Chapter 10
Remote Sensing Study of the Ancient Jabali Silver Mines (Yemen): From Past to Present

Jean-Paul Deroin, Florian Téreygeol, and Jürgen Heckes

Abstract Archaeological research into the ancient Jabali silver mines in northern Yemen is a multidisciplinary project linking archaeologists, historians, and geologists, supported by remote satellite-based sensing. Mining companies are considering the development of the Jabali deposit for zinc ore. Some of the facilities, including a large open pit, will have a destructive impact on the old pits. Multispectral (Landsat TM, Terra ASTER, ALOS-AVNIR-2, etc.) and very high spatial resolution images such as QuickBird have been widely used for the geological setting and detail mapping of the different archaeological sites. The remote sensing data also provides a solid basis when it comes to detecting current operational sites.

Keywords Multispectral satellite image • Mining archaeology • Geoarchaeology • Yemen • Jabali

10.1 Introduction

Fundamentally, the objectives of mining archaeology are found to have antecedents in ancient works. As early as 1858, Louis Simonin, working in Tuscany, demonstrated the interest of a combined study of the ore deposits, the surficial

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and underground archaeological remains, and the old texts (Simonin 1858). However, mining archaeology is a relatively recent discipline. It deals with the study of ancient mines and their relation with the regional mineral economy. Within this context, however, shafts or entrances of the old networks are generally hidden under old mining dumps or colluvial deposits. Moreover, the underground remains are frequently filled up or flooded and some of them were intersected and damaged by nineteenth or early twentieth century works. These elements explain the limited interest of archaeologists in the old mines up until the 1970s.

Some disciplines can provide relevant data for mining archaeology. The Earth sciences, for instance, provide important data on the mineralogy of ore deposits, as well as on the overall geological setting. More recently, scientific analytical methods such as geochemistry have provided important information about the chemical composition of ore, slags, and artifacts, allowing archaeologists to built correlations or identify provenance. Although mining archaeology is inherently transdisciplinary in nature, it has only taken limited advantage of the potential of remote sensing, particularly its recent developments in spatial and spectral properties.

The ancient silver mines of Jabali, Yemen, are located in a mountainous and arid area of the southern Arabian peninsula, approx. 75 km north-east of Sana'a (Fig. 10.1). The Jabali deposit is hosted by dolomitized platform carbonates located at the southwestern edge of the oil-producing Wadi al Jawf basin (Al-Ganad et al. 1994). Jabali is a Zn-Pb-Ag deposit grading approx. 9.2% zinc, 1.2% lead and 68 g/t silver. Whereas Jabali was a well-known medieval silver mine, it has currently been explored only for zinc-ore. The archaeological missions carried out in 2006 and 2008 incorporated an important geological aspect supported by remote-sensing techniques. The first objective of this approach was an improvement in the geological background of the site, favoured by well-expressed morphologies (Deroin et al. 2011). At the same time, it allowed the study of the whole mining site across approx. 100 km^2 resembling a field, where displacements are difficult and the relationship with the local inhabitants is not without complications. Further to an overview of the sole Jabali mining site, the goals of our study include the comparison of the techniques used in the medieval Islamic world and those known at the same period in western Europe. The similarity with the Carolingian site of Melle (Poitou, France) is clear, as far as chronology, geology, and mineralogy are concerned (Téreygeol 2001), whereas the cultural and climatic aspects are obviously quite different.

The chronology of the archaeological mining site has been outlined during various field missions. Two main exploitation phases have been identified. The first phase took place between the last century of the Jahiliyya or pre-Islamic period (sixth to seventh century AD) and the second century *anno hegirae* AH (eighth to ninth century AD). The second phase extended from the fourth to the sixth century AH (twelfth to fourteenth century AD).

This chronology is based on a combination of field observations, document analyses and laboratory measurements. It provides thoroughly new insights into Jabali, knowledge of which had previously been based mainly on the analysis of the *kitab al-jawharatayn al-'atiqatayn* (Toll 1968), a book written by the so-called al-Hamdani, an Arab philosopher from the tenth century AD.

