD	0,004	0,007	0,094	0,609	0,637	< LOD	0,034	0,174	3,114	0,083	38,198	< LOD
< LOD	0,003	< LOD	0,003	< LOD	< LOD	8,665	< LOD	0,005	0,003	0,023	0,073	0,114	< LOD	0,044	0,109	0,41	< LOD	24,137	< LOD
< LOD	< LOD	< LOD	< LOD	< LOD	< LOD	0,968	0,03	0,008	0,003	0,031	0,08	0,189	< LOD	0,053	0,166	0,377	< LOD	29,351	< LOD
0,009	< LOD	< LOD	0,012	< LOD	< LOD	35,624	< LOD	0,011	0,003	0,016	0,98	0,092	< LOD	0,127	1,152	< LOD	< LOD	8,288	< LOD
0,003	0,01	< LOD	0,005	< LOD	< LOD	9,102	< LOD	0,007	0,006	0,099	2,416	0,842	< LOD	0,069	3,081	3,847	< LOD	35,34	< LOD
0,004	0,011	< LOD	0,004	< LOD	< LOD	9,511	< LOD	0,007	0,005	0,102	2,291	0,825	< LOD	0,061	3,322	4,702	< LOD	36,791	< LOD
0,004	0,009	< LOD	0,005	< LOD	< LOD	8,877	< LOD	0,005	0,004	0,081	2,089	0,795	< LOD	0,056	2,662	3,906	< LOD	33,224	< LOD
< LOD	< LOD	< LOD	0,003	< LOD	< LOD	5,967	< LOD	0,006	< LOD	0,032	0,586	0,413	< LOD	0,049	1,023	0,95	< LOD	24,042	< LOD
0,002	< LOD	< LOD	0,004	< LOD	< LOD	6,699	< LOD	0,006	0,002	0,043	0,354	0,688	< LOD	0,052	0,403	1,538	< LOD	19,944	< LOD
0,007	0,007	< LOD	0,007	< LOD	< LOD	22,101	< LOD	0,007	0,002	0,016	0,744	0,179	< LOD	0,064	1,139	0,856	< LOD	12,279	< LOD
0,003	0,009	< LOD	0,008	0,007	< LOD	18,835	< LOD	0,007	0,005	0,027	0,26	0,301	< LOD	0,047	0,664	2,98	< LOD	35,445	< LOD
0,004	0,017	< LOD	0,009	0,01	< LOD	21,774	< LOD	0,011	0,005	0,033	0,342	0,348	< LOD	0,052	0,805	3,77	< LOD	38,697	< LOD
0,004	0,014	< LOD	0,009	< LOD	< LOD	21,089	< LOD	0,008	0,004	0,032	0,276	0,273	< LOD	0,042	0,687	3,114	< LOD	36,247	< LOD
< LOD	0,004	< LOD	0,004	< LOD	< LOD	7,174	< LOD	0,007	0,004	0,065	0,62	0,407	< LOD	0,021	0,656	3,082	0,043	42,394	< LOD
< LOD	0,002	< LOD	0,004	< LOD	< LOD	6,804	< LOD	0,002	0,004	0,059	0,494	0,316	< LOD	0,022	0,493	2,381	< LOD	35,146	< LOD
< LOD	0,004	< LOD	0,004	0,005	< LOD	7,17	< LOD	0,006	0,005	0,063	0,634	0,387	< LOD	0,027	0,657	2,921	< LOD	40,84	< LOD
< LOD	0,007	< LOD	0,004	< LOD	< LOD	5,464	< LOD	0,003	0,003	0,025	0,026	0,065	< LOD	0,034	0,125	0,193	< LOD	20,814	< LOD
< LOD	0,004	< LOD	0,005	< LOD	< LOD	13,271	< LOD	0,005	0,002	0,032	0,934	0,498	< LOD	0,053	0,17	2,134	0,03	15,692	< LOD
0,003	0,013	< LOD	0,007	0,008	< LOD	18,269	< LOD	0,008	0,005	0,057	0,866	0,474	< LOD	0,041	0,272	3,294	< LOD	23,843	< LOD
0,003	0,018	< LOD	0,006	< LOD	< LOD	20,594	< LOD	0,008	0,004	0,051	0,872	0,343	< LOD	0,045	0,24	2,863	< LOD	22,922	< LOD
0,004	0,017	< LOD	0,007	< LOD	< LOD	19,953	< LOD	0,006	0,004	0,054	0,891	0,406	< LOD	0,055	0,245	2,199	< LOD	21,41	< LOD
< LOD	0,007	< LOD	0,003	< LOD	< LOD	7,393	< LOD	0,006	0,012	0,1	0,32	0,269	< LOD	0,012	0,281	1,738	< LOD	40,351	< LOD

