# YSAR: a compact, low-cost synthetic aperture radar

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## ABSTRACT

The Brigham Young University Synthetic Aperture Radar (YSAR) is a compact, inexpensive SAR system which can be flown on a small aircraft. The system has exhibited a resolution of approximately 0.8 m by 0.8 m in test flights in calm conditions. YSAR has been used to collect data over archeological sites in Israel. Using a relatively low frequency (2.1GHz), we hope to be able to identify walls or other archeological features to assist in excavation. A large data set of radar and photographic data have been collected over sites at Tel Safi, Qumran, Tel Micnah, and the Zippori National Forest in Israel. We show sample images from the archeological data. We are currently working on improved autofocus algorithms for this data and are developing a small, low-cost interferometric SAR system (YINSAR) for operation from a small aircraft.

**Keywords:** synthetic aperture radar, SAR, compact, low-cost, imaging radar, Israel

## 1. INTRODUCTION

A Synthetic Aperture Radar (SAR) is an imaging radar which uses signal processing to improve the resolution beyond the limitation of the physical antenna aperture. Typical SAR systems are complex, expensive and difficult to transport. The BYU SAR (YSAR) is a relatively inexpensive, lightweight system. The system is designed to be flown in a four or six passenger aircraft at altitudes up to 2000 feet.

The system cost and complexity are kept low by using commercially available parts for most of the components. A standard PC system is used, with plug-in cards for the analog-to-digital conversion and digital signal processing. The chirp is generated by a low-cost 200 MHz Arbitrary Waveform Generator (AWG). A simple RF subsystem up-converts the transmitted chirp using double-sideband modulation and down-converts the received signal. The YSAR system has been successfully tested from a truck and an aircraft. The system has an estimated range and azimuth resolution of approximately 0.8 m. The system is also described in 1 and 2.

The system was used to take data over several archaeological sites in Israel to help map the areas for excavation. These areas include Zippori National Forest, Tel Safi, Tel Micnah, and Qumran. These data have slightly worse resolution than the initial tests because of uncorrected aircraft motion. We are currently working on applying autofocus methods to this data.

This paper describes the YSAR system and presents results obtained from the Israel flights. The following section shows the block diagram and describes the system. The next section describes the deployment of the system. Section 4 presents the results of the initial tests. Some samples of the Israel data are shown in sec. 5. The final section describes current and future work.

## 2. SYSTEM DESCRIPTION

The YSAR system is composed of an RF subsystem, a chirp generation subsystem, a digital subsystem, and an antenna subsystem. A block diagram of the system is shown in Fig. 1. The entire system weighs approximately 160 lbs, with an additional 200 lbs in the battery-power supply. Each of the subsystems is described below.

### 2.1. RF Subsystem

The RF subsystem consists of a transmitter, receiver, and offset local oscillator and weighs approximately 70 lbs. The transmitter mixes the 100 MHz bandwidth chirp up to 2.1 GHz for transmission. The receiver and local oscillator are used to mix the RF radar return from the antenna to an offset baseband and amplify it so it can be sampled by the digital subsystem. An offset baseband is used so that in-phase and quadrature sampling is not required.

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## 2.2. Chirp Generation

To reduce cost, the chirp is transmitted and received with double-sideband (DSB) modulation, as shown in Fig. 2. Though non-optimal, this avoids the cost associated with single-sideband chirp generation and increases the effective bandwidth of the chirp.

The baseband chirp signal is generated by a commercial Arbitrary Waveform Generator (AWG). The waveform is first generated by the PC and then downloaded with timing information to the AWG's memory over an RS-232 channel. The AWG is synchronized to the local oscilator in the RF unit and is used to control the timing for the entire system. The chirp bandwidth, the delay before triggering the digital sampling, and the pulse repitition frequency (PRF) are all software selectable. The LFM chirp may be windowed with 6 different windows to allow tradeoffs between range sidelobes and resolution. The AWG is the smallest system component at about 25 lbs.

