Relationship between Nazca Lines and Groundwater Flow

Susumu Ogawa[1*] and Katsuya Takaku[2]

[1]*Graduate School of Engineering, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan*
[2]*Graduate School of Environmental Life Science, Faculty of Environmental Information Science, Yokohama National University, 79-1 Tokiwadai, Hodogaya District, Yokohama, Kanagawa 240-8501, Japan*
[*]*E-mail address: ogawasusumu@nagasaki-u.ac.jp*

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In this study, our aim was identification of relationship between the Nazca lines and groundwater flow with a satellite image. The lines were extracted from an ALOS/PRISM image as bright and dark lines with the maximum likelihood procedure. Next, extracted images were checked up with ALOS/PALSAR and SRTM-3 topographic data, which show the groundwater flow. Then, a part of the biggest geometric configuration was shown with groundwater flow. The lines coincided with the groundwater flow, while the pictures indicated the locations of seepage from the groundwater. The groundwater was the most important for the ancient Nazca agriculture and the lines would relate with it.
Key words: ALOS, Binarization, Nazca Lines, Seepage, SRTM-3

1. Introduction

The Nazca Lines are located in the Nazca Desert, an arid plateau that stretches between the towns of Nazca and Palpa on the *pampa* (the plain), Peru. This area is an arid zone with annual precipitation of less than 1mm. Nazca town was constructed with a mine development 70 years ago. The population is about 30000, and mostly white, natives, black and mixed parentage. Many of the lines were drawn by digging the dark blown oxidized surface and exposing the lower light yellow soil surface. According to the date measurement of sticks used for drawing, these ages range from BC 190 to AD 660. In the era of Pre-Inca, AD 100 to 600, Nazca culture prospered and developed technology to draw the lines, ceramics painting, textile patterns, feather decorations, groundwater courses, mummies, skull trophies, etc. In Cahuachi area more than 30 of buildings and pyramids were constructed with fine finishing touches. Most rivers were underflows and used for agriculture by groundwater courses (Seki, 1997; NHK, 2005).

The Nazca lines were discovered on June 22, 1939 by Paul Kosok, an American archaeologist. From 1941 to 1998, these lines had been researched by Maria Reiche, a German astronomer. The patterns of the lines are various: birds, monkeys, spiders, fish, dogs, killer whales, human beings, and plants. These scales range 30 to 285 m. The patterns have much difficulty to judge their meaning. These animals and plants might mean a kind of the show ceremony in the Nazca culture because they were drawn on the earthenware vessels discovered in Nazca (Aveni, 2005; Kusuda, 2006).

Geometric configurations such as straight lines, trapezoids, triangles, and spirals were discovered more than animal and plant patterns. They were supposed to be runways, abundant harvest prayers, and permanent sacred symbols (Deust and Arguedas, 2002).

The meaning of the lines has been interpreted by some hypotheses. Paul Kosok and Maria Reiche proposed "astronomical calendar" theory, which is that each line has some angle to the sun rise and indicates a calendar in total. Animals and plants show asterisms in this case. "Balloon" theory is that Nazca people watched the lines from the balloon, and was proved experimentally by two persons on a gondola with a reed grass over the Nazca. "Agricultural hydrology" theory is that lines coincide with the direction of the rivers. Moreover, "archeological monument" theory and "ceremony of water prayer" theory were presented (Seki and Aoyama, 2005). Recently Sakai proposed a new theory, "harvest prayer" (Yamagata University, 2006; Sakai, 2008, 2012).

In 1972, the huge geometric configuration extended to 50 km long was discovered by Landsat. More than a hundred of new lines were discovered by Sakai (2008). In this study, our aim was identification of the Nazca lines with ALOS/PRISM data (JAXA, EORS, 2005). Next, comparing ALOS/PALSAR with SRTM-3 topographic data, underflows or groundwater courses were indicated. Finally relationship between the lines and groundwater was examined. JAXA is Japan Aerospace Exploration Agency and EORC is Earth Observation Research Center in JAXA. ALOS (Advanced Land Observing Satellite) was launched by JAXA on January 24, 2006, installed with PRISM (Panchromatic stereoscopic sensor: 2.5 m resolution), AVNIR2 (Advanced visible-infrared sensors: 10 m resolution), and PALSAR (L-band Synthetic Aperture Radar: 10 m resolution). PALSAR detects groundwater flows (JAXA, 2005). SRTM is Shuttle Radar Topography Mission by NASA, which made Digital Elevation Models, SRTM-1 (30 m resolution) and SRTM-3 (90 m resolution).