Tab. 5: Geochemical characterization of the ore-veins from the prehistorically mined ore-veins 1/1, ½ and 1/3 underground (Stöllner et al. 2010). The average of Au shows a content of 15 g/t which is the lowest value one can expect!

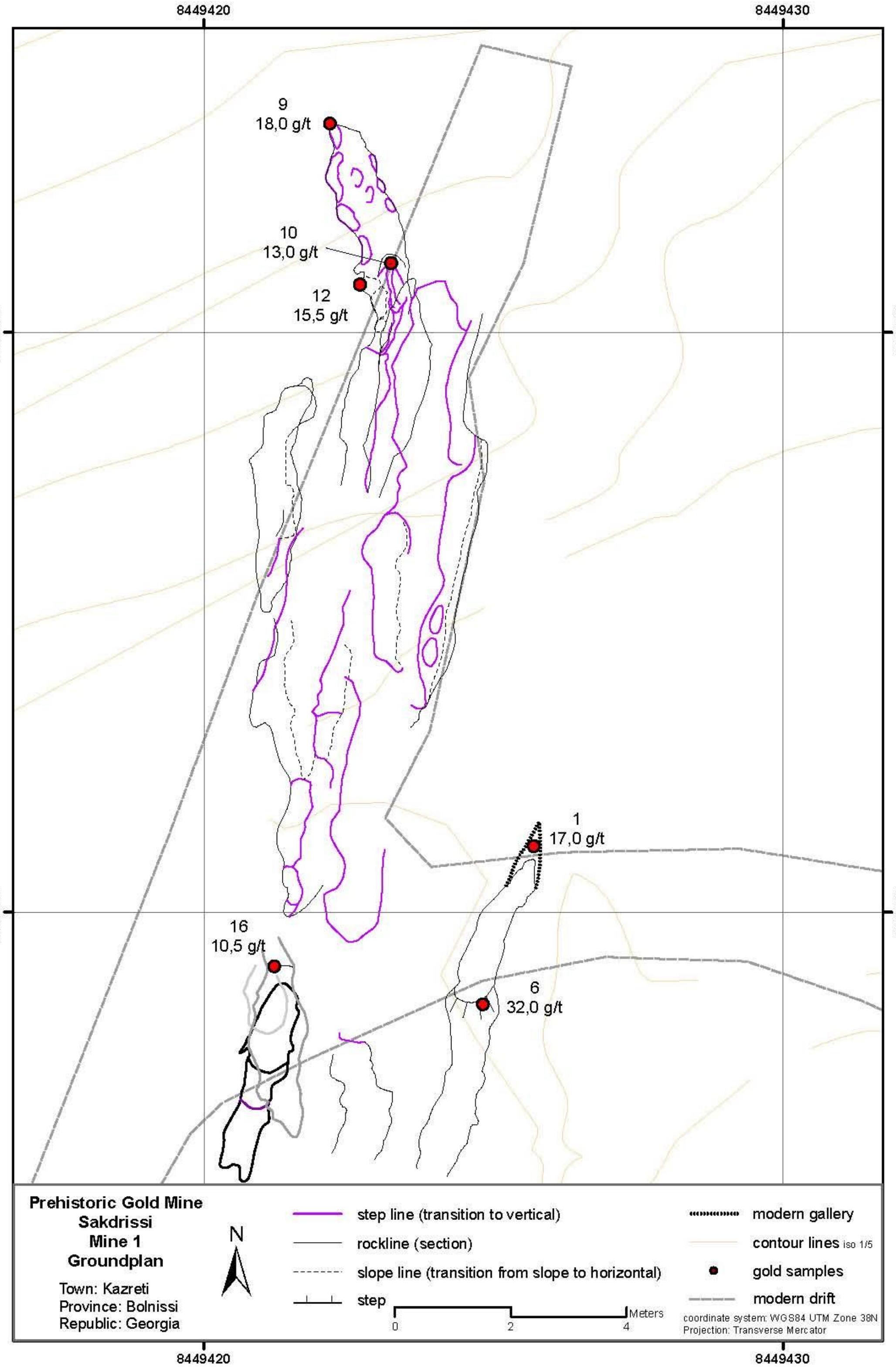


Tab. 6: Geochemical characterization of Sakdrissi gold ores in box-whisker-plots (Geo-28/15).