## 2.3. Digital Subsystem

The digital subsystem consists of a 486-based Personal Computer system which has a total weight of 55 lbs. A high performance analog-to-digital converter operates at a sampling rate of 500 MHz. The software can be configured to do the range compression and display in real-time or to simply collect and store the raw data. In order to meet azimuth

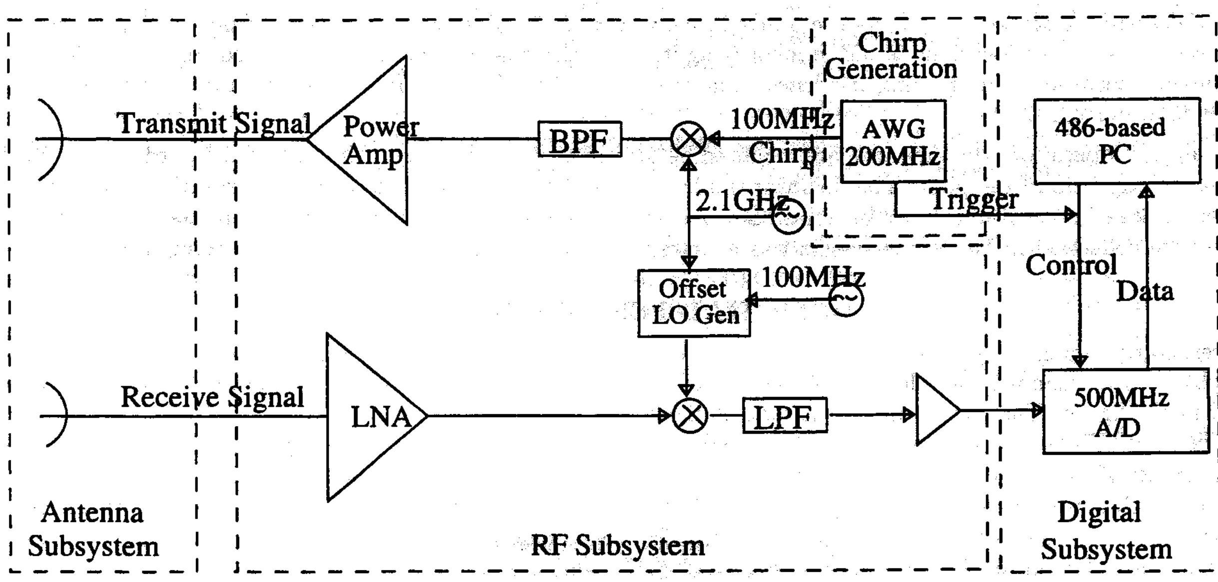


**Figure 1.** YSAR Block Diagram

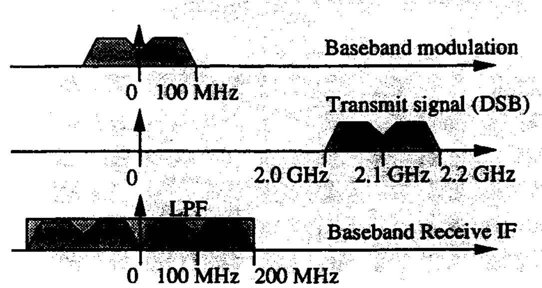


**Figure 2.** YSAR Frequency Plan

sampling constraints, the data is collected into memory and dumped to the disk after a maximum sample length of about 70 seconds. The images can be compressed onboard or downloaded to high-end workstations for further processing. A kinematic GPS system was added near the end of the initial tests to help in motion compensation.

### 2.4. Antenna Subsystem

The antenna subsystem consists of two custom microstrip patch arrays. Each antenna array is approximately 3 by 1.5 feet and is connected to the RF subsystem by standard SMA cables. Two separate arrays are used to improve isolation between the transmitter and receiver portions of the RF subsystem. The two antenna arrays are identical and are mounted end-to-end.

Commercial electromagnetic analysis package was used in the design of the microstrip patch array. The patches in the array were designed to resonate at three different frequencies to improve the bandwidth of the antenna. The feed lines were matched to the port of the antenna using transmission line methods. The patches are fed in phase and with equal power. The arrays were fabricated on an inexpensive substrate, resulting in a somewhat lossy though well-matched antenna. The standing wave ratio (SWR) of the array is below 2 over the entire 200 MHz bandwidth and is 1.27 at the center frequency. The beam width is 8.8° in azimuth and 35.0° in elevation at the center frequency. The center fed antenna array layout is shown in Fig. 3.

## 3. DEPLOYMENT

The initial system tests were conducted in a nearby canyon with the system mounted on a truck. Corner reflectors were placed at strategic locations to aid in identifying items in the image. The images obtained from these tests are lower quality because of the grazing incidence. The speed and direction of travel were also not as constant in the truck as in an airplane.