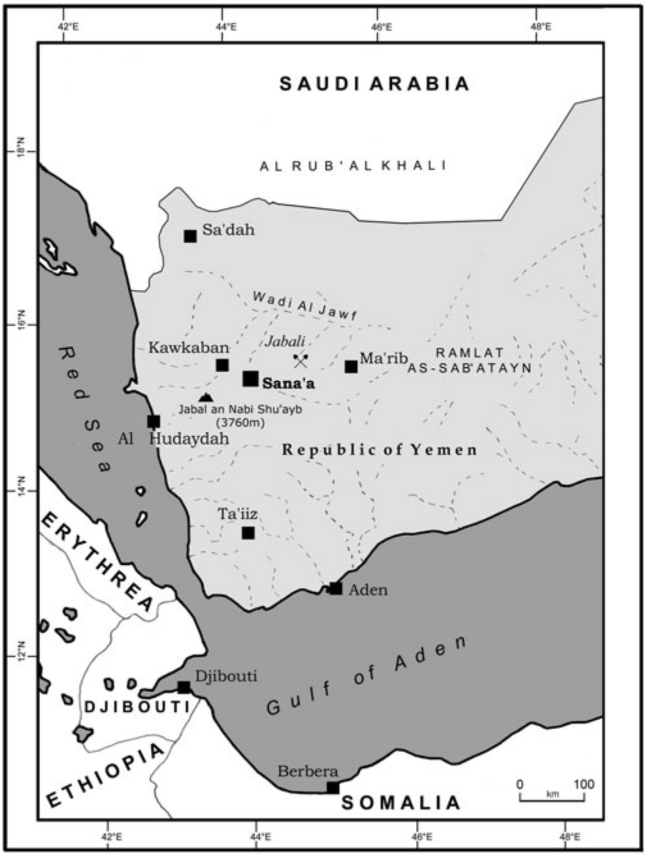

Fig. 10.1 Presentation of the study area

The text precisely describes the mines of *ar-Radrad*, which were related to the present Jabali site (Robin 1988). It defines the *terminus post quem* of the mining activities, because *al-Hamdani* indicates that silver exploitation suddenly ceased after the murder of Yu'firide Muhammad b. Yu'fir, a local sovereign in power in the year 270 AH (883–884 AD).

The miners of Persian origin were forced to flee during these troubled times. However, our observations indicate a significant renewal of the mining activities a few centuries later (twelfth to fourteenth century AD), during the Rasulide dynasty. During this revival, the mining site underwent considerable changes, including the dressing and crushing areas. Numismatic data combined with the archaeological data show a close link between this renewal and the coinage in Sana'a, the Rasulide capital city.

The history of the mining activities comprises alternating periods of exploitation and periods of relative abandonment. This also applies to the Jabali ore deposit, rediscovered by the French geological survey (BRGM) using archaeological information in the early 1980s (Christmann et al. 1983). It should be noted, that the rebirth of the site is due to a geochemical study. This study led the geologists to the old mining dumps and slag heaps, followed by the discovery of the ancient underground network and the orebody itself. The mining site of ar-Radrar, now Jabali, as a palimpsest, suffers a third exploitation phase with the project of a large open pit. Some of the planned facilities will have an irreparable impact on the mining and mineralurgical remains of the medieval pre-Islamic period.

10.2 Archaeological Remote Sensing

In archaeological remote sensing, the most conventional approach taken is the identification of crop marks from aerial photographs. Moreover, multispectral sensors can be used, particularly when dry conditions are encountered such as in arid or semi-arid regions. In the case of the remote Jabali area neither aerial photographs nor detailed topographic maps are available. However, satellite remote sensing data was available for the purpose of analyzing both the geological setting and the archaeological survey and prospection. Due to the arid conditions, interesting spectral domains such as medium or short wave infrareds are particularly relevant for geological mapping, whereas very high spatial resolution (less than 2 m) is needed for the identification of the archaeological remains. The analysis of remote-sensing data makes it possible to define and hierarchize areas of interest before the field missions, an approach that facilitates ground-based studies.

A relatively high spatial resolution is available with the declassified CORONA satellite images from the 1960s and now with the commercial remote-sensing imaging satellites such as Ikonos or QuickBird (Lasaponara and Masini 2005, 2006; Deroin et al. 2011). The comparison of very high and standard multispectral satellite imageries is rare (Schmid et al. 2008; Deroin et al. 2011).

We have used a wide range of satellite data. This data was mainly obtained by multispectral sensors (Landsat TM/ETM+, Terra-ASTER, ALOS-AVNIR-2), which are of particular interest because of their spectral response in the infrared range (700–2,400 nm) and in the red range (600–700 nm) and where iron caps or ferruginous soils are concerned (Table 10.1). Among this data, the Landsat ETM+ and ASTER

Table 10.1 Main satellite data used

Satellite	Sensor	GSD (m)	Spectral range (μm)	Period	Main data take
Landsat 1–5	MSS	80	0.50–1.10	1972–1992	7 scenes
Landsat 4–5	TM	30	0.45–2.35	Since 1982	26 scenes
Landsat 7	ETM+	30	0.45–2.35	Since 1999	18 scenes
Spot 1–3	PAN	10	0.50–0.73	1986–2009	April 21, 1995
Spot 5	PAN	5	0.50–0.73	Since 2002	August 29, 2002
EOS-Terra	ASTER	15 or 30 (SWIR)	0.52–2.36	Since 1999	10 scenes
ALOS	AVNIR-2	10	0.42–0.89	Since 2006	January 21, 2007 October 26, 2009
QuickBird	XS/P	0.61	0.45–0.90	since 2001	March 30, 2002