Sampling points M. Tschochonolidze (Tab. 3) at the Gold mine of Sakdrissi (surface)

Sampling gold containing ores underground in Sakdrissi by Dr. A. Courcier (Lyon/Bochum) and Prof. Dr. Th. Stöllner (Bochum), right: ore crushing and milling; left: PXRF-measuring.



Sampling points T. Stöllner (Tab. 4) at the Gold mine of Sakdrissi (below ground, prehistoric mining)

Prehistoric Gold exploitation: Fire-setting and the technical solution of gold mining

The gold-mining process documented in the Mashavera-valley (Stöllner & Gambashidze 2011; Stöllner et al. 2012) consisted of several steps and was well organized. In many steps it can be compared with techniques described for antique and younger periods (Agricola 1556; see also Tylecote 1987; Bachmann 1999; Craddock 2000).

1. The ore-mining was carried out by help of fire-setting and extraction work by help of a typical chalcolithic tool set: hammer-stone often adapted to the very narrow veins as well as bone and antler-chisels were combined to extract gold bearing host rocks and pure quartzite veins. The gold almost was invisible but by testing the gold-content the grad of the ore was determined (see above).

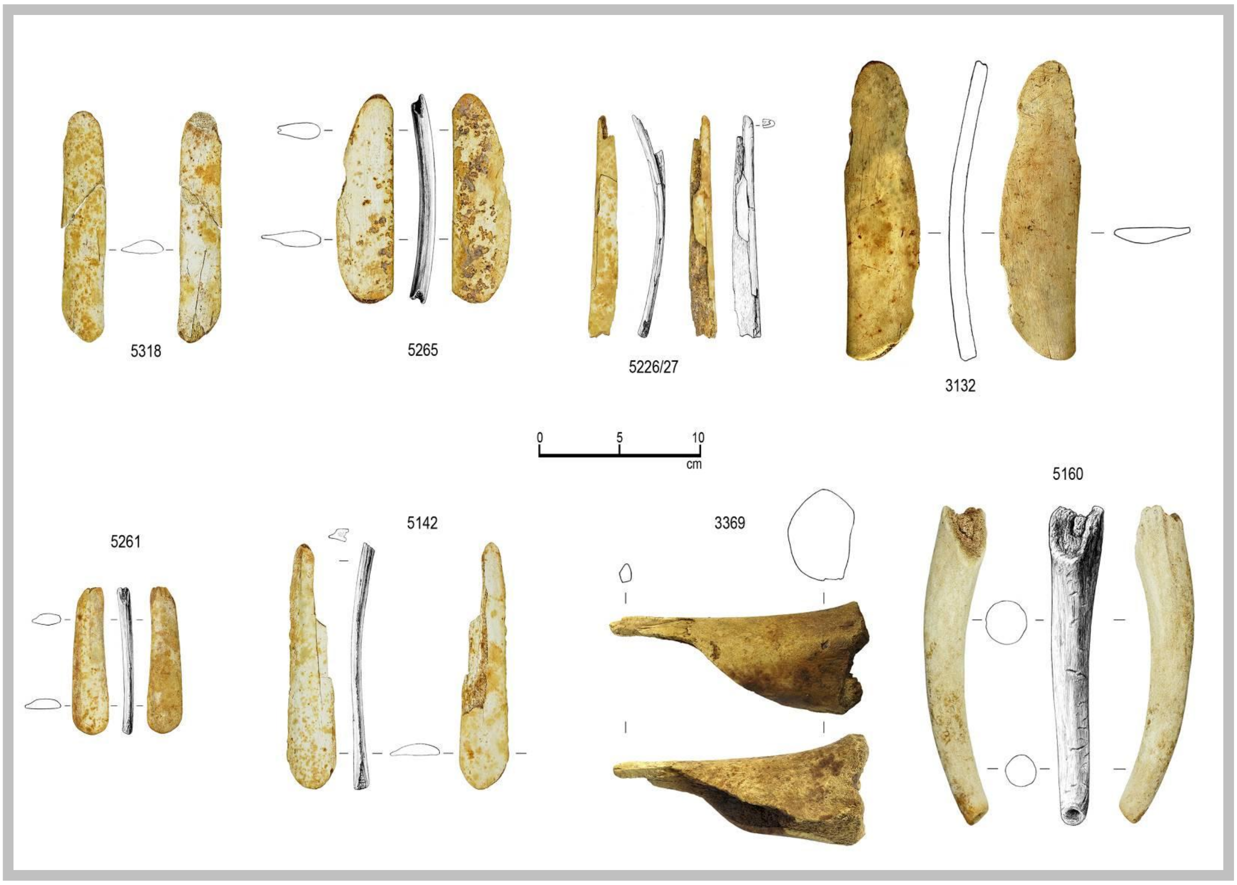
Fire-setting at the mining gallery 1/2; at the front part a gold grade of 17g/t have been measured. The soot of the fire-setting is clearly visable at the roof of the gallery. Typical for the fire-setting traces are the rounded walls, that had been overworked by stone-hammer working. The front part has no soot as it was reworked with stone hammers during the last working step, Foto: Th. Stöllner, Bochum