For aircraft operation, the antennas are mounted below the airplane fuselage. The rest of the hardware occupies the seat directly behind the pilot. The operator sits in the rear seat. The initial test was in a rural area with corner reflectors placed in the primary target areas. Several passes were made to try different parameters and altitudes. For the data collection in Israel, the system was mounted on an identical plane with the same configuration.

## 4. INITIAL TEST RESULTS

A representative image from the truck tests is shown in Fig. 4. This image was taken at approximately 22 m/s (50 mph) with an azimuth sample rate of 200 Hz and a chirp length of 1$\mu$s. Several of the identified features are labeled in the figure. The radar was on the road at the top of the image (not seen), moving to the left and looking down the page. There is a short section of guardrail along the road to the right of the figure. Just behind that and a little further along the road are some parked cars. Near the left of the picture and close to the road is a set of small hills with a corner reflector on top of one of them. In the center of the image there are several tree-covered hills, with a corner reflector identified on one of them. In other images further up the canyon a pipeline can clearly be seen at about 200 m up the hillside.

Fig. 5 shows a close-up view of a set of corner reflectors from one of the initial arplane tests. The reflectors are arranged in a line, with a large (1 m) reflector in the center and smaller (2 ft) reflectors at the ends. This type of one-look image was used to estimate the resolution as 0.87 m in azimuth and 0.82 m in range.

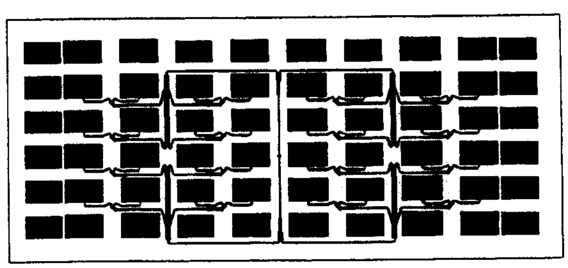

**Figure 3.** Layout of An Antenna Patch Array

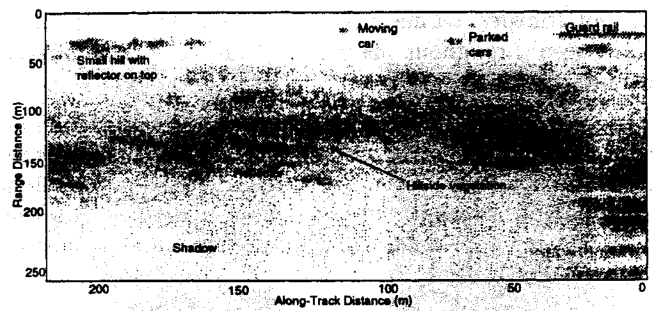


**Figure 4.** A one-look grazing-incidence image taken from a truck in Provo Canyon. In this image, bright radar returns are shown as the darker shades.

## 5. ISRAEL RESULTS

The YSAR system was taken to Israel to collect data over archaeological sites in September 1996. Data was collected using the radar and 35mm cameras in six flights over four sites, from 12 September to 17 September. The sites were in Zippori National Forest, Tel Safi, Tel Micnah, and Qumran. The resolution of the images obtained is comparable to that obtained in the test flights, but is slightly worse due to more uncompensated aircraft motion. The motion was especially bad at the Qumran site due to excessive turbulence.

Sample images from each of the sites are shown and described below. Each of the images shown in this section has been averaged to 64 looks in order to show an entire strip on the page. The flight direction is top to bottom, with the radar looking to the left. Each strip is approximately 600m by 3.5km, with pixels about 2.5m by 2.5m.

The Zippori National Forest contains a large planted forest, a fortress built by the Crusaders, and ruins believed to be the site of a large center of learning after the fall of Jerusalem in CE 70. The site sits on a large hill and contains many partially excavated ruins. Some of the ruins are largely covered with trees and brush. The biggest challenges to imaging this area are the rocky ground and the hilly topography. A sample image of the area is shown in Fig. 6. The photo-mosaic in Fig. 7 correspond to the area indicated by the box in Fig. 6, which is below the hill of the main site. The main archaeological site is just above the upper right corner of the portion covered by these photographs.