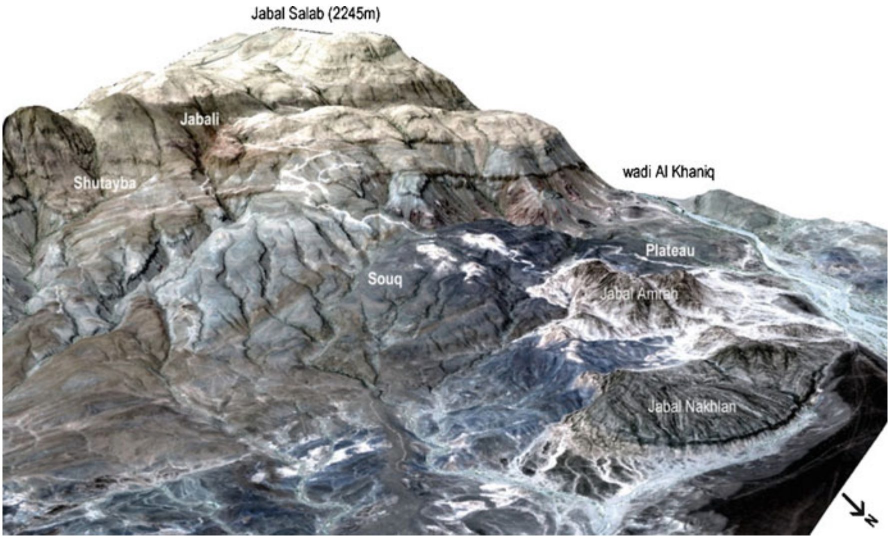

Fig. 10.2 3D view of the site. The QuickBird image acquired on 30 March 2002 is draped over the digital elevation model extracted from the 1:50,000 scale topographic map of Yemen. The area covered is about 15 km

data is of interest due to its spectral range extending toward the short wave infrareds (but with a medium spatial resolution), and that from QuickBird for the very high spatial resolution of this sensor. ALOS AVNIR-2 data, which has recently been made available, represents a good trade-off with its multispectral sensor (limited to the near infrared radiations) associated with a high resolution (10 m). This data was selected for the geological mapping of the area (Fig. 10.3). In addition to the set of image data, we also used digital elevation models (DEM). We built different DEMs using remote sensing data (Spot, SRTM, ASTER) and local topographic maps at 1:50,000. Satellite data could be draped over the DEM to obtain 3D-views.

Although relevant for geological mapping, the ground resolution from 10 to 30 m is clearly too rough for detailed field investigations required by the geoarchaeological survey. Therefore, we used the pansharpening of very high resolution multispectral images from QuickBird with a 0.67-m ground resolution. The QuickBird data draped over a high resolution DEM (5 m) allows quantification of the elementary watershed used for concentrating the water necessary to supply the ore-dressing areas (Fig. 10.2).

The work was complemented in the field by GPS measurements of the old canals and their connection with the ore-dressing areas. Some of them have been already destroyed, but it is expected that the satellite data could allow the detection of specific landforms.

The geological interpretation of this QuickBird data for the mine area results in a map representing 14 image facies corresponding to different limestone and dolomite facies (Deroin et al. 2006a). The latter were correlated with the lithologies as