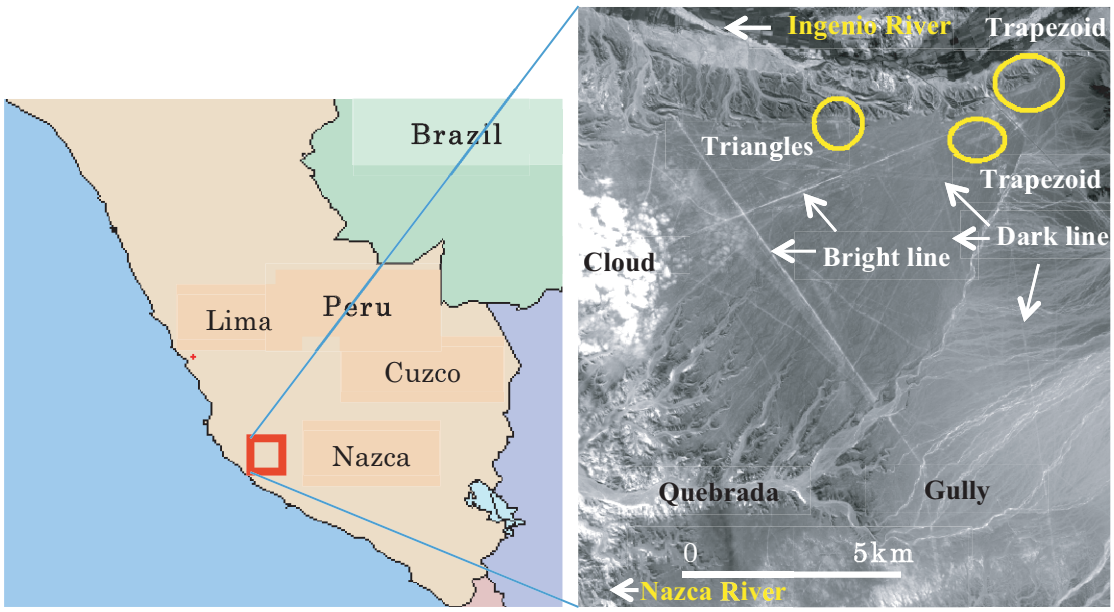

Fig. 1. Original image of PRISM (right). Yellow circles indicate geometric configurations.

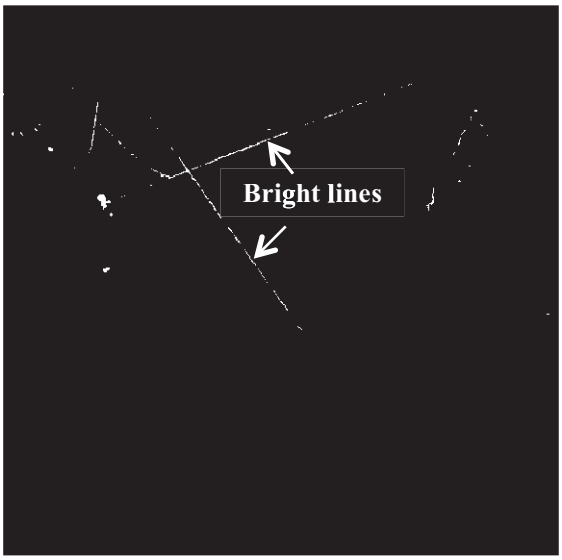

Fig. 2. Extracted image of "bright lines": mainlines.

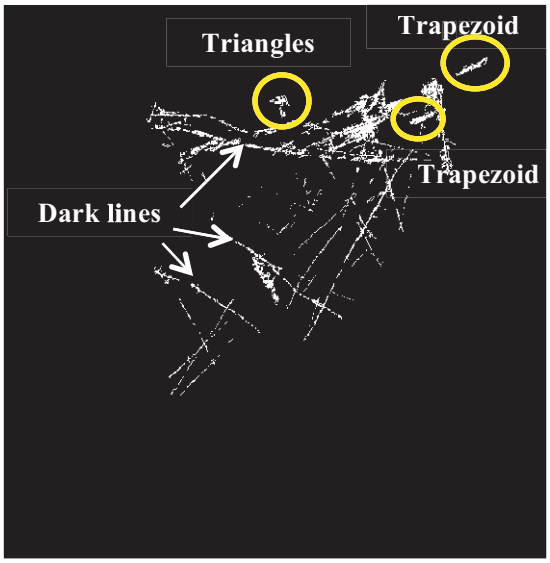

Fig. 3. Extracted image of "dark lines": lines and geometric configurations.