Another image from the Zippori site is shown in Fig. 8. This image covers much of the main site of interest. A set of corner reflectors arranged in a cross can be seen in a field near the start (top of the page) of the image,

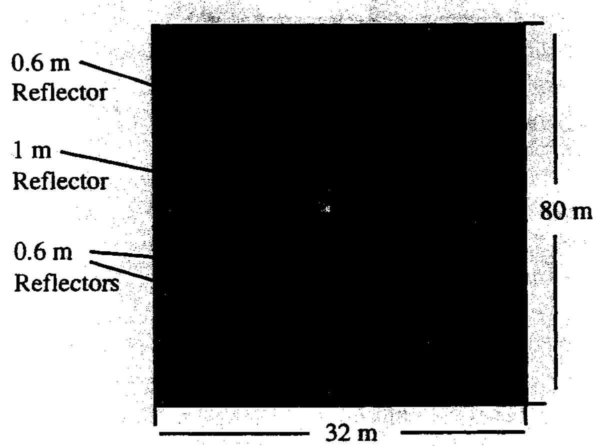


**Figure 5.** Close-up image of corner reflectors.

indicated by the arrow. The 2-foot trihedral corner reflectors are spaced 10m apart. Many rock fences, excavations, buildings, roads, and trees can be seen throughout the image. Analysis of these images is continuing, both for better focusing and for archaeological interpretation.

Tel Safi is believed to be the site of the ancient Philistine city of Gath, home of Goliath as mentioned in the Bible. There is also evidence of other, more recent settlements on the site. The site sits on a small hill (tel) in a large, mostly flat plain. Figure 9 shows an image from Tel Safi. The tel spans the middle portion of the image. Many features can be seen in this portion which were not evident from the ground. A set of 2-foot corner reflectors in an 'L' configuration is indicated by the arrow. Variations in field types can also be seen, and a large wadi is evident near the start of the image.

Figure 10 shows another image from Tel Safi. The area covered by this image is very close to that in Fig. 9. Two sets of corner reflectors can be seen, including the set which appears in Fig. 9. The bright line (saturating the gray scale) is the edge of the tel, where many targets appear at the same range from the radar.

Qumran is the site of an ancient settlement and is famous as the site where the Dead Sea Scrolls were found. This site was especially difficult to image because the entire site sits at the base of a cliff. Thus each point in the image comes from at least two points, one on the ground and one partway up the cliff. Other complicating factors were more turbulence for the flight in this very hot desert region, and limited ground truth information to compare with the SAR image. Figures 11 and 12 show images from the Qumran site. The road along the Dead Sea can be clearly seen in both. A large orchard is evident in Fig. 11. Many small, bright targets can be seen between the road and the water in Fig. 12. Tel Micnah is the site of another ancient settlement. This site has been under excavation for some time. Figure 13 shows an image from this site.

## 6. CURRENT AND FUTURE WORK

We are currently working on and planning several projects to improve the imaging capabilities of the YSAR system. Some of these are described in the following.

Motion compensation is a significant problem in all SAR systems, and more so in the small, low-flying aircraft used for YSAR. The initial system tests were conducted in good weather conditions and at optimum times of the day. We were unable to choose our flight times as well for the flights in Israel, so these images are more corrupted by motion of the aircraft. We are currently adding more motion measurement to the system and working on improved methods of autofocusing. For future flights, the kinematic GPS system will be better synchronized with the SAR data collection. There will also be a set of accelerometers to interpolate between the GPS measurements. The accelerometers are based on recent advances in technology and provide good performance while preserving the low cost of the YSAR system.

Autofocus for YSAR is made more complicated than in traditional systems by several factors. Most of the autofocus algorithms currently in the literature are for spotlight SAR, while YSAR is a stripmap system. YSAR covers a much wider range of incidence angles (nadir to 70° in many cases). We are working on modifying autofocus algorithms to apply them to our system.

We are also in the final stages of building a 10 GHz interferometric SAR (YINSAR) which will be operational this summer. This system is smaller than YSAR, with better data collection capabilites. The operator controls of this system will better utilize maps and GPS data to allow flight paths to be followed more accurately and to allow the operator to know exactly what area the instrument is imaging. We plan to operate both systems together to obtain 10 GHz and 2 GHz images of the same areas.