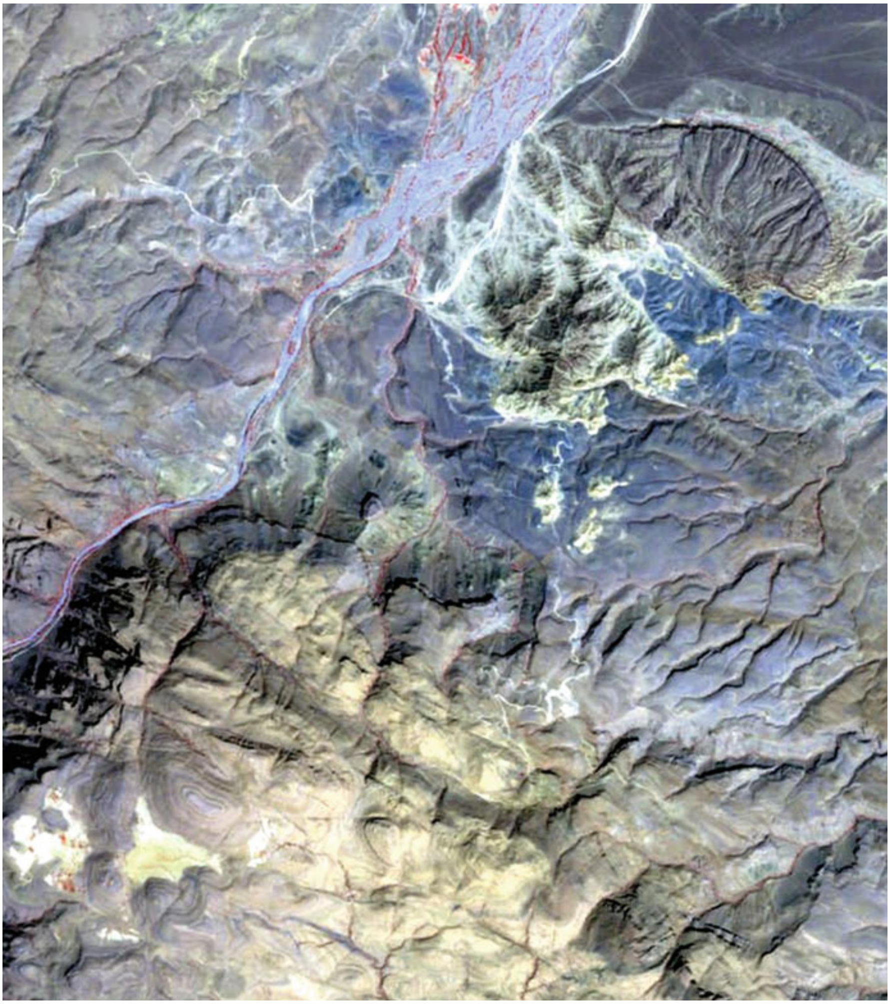

Fig. 10.3 ALOS colour composite. The image was acquired on January 21, 2007. *Red* near infrared range, *Green* red range, *Blue* blue range. The area covered is about 10 × 9 km

observed in the field, using their spectral and textural characteristics. Thus, different kinds of limestone and dolomite were distinguished. QuickBird-based data represents the key image for the mapping of the archaeological remains.

10.3 The Geology of the Mining Site

The geology of the Jabali area is clearly put into light when using the ALOS image at an intermediary scale (Figs. 10.3 and 10.4). Other investigations have shown the interest of very high resolution data (Deroin et al. 2006b). The Jabali Zn-Pb-Ag

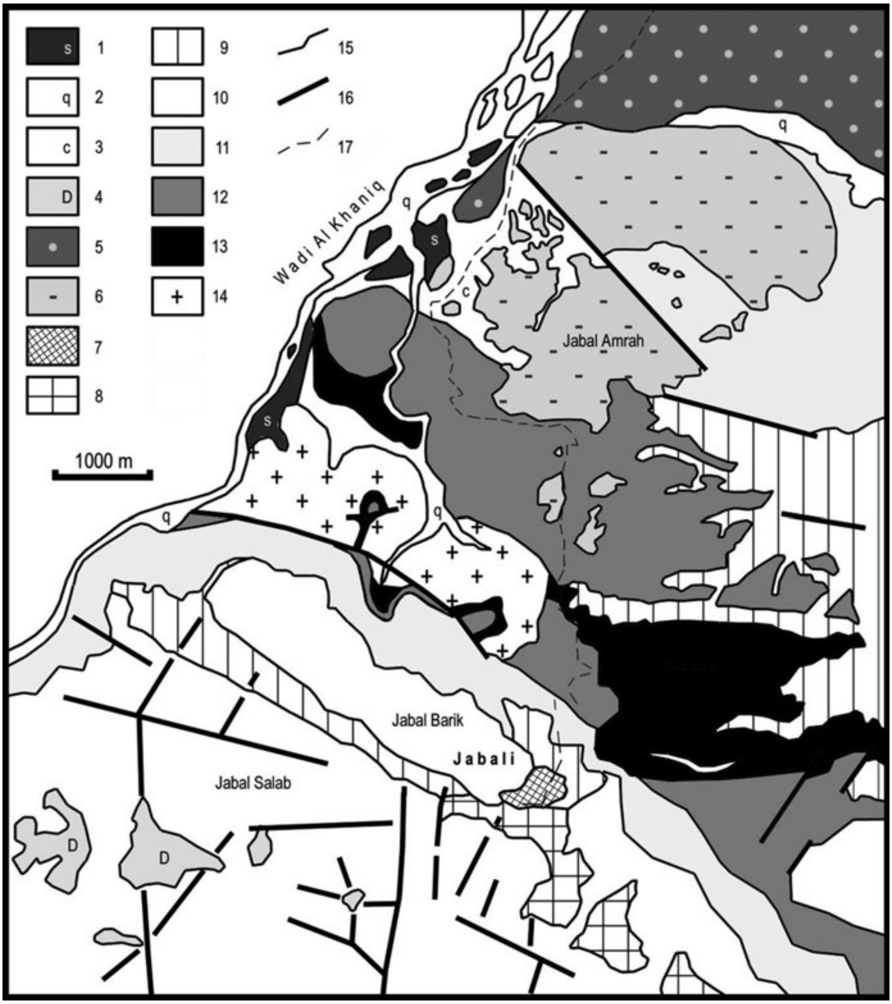

Fig. 10.4 Interpretation of the ALOS data represented in Fig. 10.3. *1* Main slag areas, *2* wadis deposits, *3* pediment deposits, *4* doline, *5* reg surface developed on marly facies, *6* volcanites, *7* Jabali iron cap, *8* late dedolomitization, *9* secondary dolomitization, *10* massive bioclastic limestone (U7) and black mudstone (U8), *11* greenish mudstone grading to limestone and marl (U6), *12* bryozoan calcarenite and oolitic limestone (U5), *13* sandstone, mudstone, and limestone (U1 to U4), *14* granite, *15* main lithological contour, *16* main fault, *17* track to the mine. NB. U1 to U8 (Triassic? to Upper Jurassic) are cited according to Al Ganad et al. (1994)

deposit lies within the topmost layers of the Amran Formation, which was deposited during a marine transgression that reached its maximum in the Late Oxfordian-Early Kimmeridgian (Upper Jurassic). This formation crops out along the south-western edge of the Wadi Al Jawf basin, the place of oil deposits, located in the 1980s. The lithological succession comprises a 300-m-thick sequence, the so-called