2. Materials and Method

2.1 Used data

Two satellite data were used: ALOS/PRISM taken on June 1, 2006 for extraction of Nazca lines and ALOS/PALSAR taken on July 26, 2006 for groundwater detection. Both two images are monochrome in gray scale. SRTM-3 was used as a digital contour map for estimate of flow directions.

2.2 Binary conversions

The ALOS/PRISM image was categorized as clouds, roads, Nazca lines, *pampas*, *quebradas*, and *gullies* with the maximum likelihood procedure. *Pampa* means the plain in Quechua language. *Quebrada* is a ravine or a deep valley in Spanish. A *gully* is a landform created by running water. Nazca lines are composed of "bright lines" and "dark lines" depending on the widths with 1 to 2 m. The longest lines are bright lines. Most geometric configurations were categorized to dark lines. But all pictures are invisible for their low resolution. Next, the bright and dark lines were digitalized with binary conversions.

2.3 Clump, expansion, contraction, and overlay processes

The clump process was carried out for each image to group neighborhood pixels with the eight neighborhoods. Next, minute areas included in images were removed. Also, minute areas included in extracted lines and geometric configurations were removed with expansion and contraction processes. Next, the objects that had pixels except the lines were removed. Finally, two kinds of images overlaid. This

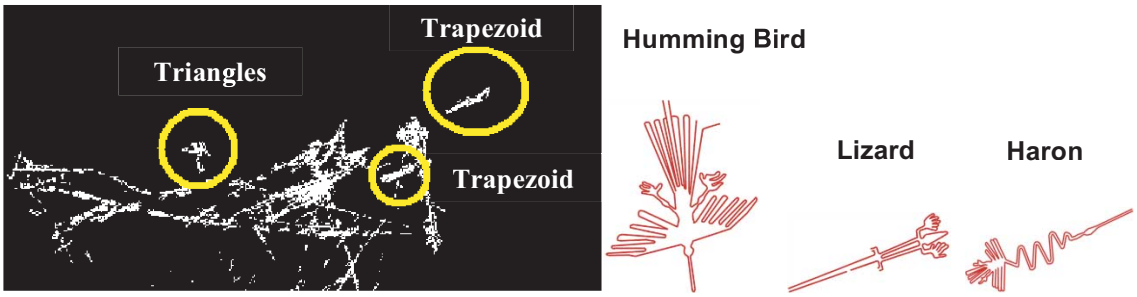

Fig. 4. Extracted images of geometric configurations are near the locations of a humming bird, an iguana (*Lizard*) and a flower (*Haron*).

image was determined as the extracted images of the Nazca lines (Agui and Nagao, 2000; Takagi and Shimoda, 2004; Agui *et al*., 2005; Kasai, 2006).

2.4 Checkup

For the ALOS/PALSAR image, the noise removal process was carried out with the Laplacian filter. Then, the noise removal image was digitalized with binary conversions. For the threshold, the numerical range of bright lines was applied by pixel values in the Nazca line area (Takagi and Shimoda, 2004). Next, a 20-m-contour line image was made from SRTM-3 topographic data. Finally, the extracted images of ALOS/PRISM and ALOS/PALSAR and the 20-m-altitude contour image were overlaid. Then, the overlaid image was checked up.

3. Results

As a reference of extraction images, the original image of ALOS/PRISM and the geometric configurations positions are shown in Fig. 1. There were comparatively bright straight lines to intersect in the central part (10 km long). These lines are a part of the biggest geometric configuration. Several dark lines were confirmed in the circumference. There are triangles to intersect (500 m long) in the north and two trapezoids in the northeast (650 m long).