## REFERENCES


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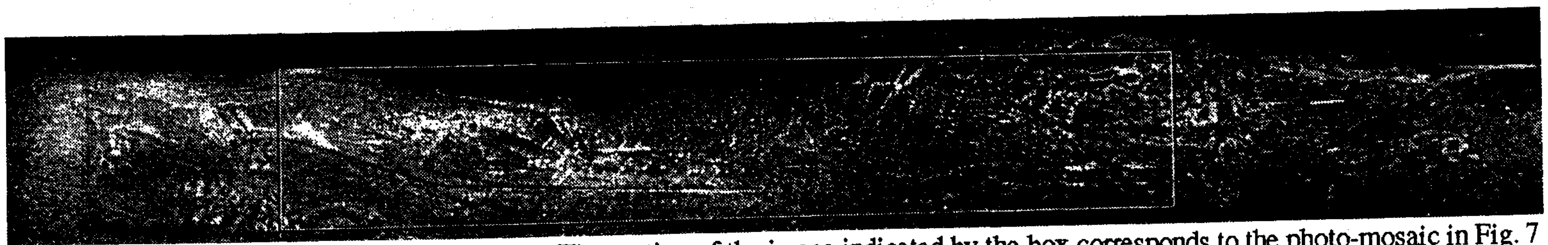

Figure 6. A sample image from the Zippori site. The portion of the image indicated by the box corresponds to the photo-mosaic in Fig. 7

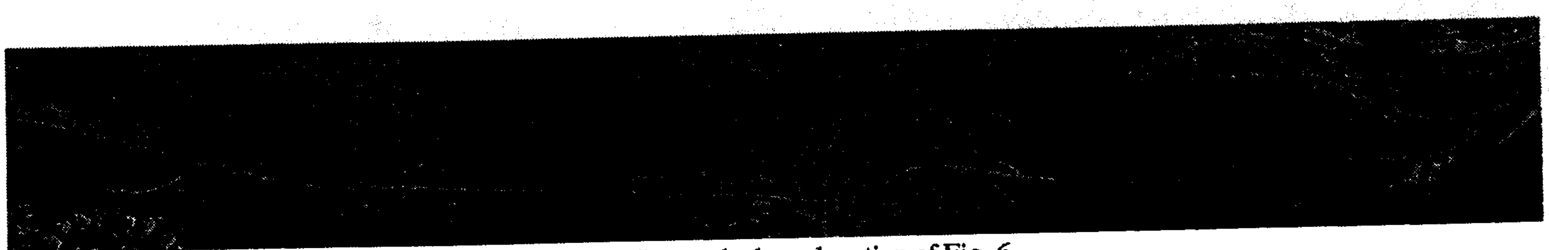

Figure 7. A photo-mosaic of the Zippori site corresponding to the boxed portion of Fig. 6.

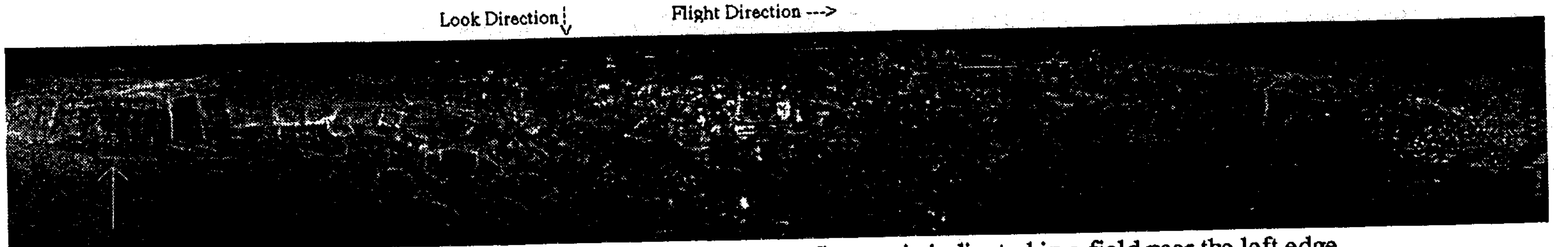


Figure 8. An image showing the main Zippori site. A cross of corner reflectors is indicated in a field near the left edge.

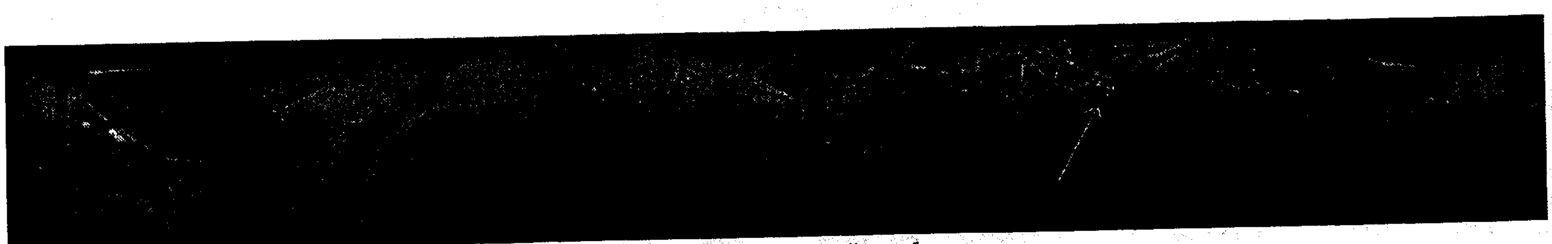

Figure 9. An image from the Tel Safi site. An 'L' of corner reflectors is indicated.