Amran Formation, divided into eight units, Unit 1 to Unit 8 according to Al-Ganad et al. (1994). Due to their low thickness, the basal units (Unit 1 to Unit 4) are generally difficult to separate using remote sensing techniques. They correspond to no. 13 in Fig. 10.4. Unit 1 is a 10 m-thick sandstone and conglomerate unit that occurs unconformably above the Proterozoic basement and, for the Jabali area, above Cenozoic granites (no 14). It could be older than Jurassic (Permian or Triassic?). Unit 2 is made of gypsiferous mudstone, marl and limestone reaching 25 m in thickness. Unit 3, dated to Callovian, is the first unit that could be stratigraphically dated owing to fossils present in the micritic limestone (about 50 m thick). Note that in the south-east area a micritic limestone, so-called Unit 3, is mainly outcropping. Unit 4 is also made of a micritic limestone associated with bedded dolomite of lagoonal facies (15 m). The field Unit 5 is a key unit, because it is a bryozoan calcarenite frequently overlain by coral-bearing oolitic limestone. This 40 m-thick unit is of Late Oxfordian-Early Kimmeridgian age. Unit 6 and Unit 7 are the thicker units with about 80 m each. Unit 6 (no 11, Fig. 10.4) is mainly made of gypsiferous mudstone at the base, grading to interbedded limestone and marl toward the top. Unit 7 (no 10, Fig. 10.4) comprises massive limestone but they are almost completely dolomitized. The Amran Formation contains a number of Pb-Zn-Ba occurrences. The Jabali deposit is hosted by the dolomitized limestone of Unit 7. Thus, the mineralization is associated with dolomitization controlled by WNW- to NNW-striking faults. Such a fault is clearly visible in the ALOS image (no 9, Fig. 10.4). Non-economic Pb-Ba occurrences are hosted by the lower layers of the Amran Formation (Unit 5 mainly).

The oxidized mineralization consists mainly of smithsonite (zinc carbonate), hydrozincite, cerussite (lead carbonate), and iron and manganese oxides forming a large iron cap or gossan at Jabali (no. 7, Fig. 10.4). Most of the mineralization is concentrated in massive bioclastic and biomicritic limestones, locally oolitic and containing corals (Unit 7, see unit no. 10, Fig. 10.4). This unit is dolomitized in its northern part, as well as in Jabali (no. 9, Fig.10.4). The secondary dolomitization phenomenon affects also a large part of the bryozoan calcarenite of Unit 5 which is represented by no. 12 (Fig.10.4). The southern part of the orebody is limited by late dedolomitization processes illustrated as a dark strip within the white carbonates (no. 8, Fig. 10.4). The top of the unit is deeply affected by fracturing and karstification in the highlands of the area (Jabal Salab), characterised by a number of sinkholes (dolines) (no. 4 and 10, Fig. 10.4).

Volcanic rocks are clearly visible in the north-eastern part of the image (no. 6, Fig. 10.4). It consists of trachytic rocks. Thermal metamorphism induced by the laccolith emplacement leads to transformation characterised by blue tones in Fig.10.3. The concerned units are Unit 5 and Unit 6 to the south-west and the east of Jabal Amrah, respectively. The magmatic rocks of Jabali are of particular importance to understand the geological setting of the mineralization (unit no. 6). They crop out in the large Jabal Amrah massif in the north of the mining area. A formation of small dykes of hypovolcanic rocks (trachyte) appears close to the gossan. From a geometrical point of view, a sill of volcanic rocks extends from the Jabal Amrah to the North, toward the ore deposit to the south (not visible in

Fig. 10.3). This sill has been cut off by drilling and its role in the emplacement of the orebody is clear.

Recent alluvial deposits are put into light owing to the large width of the wadis (no. 2). Some old terraces (not detailed in Fig. 10.4) have been identified with an amount of large blocks and boulders. Some of these blocks are metric in size, representing the hard rocks of the subtrate, granite, quartzite, migmatite, etc. Colluvial deposits are particularly dense on the western side of the Jabal Amrah (no. 3) due to the weathering (mainly kaolinization) of the volcanic rocks. A formation of slag areas mixed with alluvial materials have been identified in the field (no. 1). They cover at least 70 ha.

10.4 The Environment of the Mining Sites

The archaeological and geological study of the Jabali area using field observations supported by remote sensing data leads to an integrative view of the mining site over more than 20 km from the mines to the Wadi Al-Khaniq. Three main items should be emphasized: mineralization, water, and vegetation.