2. Gold-ore testing was presumably undertaken at the site, both by milling crushed ores and by separating them by simple gold washing. This method is most effective if an empirical test is proposed.

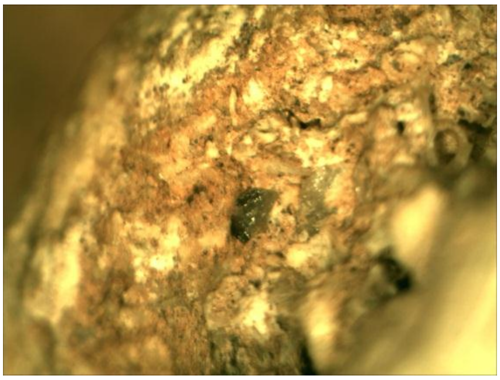
Sakdrissi, Mine A, 1: Milling and grinding tools, concentrated in a mining dump; right: mining debris, backfilled in mine 1/2 underground; several layers consisted of ore that was crushed; measuring did prove the Au content between 0,3 and 15 ppm (g/t). The original contents must have exceeded this grade! (Foto/Maps: DBM, Bochum)

3. Hand-sorting and crushing of gold ores were the main steps of ore-beneficiation that can be evidenced at the gold mine of Sakdrissi. A first sorting and parting was done even underground where simple handheld hammers and dimples in the rock (as mortars) might have served as devices. The grade of the refilled beneficiation debris – crushed down to sizes of about 3 mm to 2 cm – still had around 1 ppm of gold thus indicating that something between 100/70 ppm and 1 ppm of gold (as observed in some of the vein) was taken out (see above the minimum averages!)

Grinding and milling plates found in the above mentioned dump in Sakdrissi mine A, 1, Foto: T. Rabsilber, Bochum