Figure 10. An image from the Tel Safi site. Two sets of corner reflectors are indicated.

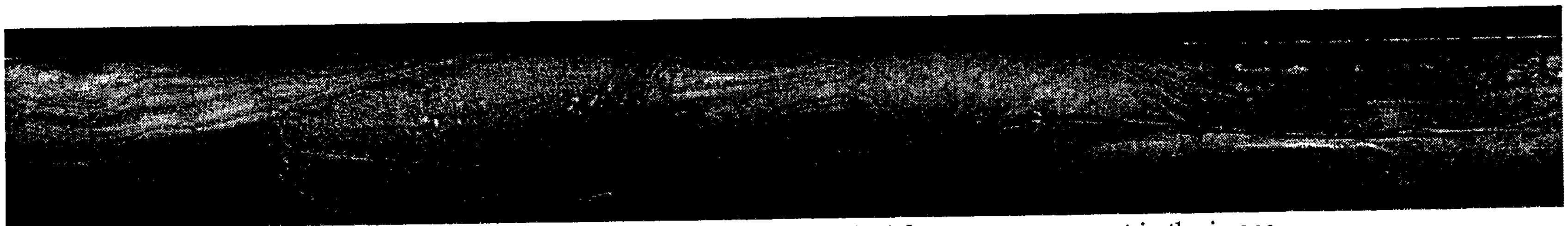

Figure 11. An image from the Qumran site. An orchard, a road, and geological features are apparent in the image.

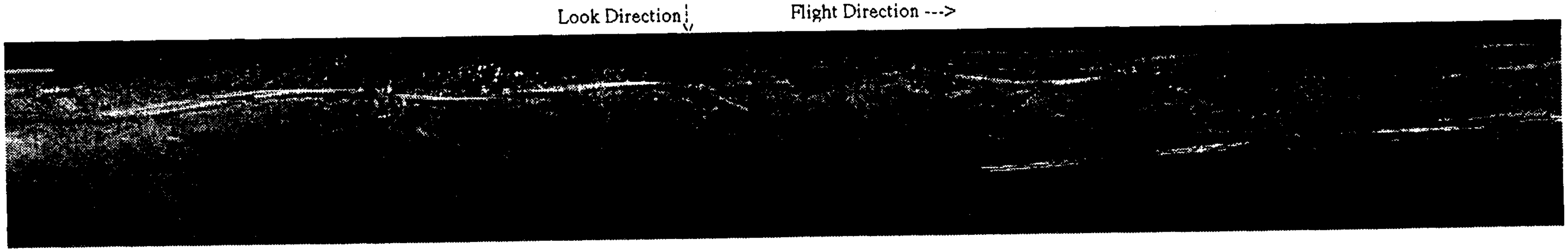


Figure 12. An image from the Qumran site.

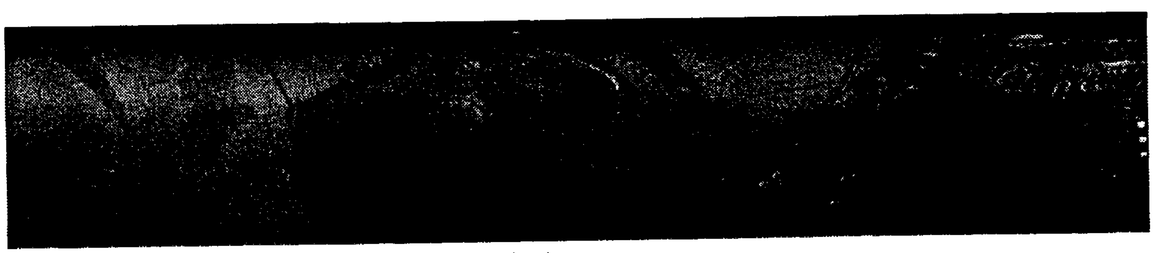

Figure 13. An image from the Tel Micnah site.