10.4.1 The Mineralization

The book written by Al Hamdani is named "*the book on gold and silver*" (Al Hamdani 1968). It could be considered as an actual treaty on silver and gold metallurgy, because it treats the technology and ancient chemistry of the metals from their extractions from the mines to the fabrication of coins. The Arab writer was well acquainted with Greek philosophers, particularly Aristotle, and with their ideas on the generation of substances from the four natural elements: air, earth, fire, and water. He mentioned a silver ore clearly associated with the lead: 'The evidence for silver ores is the "kohl" [. . .] the latter is represented by small quantities such as the quantity of moonlight is small regarding its size (Chapter V).' Al Hamdani's book also mentions the association of silver with galena and estimates the rate and geochemistry of the metals. However, Al Hamdani never describes the mine itself and the host rocks. He only mentions that miners from Jabali state and that there are no similar mines in the Khurasan, the old Persian province located in the North-eastern part of the present Islamic Republic of Iran.

Another study (Deroin et al. 2011) indicates that mapping, using remote sensing in the visible to short wave infrared range has great potential for the identification of iron caps possibly related to archaeological remains. The phases of works in Jabali have been clearly put into light by the study of a time series of Landsat data. Iron cap can be detected by the multispectral remote-sensing method and can also be used as a guide in the field for prospecting ore deposits.

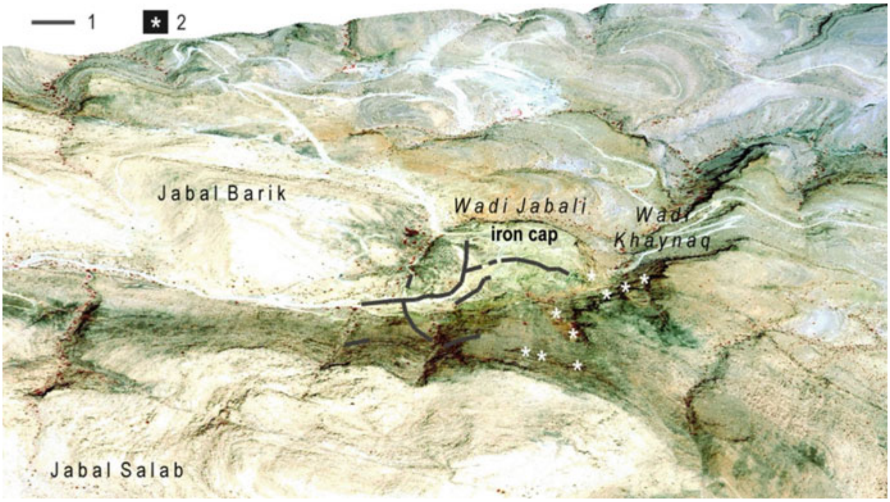

Fig. 10.5 Detail of the Jabali mine area (3D view). Background: QuickBird data acquired on March 30, 2002. *1* Main canals according to Christmann et al. (1983), *2* main underground mine entries. Note the small watersheds. The shrubs appear as *red dots*

10.4.2 Water

Although dangerous for mining activities, water is obviously vital for a perennial life on site. Today, the area allows only a nomadic way-of-life. Water was possibly more present during the period of exploitation. In any case, there are a lot of canals running from the surrounding mountains as already mentioned in the first geological works (Christmann et al. 1983). Some other canals linked to small watersheds have been identified in the southern part of the Jabali iron cap (Fig. 10.5). The slag heaps also show evidence of major gullying.

10.4.3 Vegetation

Vegetation is closely related to water. It is necessary for life but also for the different phases of the metallurgical process. In the Jabali area, fuel can only be derived from woody vegetation, particularly from shrubs and trees. Wood intervenes as a reduction agent during the ore melting. It is also essential for cupellation, the process used to separate silver from base metals such as lead and zinc. The amount of wood available plays an essential part in reduction, cupellation and revivification, the reduction of a metal from a state of combination to its metallic state. Here charcoal is used only. Al Hamdani gives evidence for this practice: e.g. ‘The best fuel for refining is charcoal’, ‘If you want to convert litharge