Extracted images of the bright lines are shown in Fig. 2, the dark lines are shown in Fig. 3, and the enlarged image of geometric configurations in Fig. 3 is shown in Fig. 4. In Fig. 2, the bright lines were extracted clearly, and the other objects were removed. In Fig. 3, the dark lines were extracted in detail, but the lines with the same pixel values as *quebradas* (deep valleys) and gullies (narrow channels) were lost. In Fig. 4, the geometric configurations were extracted well. Their locations are near a humming bird, an iguana and a flower. The overlaid image of Figs. 2 and 3 is shown in Fig. 5. The bright lines and geometric configurations were extracted well, but a part of the dark lines was lost.

The noise-removal image of ALOS/PALSAR is shown in Fig. 6, and a binary image of ALOS/PALSAR is shown in Fig. 7. Also, checked-up images of the bright lines are shown in Fig. 8. The dark lines are shown in Fig. 9, and the geometric configurations are shown in Fig. 10. The contour line image indicated that northeast part was high, while southwest part was low. In Fig. 8, the bright line that directs to northeast was perpendicular to the contour lines, and the bright line that directs to southeast was parallel to the contour lines. In Fig. 9, most of the dark lines in PRISM

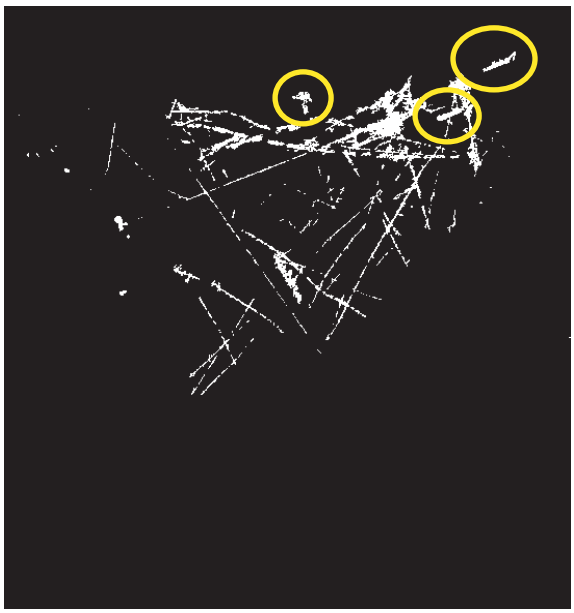

Fig. 5. Overlaid image from Figs. 2 and 3.

overlapped thin bright lines in PALSAR. In Fig. 10, the geometric configurations were perpendicular to the contour lines.

In Fig. 6, PALSAR, white pixels express water: strong white parts are the ancient rivers, while thin bright lines are underflow because they are invisible in Fig. 1, PRISM. In Fig. 7, the upper stream is east and the alluvial cone exists at northeast. The source is this alluvial cone. Invisible underflow flows to southwest. By deforestation over the mountains, today river discharge decreased, but once rivers flowed over the alluvial cone. Underflow appears over the seepage line. The cause of deforestation may be production of ceramics and metals as fuel, and agricultural development like shifting. In Fig. 8, two big bright lines intersect and correspond to the main river and seepage line. In Fig. 9, some dark lines intersect and are drawn over the underflow and alluvial cone. These lines might express underflows and their seepage line. In tropical area, the climate has the rainy season and dry season: in the dry season rivers disappear and in the rainy season rivers appear from the seepage line. In Fig. 10, three symbolic pictures exist and correspond to the source, underflow and see page locations. They are a humming bird at the seepage point, *lizard* (iguana) over the underflow and *haron* (flower) on the source. Over the al-

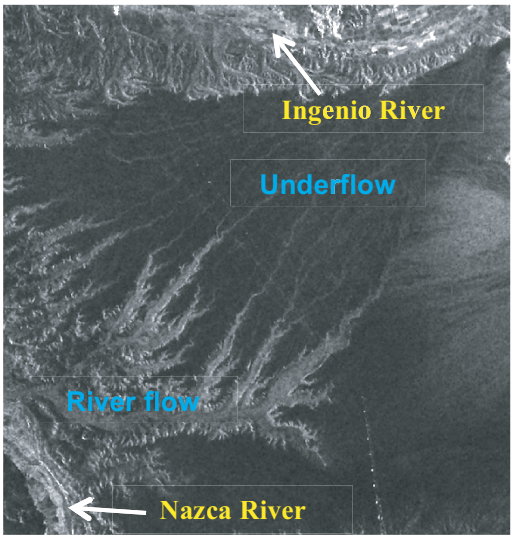

Fig. 6. Noise-removal image of PALSAR.

