TELEDETEKCJA ŚRODOWISKA
dawniej „Fotointerpretacja w geografii"
Tom 54 (2016/1) s. 61-73
ISSN 0071-8076

POLSKIE TOWARZYSTWO GEOGRAFICZNE
ODDZIAŁ TELEDETEKCJI I GEOINFORMATYKI
http://www.ptg.pan.pl/?Teledetekcja_%A6rodowiska

Aerial photographs of mainland China acquired by U-2 spy planes: their characteristics and potential uses

Zdjęcia lotnicze Chin kontynentalnych wykonane z samolotów U-2: ich cechy i potencjalne zastosowania

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Abstract

This paper reported characteristics of aerial photographs of mainland China taken by U-2 spy planes, which were archived and made public in NARA II of USA, and discussed the possibility to use them for environmental studies. U-2 photographs of China, which have high ground resolution of about 75cm were mainly taken in the first half of 1960s. Large amount of photographs including oblique photos as well as overlapped vertical photos covers vast range of China and enable us to use for detailed stereoscopic interpretation as well as creating ortho photos and digital surface models. Case studies in Loess Plateau (Shaanxi Province, China) showed the possibility of detailed observations of land features and land uses such as cave dwellings, check dams, agricultural terraces and cultivated crops, as well as estimation of the amount of gully erosion. In the process of archival research in NARA II, however, various inconveniences were found and improvement of retrieval system were desired.

Key words: U-2, aerial photo interpretation, NARA II, Loess Plateau, China

W artykule opisano charakterystykę zdjęć lotniczych Chin kontynentalnych wykonanych przez samoloty szpiegowskie U-2, które zostały zarchiwizowane i upublicznione w NARA II w USA, a także omówiono możliwości wykorzystania ich w studiach ochrony środowiska. Fotografie lotnicze z samolotów U-2, wykonanych nad terytorium Chin, mają wysoką rozdzielczość terenową, wynoszącą około 75 cm, zostały wykonane głównie w pierwszej połowie lat sześćdziesiątych XX wieku. Duża liczba zdjęć, w tym zdjęcia skośne, a także zdjęcia pionowe w pokryciu stereoskopowym obejmują znaczną powierzchnię Chin. Pozwalają one na szczegółową interpretację stereoskopową, jak również na tworzenie ortozdjęć i cyfrowych modeli terenu. Studia przypadków na płaskowyżu lessowym (prowincja Shaanxi, Chiny) wskazały na możliwość szczegółowych obserwacji cech terenu i użytkowania gruntów, takich jak mieszkania w jaskiniach, tamy kontrolne, tarasy rolnicze *i pola uprawne, a także oszacowanie wielkości erozji. W procesie korzystania z archiwalnych zasobów zdjęć w NARA II (National Archives and Records Administration – USA) stwierdzono różne niedogodności i pożądane było ulepszenie systemu pobierania zdjęć.*

Słowa kluczowe*:* U-2, interpretacja zdjęć lotniczych, NARA II, Płaskowyż lessowy, Chiny

1. Introduction

Aerial photography technology emerged concurrently with the development of engine-powered airplanes in the early 20th century. The technology flourished first during World War I for the purpose of military reconnaissance, especially on the battlefields in Europe, and later during and after World War II, when aerial photographs were acquired all over the world for military and cartographic purposes. After serving their original purposes, large amounts of aerial photographs have been archived in public record offices in the USA, UK, and other countries, and many of the photos are available for public use. These archival sources are excellent for determining historic land use and land cover in various regions of the world, especially for periods before the 1970s when other remote sensing data was not yet available. These archives provide many benefits for regions and countries where access to topographic maps and aerial photographs is strictly limited, such as in mainland China. Aerial photographs acquired in the early 20th century and archived in other countries can offer a valuable source for quantitative analysis of long-term environmental changes and land use/land cover analysis in regions that do not possess such archives.

Research has been conducted using Japanese-created maps of the Asia-Pacific region before and during World War II, and on land cover/land use dynamics in the Loess Plateau of Northern China (Sato et al. 2012; Kobayashi 2012). During archival research on maps and photos in the National Archives and Records Administration at College Park (NARA II) in the United States, we became aware of the public availability of aerial photographs taken by U-2 spy planes. The target regions and countries of these photographs were China, Cuba, Southeast Asia, New-Guinea, the Soviet Union, and other countries, and there existed a large number of photos acquired over China. The use of photographs acquired by the Corona satellite for environmental studies and determination of historic land use/land cover is well known. In spite of the flight altitude of over 20,000 m above ground, the ground resolution of the U-2 photos is approximately 0.76 meters (Corona photos are approximately 7.6 meters), and stereoscopic interpretation is possible using overlapping stereo pairs.