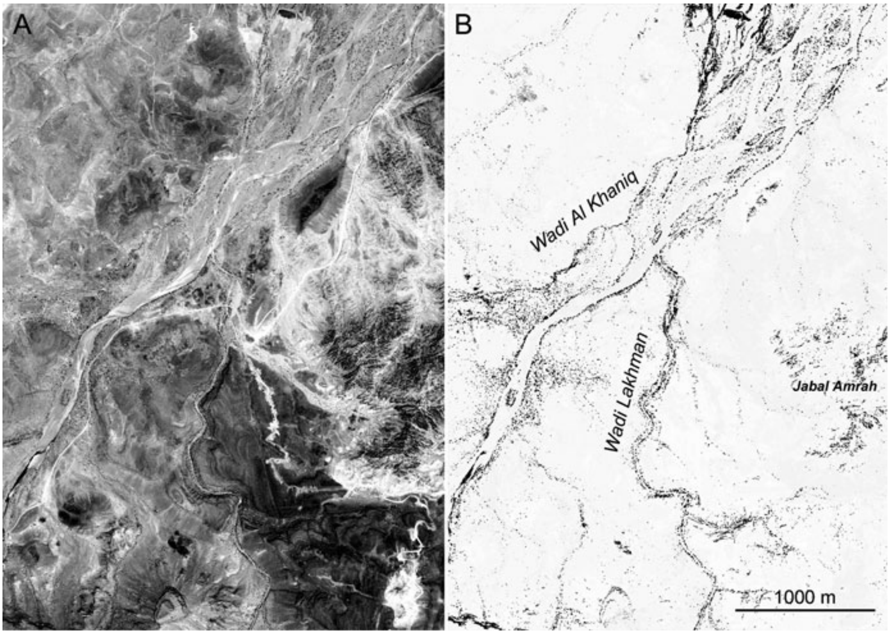

Fig. 10.6 (**a**) ALOS colour composite (see also Fig. 10.3). (**b**) Vegetation. Each black dot represents a small shrub. Note the concentration of vegetation along the Al Khaniq and Lakhman wadis

into lead, melt it twice', 'The village of the mine was a large village located in a watered valley (ghayl) with palm trees', 'There were 400 furnaces', etc. (Peli 2008).

Figure 10.6 shows the current vegetation extracted from the QuickBird image acquired on March 30, 2006. We have used the Normalized Difference Vegetation Index (NDVI). The NDVI is one of the most frequently used vegetation indices. The combination of its normalized difference formulation and use of the highest absorption region of chlorophyll (red range) and highest reflectance region of vegetation (near infrared range) make it robust over a wide range of climate conditions. For the multispectral QuickBird data, NDVI is defined by the equation

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \tag{10.1}$$

Where NIR is near infrared band, Red is the red band.

The value of this index ranges from -1 to +1. The common range for green vegetation is 0.2–0.8. In the case of Jabali studied with the help of QuickBird data, 0.15 is the inferior threshold because of the low chlorophyll activity in this early spring image. By applying that threshold and conducting field checks, we were able to extract the main shrubs and trees. They are usually represented by black dots in

Fig. 10.6. Vegetation is clearly related to the banks of the two main rivers, the Al Khaniq and Lakhman wadis. It should be emphasized that currently there is a definite absence of palm trees in the local wadis, in fact there are small trees only.

10.5 Discussion: Jabali, a Moving Area

The area of Jabali was mined for silver as early as the pre-Islamic period. Basically, Jabali is known as one of the most important silver mines of the Abbasid world (Robin 1988). In the tenth century AD Al-Hamdani described this place then named al-Radrad. It was precised to have been exploited from a period before the coming of Islam until the end of the ninth century AD. However, new datings demonstrate that the mining activities occurred until the fourteenth century AD. According to Al-Hamdani, the village of al-Radrad (Jabali) was extensive and located in a watered valley where palm trees grew, the current wadi al-Khaniq. The mine was connected to southern Iraq by a road passing notably through al-Bahrayn and al-Basra (Peli and Téreygeol 2007). This site had been completely lost until the early 1980s, when geological prospections rediscovered the ancient silver mine and opened up new perspectives for the mining activities of Yemen.

At Jabali, the old workings cover up to 10 ha. Other archaeological places have been identified, such as Shutayba, Souq, plateau or in the wadi Al Khaniq (Fig. 10.2). At Jabali, the irregular landforms follow the ore concentration morphology. The latter is crossed by many shafts, drifts, low chambers and large tunnels, which in some cases exceed 100 m in length (Robin 1988). Apart from silver, the only exploited metal, Arab medieval metalworkers identified a zinc oxide, the so-called *tutyia*, deposited on the walls of the furnaces during the smelting process (Peli and Téreygeol 2007). The Jabali area is currently explored for zinc-ore. The deposit contains a geological resource estimated at 12.6 million tonnes of oxide ore, grading about 9% zinc. The mineralization located within Jurassic limestones and dolomites includes carbonates and oxides (smithsonite, hydrozincite, etc.). It should be noticed that silver is mainly related to sulfides, which are also represented, even less than oxides, by rare sphalerite and especially galena (Al Ganad et al. 1994).

The area is the focus of attention of archaeologists, historians and geologists. Basically, for these three topics Jabali offers an exceptional setting. However, the continuance of the site is now in question. Some of the planned facilities, particularly a large open pit located close to the major site, will have a destructive impact on the old pits, the ore-dressing and ore-crushing areas, and especially on the old canals coming from the Jabal Salab, already damaged by the preliminary mining works carried out since the 1980s. Other archaeological remains and slag heaps located far from the mine itself, especially in the wadi Al Khaniq will be unaffected.