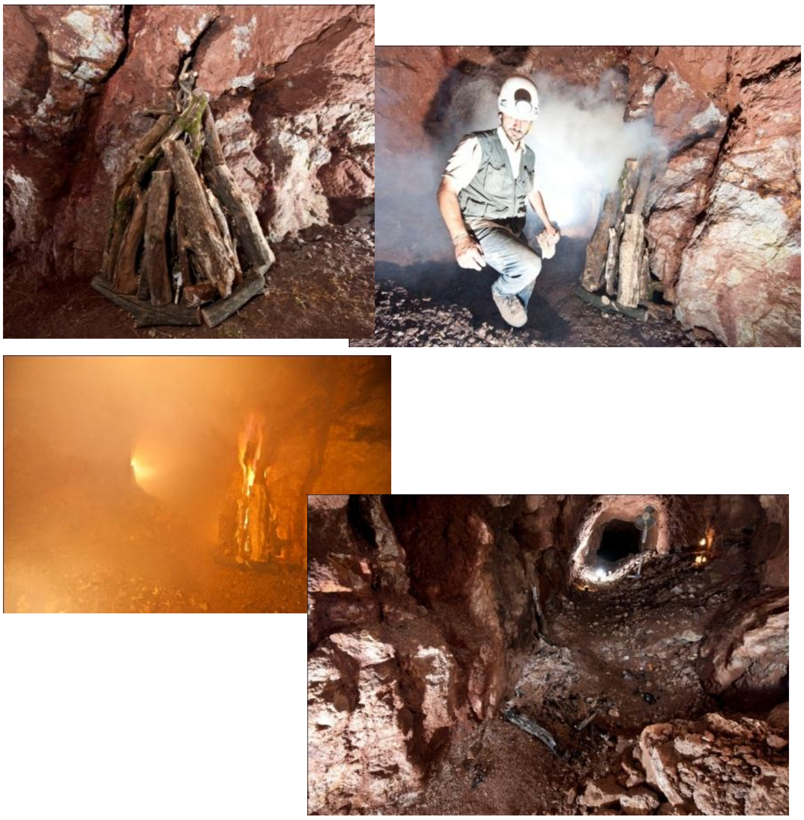


Bone tools used for scraping and cleaning the surface of the ore-veins after fire-setting, Foto: T. Rabsilber, Bochum



Rib scrapers 3132 (left) and 5265 (right) with remnants of typical Sakdrissi ore: reddish hematite, some charcoal and quartz, Fotos: Keti Tamasashvili

Fire-setting 1/2011
Fotos Th. Stöllner



Underground fire-setting 2011:
The experiment does prove the possibility fire-setting underground in Sakdrissi; the method is well proven e.g. by G. Agricola 1556, Fotos Th. Stöllner

Fire-setting experiment 2 that produced 101 kg of ore: Usage of hammer stones and antler-picks after the fire-burning. Below: Tool-kit of the fire-setting-experiments