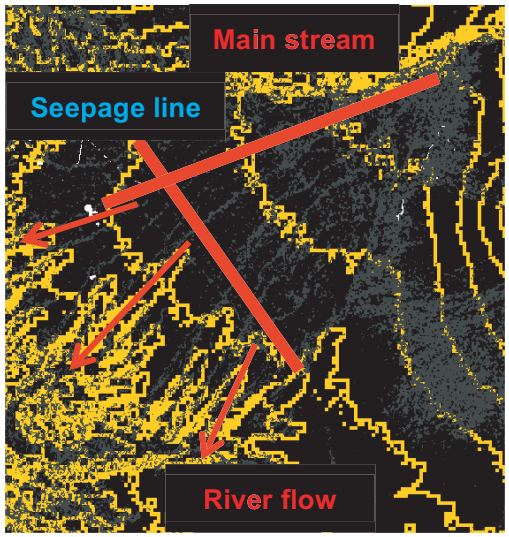

Fig. 8. Checked-up image of bright lines (red).

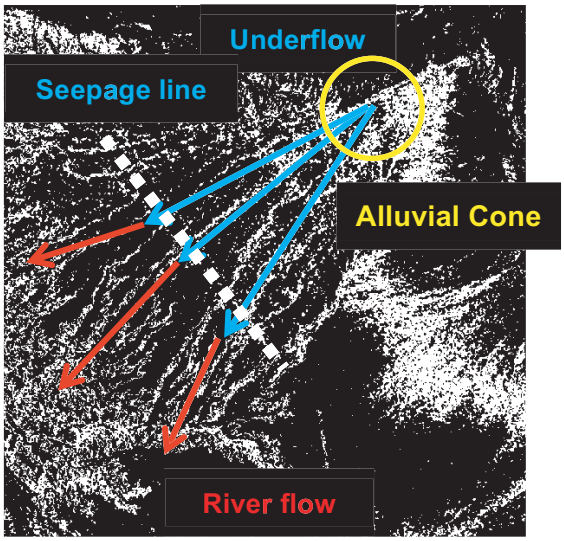

Fig. 7. Binary image of PALSAR.

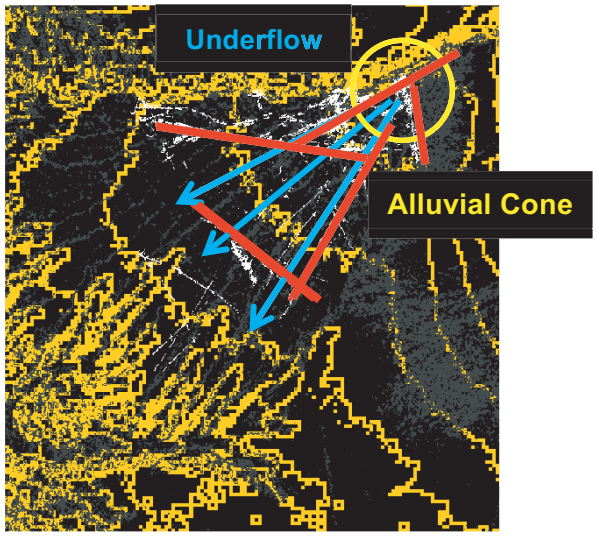

Fig. 9. Checked-up image of dark lines (red). Bright lines correspond to rivers. Dark lines correspond to underflows.

luvial cone once agriculture might exist. By deforestation over the mountains agriculture disappeared finally.

4. Discussion

Extraction of the Nazca lines was attempted. Since the pixel values of dark lines were near the ones of quebradas and gullies in ALOS/PRISM, extraction of dark lines was difficult. Then the conditions except the pixel values were expected to increase accuracy of the extraction. As the widths of the lines were narrower than the resolution of 2.5 m for PRISM, extracted lines became broken partially. Therefore, more advanced extraction method should be attempted for images with less than resolution (Sakurai *et al*., 2005).

Moreover, examining the contour lines and extracted lines, the bright lines of ALOS/PALSAR and the Nazca lines coincided, directing to northeast of the highland and southwest of the lowland. As ALOS/PALSAR indicates the bright pixels where soil moisture was high, the lines would indicate the position and direction of groundwater flow which flowed from the surrounding mountains, while the pictures of animals and plants would indicate seepage points. In fact, more than 40 underground canals were found in Nazca, which were designed for agriculture by taking the groundwater. Still these canals are available for agriculture.