The most recent impact has been characterized using a pair of ALOS AVNIR-2 data (Fig. 10.7). The 2007 ALOS image (already illustrated in Fig. 10.3) is compared to the last acquisition obtained by the same sensor on October 26,

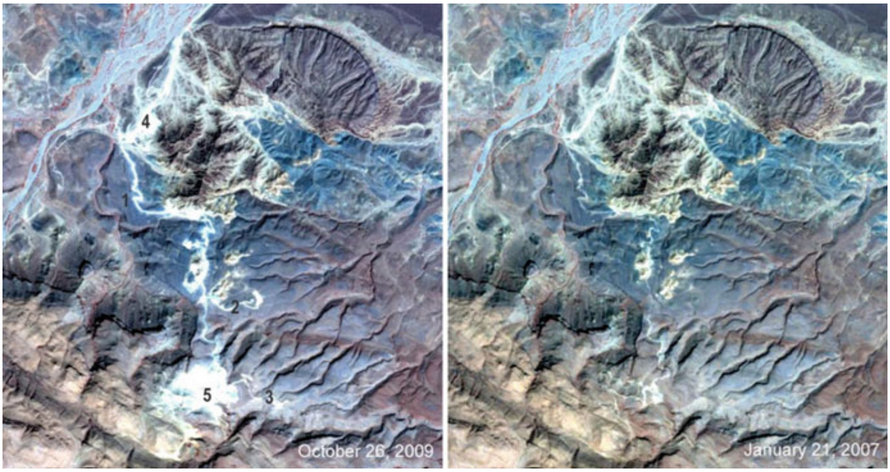

Fig. 10.7 Comparison of the recent evolution of the Jabali site using ALOS AVNIR-2 data. Each image represents about 6 × 7 km (subimage of Fig. 10.3). Both colour composites correspond to the following composite: *Red* near infrared range, *Green* red range, *Blue* blue range. Numbers *1–5* refer to the text

2009. The main track is larger (1), there are new tracks in the Souq area (2) and to the iron cap (3), the area close to the lower military camp has been reworked (4). The main difference is at Jabali itself with works for the new open pit and for building the new plant (5). Thus, the mineralurgical area is the most affected by the new mining activities. Unfortunately, this is also the less known aspect of the Jabali silver mines. Indeed, Al Hamdani only describes a few elements of the process. For example he writes about the grain size of the ore: '*one crushes (the ore) to obtain the size of large grapes. The fine part is mixed with water and yellow clay*'. The preparation of the ore was probably limited to crushing and manual sorting.

Al Hamdani's account is particularly vivid where metallurgical activities are concerned: '*When birds came near the village of the mine, they dropped dead because of the fire from the furnaces*'. In some ways he is right, because field prospections confirmed the presence of a large amount of slags on about 70 ha. However, the quantity of slags is relatively low because the thickness of the slag layer never exceeds 20 cm. In addition, the detailed chronology of the deposit is missing. The metallurgical wastes may have been created between the sixth and the fourteenth century AD. Although slags are reprocessed by crushing and sorting out, it is frequent to find lead billet as large as 5 mm. There is obviously no shortage and the ore production was probably large enough to feed the furnaces.

10.6 Conclusions

Teleanalytical geological mapping is a powerful method to analyse and interpret the geological setting of a poorly-known region such as the Jabali area. During this study, new geological topics have been pointed out, such as the setting of the Jabal Amrah magmatic body, the extent of Zn-Pb-Ag mineralizations (iron caps), the mapping of Quaternary terraces along the Wadi al-Khaniq or the detailed cartography of (de)dolomitization phenomena. Among the set of available sensors, the ALOS-AVNIR-2 sensor with its 10 m-ground resolution and its visible-near infrared range appears as a good trade-off for classical geological mapping at 1:50,000, complementary to the widespread large-scale LANDSAT imagery and to the higher resolution data (for example QuickBird or SPOT 5).

One major issue of the study of the ancient Jabali silver mines concerns the climate of the past: Where did the trees grow, necessary for the melting of the ore? Al Hamdani mentioned 400 furnaces and the slag heaps cover more than 70 ha. Moreover, the mineral extracted from the mine was washed to separate ore from the gangue, an operation that requires a large amount of water drained from the local watersheds. Therefore, the hydrological regime (precipitation, run-off, palaeocourses of the wadis) as well as the landscape were clearly different from the present state. Thus, field data and the detailed analysis of ALOS and QuickBird images opened up promising perspectives. New places for future field prospections have been identified using remote sensing data. We have particularly recognized new gossans (iron caps) to the south-east of Jabali owing to the specific spectral reflectance of the iron oxides in the red range.

According to Jansen et al. (2007) the Medieval Warm Period (MWP) occurred from about AD 800–1300. The MWP is well illustrated during the European Middle Ages using information such as evidence of treeline and vegetation changes, or records of the cultivation of cereals and vines. This information is particularly extensive for western Europe. It was initially believed that the temperature changes were global. However, this view has been questioned. Unfortunately, there is insufficient documentation as to the existence of this warm period in the Arabian peninsula. The detailed study of Jabali can probably provide new data for metallurgical studies, as well as for the palaeoclimate studies.

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