Ore-grinding and measuring the yield

Fotos K. Stange, Th. Stöllner

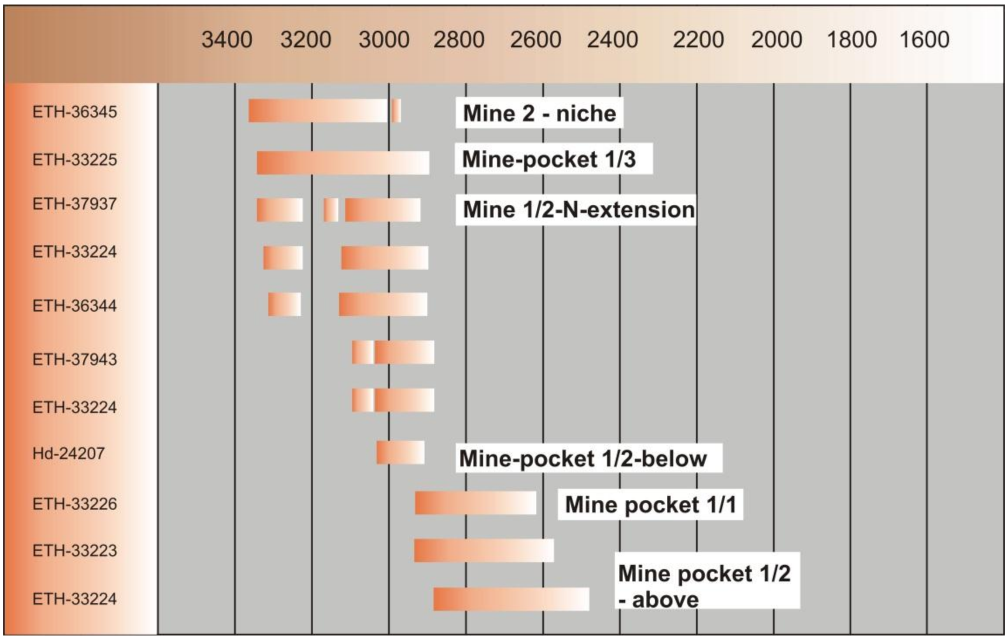


Washing the gold concentrate, Fotos K. Stange

In 2011 extensive fire-setting experiments were carried out in collaboration with Dr. Simon Timberlake (Cambridge) and Brenda Craddock. We worked according to the techniques documented in Sakdrissi by using oak wood for fire-setting (the burned wood and charcoal was found in the prehistoric mining debris) and hafted hammer-stones and stone tools that we prepared of river pebbles (mainly andesite), raw hide and oak handles and hazelnut binding. Four experiments were carried out so far; one of them even underground to test the oxygen and air-circulation. Each of the experiments and fire-sets took several hours and produced ore that finally had been crushed, milled and panned to test the Au-grade. It was interesting to learn about the durability of the stone tools which were made according to hafting-evidences from Bronze Age Mining found in Britain, Austria and Central Asia. Besides the hammer-stones also picks made of deer antlers were in use! Remnants of those also werediscovered during the excavations in the early Bronze Age mining debris in Sakdrissi. The tool-kit did perfectly work: after burning the ore-lode it only took us half to one hour to produce an ore volume between 48 and 186 kg; certainly it worked better near the surface than 25 m below ground (see Tab. 7).

	Feuersetzen 1	Feuersetzen 2	Feuersetzen 3
Holzmenge	**214 kg**	**48 kg**	**84 kg**
Brenndauer	3 h	2 h	+ 3h
Schlägelarbeit	1h	0,5h	0,5h
Wasserbruch	9,2 kg	-	-
Exfoliation	78,09	14,7	12,2
Schlägelbruch	98,7	86,5	32,8
Gesamtgesteinsmenge	**186**	**101**	**45**
Holz-Gesteinsausbeute Verhältnis	**1:0,87**	**1:2,1**	**1:0,54**

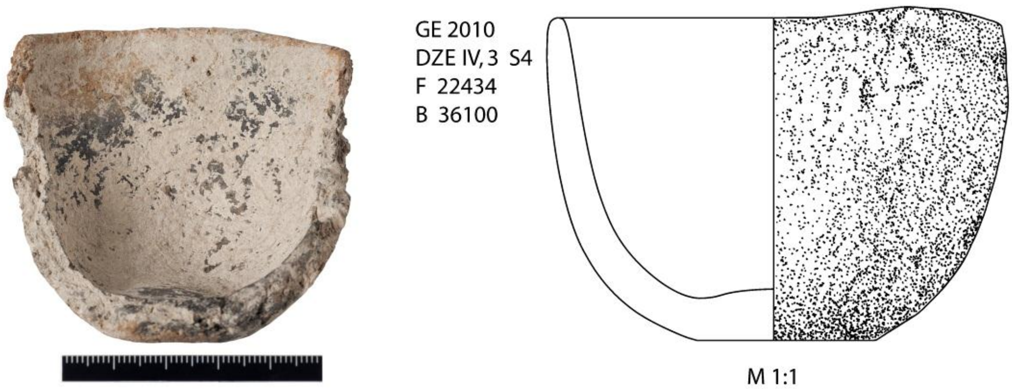
Tab. 7: Ratio of wood used, ore produced and time that was consumed (2-3 h of wood burning, 0,5 to 1 h of hammering work) of three fire-setting experiments carried out 2011.



Prehistoric 14C-Radiocarbon-dating performed by Laboratories in Zurich and Heidelberg prove that Sakdrissi is the oldest gold mine in the World, the orange stripes symbolize the 2σ-statistical ranges of the dates

4. Once the ore was crushed and sorted most of the high quality gold bearing coarse sands were transported where this material was fine grinded. The results of house 3/2009 made apparent that this milling of ore was done in large workshop rooms. According to experimental results from 2011 the milling should not be to fine not to lose the finer grained gold flakes being finely disseminated into the ores. Having found also gold contents of about 1 ppm in this workshop room (and being considerably elevated in comparison to the surrounding) proves the workshop and milling theory as also the abundance of mill-stone does in general.

5. If finally the sands got washed and fire-assayed in crucibles is till now a likely but unproven hypothesis. This needs further fieldwork and perhaps the one or another “lucky” finding of a gold crucible in the workshop areas of the nearby Balitshi-Dzedzvebi settlement. 2010 a crucible was found in a pit of the early 4th millennium. The metallurgical crust of the crucible showed an slight enrichment of silver according to the silver content of the ore-deposit, while the copper is not enriched (Tab. below in comparison to Tab. 5)



Tiegel 22434	Ag [ppm]	As [ppm]	Zn [ppm]	Cu [ppm]	Ni [ppm]
außen	< LOD	20	80	50	60
innen_Messung1	80	< LOD	50	140	< LOD
innen_Messung2	140	< LOD	< LOD	130	< LOD

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