The acquisition period of U-2 photographs over China available from NARA II ranges from 1957 to 1978, but most photos were obtained during the first half of the 1960s. After foundation of the People's Republic of China in 1949, the central government developed new policies aimed at rapid industrial development, especially in the era of the 'Great Leap Forward' (1957-1962). During this time, large-scale water conservancy, civil engineering, and iron-making projects were implemented in rural areas on a nation-wide scale, and as a result, large-scale environmental alteration and destruction occurred (Dikötter 2010). However, the actual conditions during that time have not been verified qualitatively or quantitatively, and most reports are based on speculation and fragmented sources. Given the state of environmental studies during the mid-20th century in China, the possibility of using U-2 photographs for environmental studies is appealing.

In this paper, we describe the framework of the U-2 reconnaissance project in the USA, the characteristics of the cameras and films, and details of the archival information available from NARA II regarding U-2 films of China, including the areal coverage and the process of browsing and investigating microfilm overlays. Finally, we use U-2 photographs of the Loess Plateau region to examine possibilities for interpretation and analyses.

2. Outlines of U-2 spy planes and characteristics of photographs

The Lockheed U-2 spy plane was developed as a reconnaissance aircraft under utmost secrecy, and its flight began in 1956. The initial missions of the U-2 reconnaissance plane were aimed mainly at imaging facilities for the development of nuclear weapons and missiles in the Soviet Union and eastern European countries. Because the U-2 flew in the stratosphere at 20,000 meters above ground, at the time, the Soviet Air Force had no fighter aircraft able to intercept the U-2. However, during a reconnaissance flight over the Soviet Union, the U-2 was shot down by a Soviet S-75 surface-to-air missile in May of 1960, and the pilot of the U-2 was taken captive. After this incident, the existence of the U-2 became known to the world, and U-2 reconnaissance flights over the Soviet Union ceased. With the development of the CORONA satellite in 1959, reconnaissance activities over the Soviet Union were taken over by the CORONA program, and U-2 reconnaissance missions targeted mainly China. Before the U-2 was shot down, the CIA was preparing for reconnaissance flights over mainland China by training pilots of the Republic of China Air Force as U-2 pilots, and in 1962, the U-2 reconnaissance flights over China began in earnest.

The Republic of China (RC) Air Force had implemented reconnaissance flights over mainland China using other aircraft in secret cooperation with the USA prior to this time, and the troop was called "The Black

Bats". With regard to the U-2 reconnaissance mission, a specific troop called "The Black Cats" was founded in order to conceal the relationship with the USA. The reconnaissance flights of the Black Cats over China were implemented based on the approval by the National Security Council, the President of the USA, and the government of the Republic of China. The main purpose of the reconnaissance flights over China was the detection of facilities for the development of nuclear weapons, submarines, military airports, and missile bases. Exposed films were sent to the USA and copied positive films were sent back to the RC (Pedlow and Welzenbach 1992). As the air-defense capability of China improved, the frequency of continental over-flights decreased post-1968 and was replaced with electronic reconnaissance. The total number of flights over continental China during 1962-1968 was 104, or 220 flights with the inclusion of electronic reconnaissance flights implemented after 1968. During this time, five airplanes were shot down, two pilots died, and three people were taken captive. Five pilots died because of accidents during exercises.

At different times, the U-2 was equipped with at least six different types of cameras, and the camera used for taking aerial photographs in China was called "B camera" (Fig. 1). The B camera was a 36-inch focal length swinging camera, which had seven 'stop and shoot' positions (left, right, 1, 2, 3, and vertical) while moving left and right (Pocock 2000: 257). The outer oblique positions covered a large geographic range up to the horizon.

The film used in one flight was 1220-1980 meters long and over 200 kg in weight, therefore the film was split in two, and the each roll was wound from opposite

Fig. 1 The U-2 spy plane (upper photo) and the U-2 B camera (lower photo) exhibited in the National Air and Space Museum in Washington D.C.