At present, this area is a desert shown in Fig. 1, ALOS/PRISM. But there once were many rivers with underflows as shown in Fig. 6, ALOS/PALSAR. Invisible ancient rivers remain as *quebradas* or gullies today and underflows remain as thin bright lines in PALSAR. Deforestation would make a desert and gullies. Probably deforestation might mainly relate with production of ceramics and metals. Before deforestation there would be many agricultural fields in this area.

"Astronomical calendar" theory was dominant at that time. Because the movement of the sun is east to west,

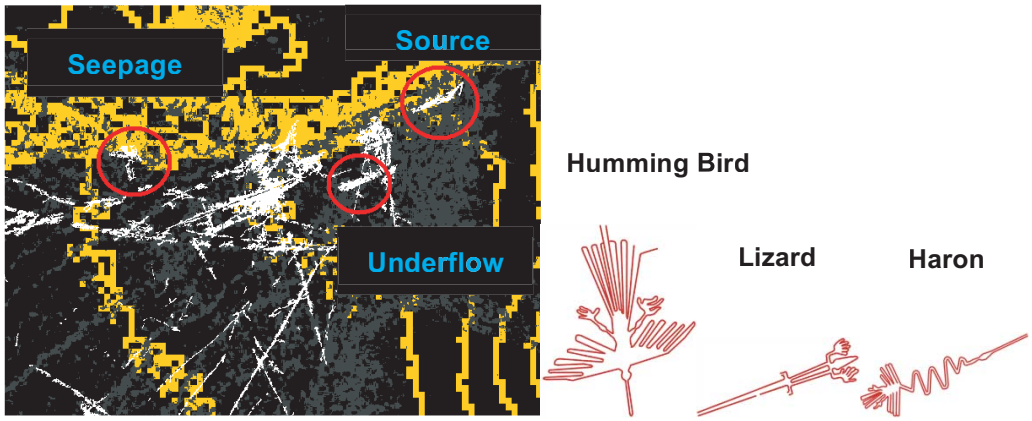

Fig. 10. Overlaid image of geometric configurations. Pictures are invisible for their low resolution. Each position shows the source, underflow and seepage.

and the directions of rivers and the groundwater flows are also east to west. Both directions are coincident. However, recently the exact field survey was carried out for lines and difference between lines and the movement of the sun was detected obviously. Then, this theory became inferior to "ceremony of harvest prayer" theory by Sakai (2008). The latter theory became dominant at present. For the ancient Nazca people, agriculture was very important in the Nazca Desert on the arid plateau, and irrigation from the groundwater was required for dry farming. The groundwater was available at the seepage points and its downstream. Therefore, the Nazca lines would indicate the directions of the groundwater and the locations of seepage from the groundwater.

5. Conclusions

In this study, using ALOS/PRISM, the Nazca lines extraction was attempted. Moreover, comparing ALOS/PALSAR and SRTM-3, the relationship between the lines and groundwater flows was examined, from which the following conclusions were derived.

(1) Extraction of the Nazca lines was attempted using ALOS/PRISM. Since the pixel values of dark lines were near quebradas and gullies in ALOS/PRISM, extraction of the dark lines was difficult. As the widths of the lines were narrower than the resolution of 2.5 m in PRISM, extracted lines became broken partially. Therefore, more advanced extraction should be attempted for images with less than resolution (Sakurai *et al*., 2005).

(2) Examining the contour lines and extracted lines, the thin bright lines of ALOS/PALSAR and the Nazca lines coincided, directing to northeast of the highland and southwest of the lowland. The Nazca lines would indicate the position and direction of the groundwater flow which flowed from the surrounding mountains, while the pictures of animals and plants would indicate seepage points.

(3) "Astronomical calendar" theory was dominant before. However, recently the exact field survey was carried out for lines and difference between lines and the movement of the sun was detected obviously. Then, this theory became inferior to "ceremony of harvest prayer" theory by Sakai (2008). The latter theory became dominant. For the ancient Nazca people, agriculture was very important in the Nazca Desert on the arid plateau and irrigation from the groundwater was required for dry farming. The groundwater was available at the seepage points and its downstream. Therefore, the Nazca lines would indicate the directions of the groundwater and the locations of seepage from the groundwater.

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