Ryc.1 Samolot szpiegowski U-2 (górne zdjęcie) i kamera U-2 B (niższe zdjęcie) wystawione w Muzeum Narodowym Lotnictwa i Przestrzeni Kosmicznej w Waszyngtonie, D.C.

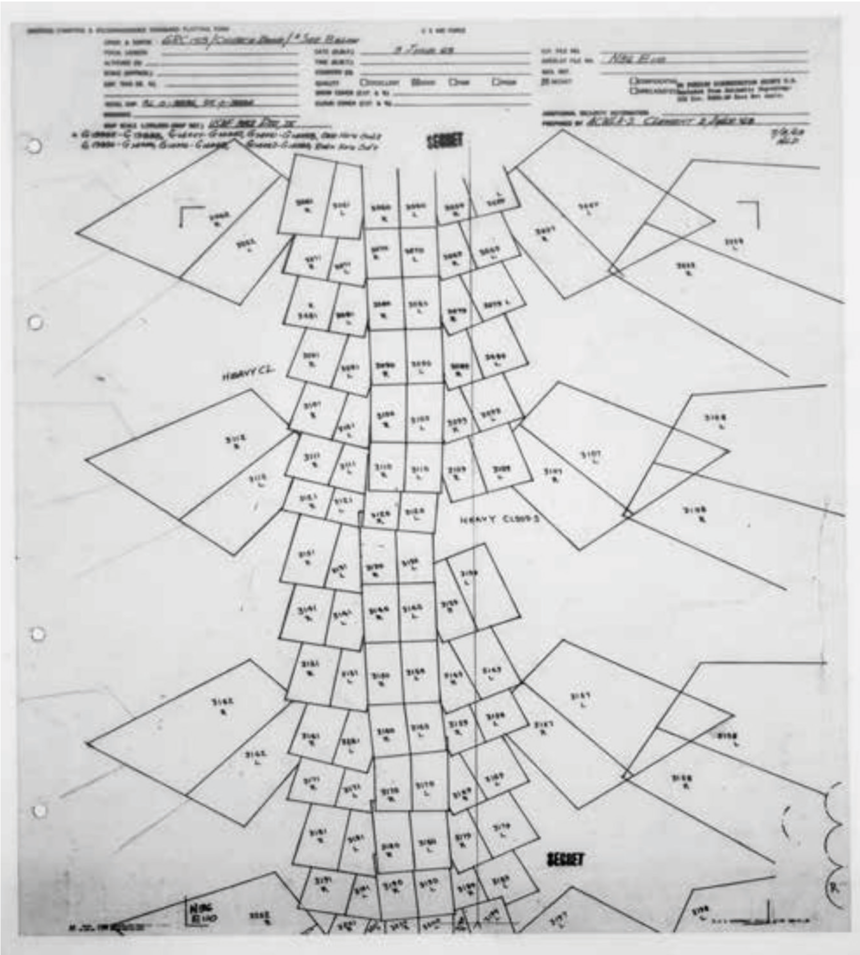


Fig. 2. An example of an aerial flight microfilm overlay of the U-2 photographs (mission-GRC 153; N36º/E110º)
Ryc. 2. Przykład skorowidza z pokryciem zdjęciami z lotu U-2 (misja-GRC 153; N36º E 110º)

directions ("contra-winding film") to balance the airframe. This meant each image was exposed on each of the two 9 x 18 inch rolls, and the final image was 18 x 18 inch. Due to the split of the film in the center, there was a narrow gap (no exposure) between the left and right film. According to our measurements, the gap was approximately 150 m wide. Although this issue with the B camera was not considered a large problem in the early stages of development, during the first flight mission over Eastern Europe with a purpose to reconnoiter airstrip buildings, the pilot failed to photograph the airstrip because he flew directly overhead (Pocock 2000: 103).

As many as 8,000 photos (16,000 if the left and right images are counted separately) were acquired in one flight, exposed, divided into tens of rolls, and packed into individual canisters after the completion of each mission. (For example, a mission called GRC-153, which was the source of our interpretation sample, was stored in 59 canisters.) At NARA II, microfilm overlays acquired for every 1º latitude/1º longitude range are available for searching, regardless whether U-2 photographs exist in a specific area or not. For investigating U-2 films, we had to check the flight number and the photo numbers and then determine the corresponding catalogue numbers ascribed to each canned film before ordering. However, it is unknown in which canister (among tens of canisters) the targeted photographs are stored until checking the information on the lid of the canister. In the worst case, this means we had to order and check all the canisters of the same mission. Films are stored in a facility in Kansas, and it requires several days before the data can be evaluated at NARA II. Moreover, no more than 10 canisters can be ordered at one time. Cloud cover is common and affects photo interpretation, and without seeing each image, it is difficult to evaluate the details of each photograph, although general cloud cover percentages are marked on the microfilm overlays.

3. The U-2 films of mainland China at NARA II: coverage and ordering process

We investigated all the microfilm overlays and catalogues regarding U-2 photographs of China in the Cartographic and Architectural Research Room (the 3rd floor) at NARA II to determine the coverage of the U-2 photographs available to the public. There were records for 293 flights over China between 1957 and 1978 (there were another two flight records from 1937 in the same catalogue). These records may include the reconnaissance flights over China by another aircrafts. The number of U-2 flights over China has been estimated as 104 between 1962 and 1968 (Pedlow and Welzenbach

1992: 244). Some records share the same mission name but have different photography dates, so it was assumed that some missions had a duration of several days. Aside from China, other targeted countries (areas) of the U-2 were Cuba, Indonesia/New Guinea, the Soviet Union, and others. Several missions were named "Southeast Asia", and many of them were assumed to be missions over Vietnam and Laos.

Each target location and coverage is recorded in microfilm overlays for an area covering 1º latitude and 1º longitude (Fig. 2). Microfilm overlays of the U-2 photographs can be specified based on the unique configuration of the coverage of oblique photos acquired with the B camera (see Fig. 2) and the recorded mission names. We attributed the U-2 overlays with geographic coordinates using GIS to measure the area and distance of each image. The width of the vertical image (the sum of both sides of one image) was approximately 10 km, the width between the left and right low oblique images was approximately 36 km, and the width between left and right medium oblique images was approximately 100 km (Fig. 3). The actual films acquired by the U-2 include two additional (left and right) high oblique images whose coverage reaches to the horizon. Because this coverage is too vast to be depicted in overlays, only partial lines showing the angles of the photos are depicted in the overlays (Fig. 4). We created a map showing the entire coverage of U-2 photographs of vertical and low/medium oblique photos (namely 5 types of images) over China by using a buffer of 5 km, 18 km, and 50 km from the center line of the flight route, based on our measurements of the assumed coverage (Fig. 5). Fig. 5 shows the large area covered by the photos, though there is almost no photo in the Tibet Autonomous Region, Chinghai, and Sichuan Province. The area based on the 50 km buffer was 2,913,731 square km, and this represents the area covered by the five types of images. The net area, which excluded the area outside the national boundary and coast line, was 2,586,523 square km, which was equivalent to about 28% of the total land area of China. The area of coverage of the vertical images was 420,784 square km, which was equivalent to less than 5 % of the total land area.

When researching a specific area of the U-2 films, first we need to check the coverage and mission number from the overlays, and next the ID numbers of the same mission in the catalogue. As mentioned before, the large number of images acquired in a flight area, coupled with the lack of knowledge of which image is located in which canister, renders it difficult to determine the target image prior to ordering (Fig. 6). Therefore, in the worst case we need to order tens of canisters in order to obtain a targeted image. We inspected the films we had ordered in the reading room for aerial photographs at NARA II using a designated viewing platform. We took photos and scans of the photographs, since it is allowed to bring this type of equipment into the room. Fig. 7 shows a sample of a scanned U-2 vertical image of the Yellow River area (Shaanxi and Shanxi), acquired in June 1963.

4. Interpretation of the U-2 photographs: the case of the Loess Plateau area

We have conducted surveys on land-use dynamics in the Loess Plateau area (mainly Boata district, Ansai, and Yanchuan country in Shaanxi Province) since 2004 to examine the effects of the "Grain for Green Project". This is a national project to transform agricultural fields and grazing areas on steep slopes into forest, as well as to encourage large-scale terrace construction (Sato et al. 2012). As a result, we have refined a process of large-scale afforestation and terracing in this area since 1999, but it is difficult to determine land cover/land use dynamics prior to 1998. It is well-known that the Chinese government has implemented large-scale land modifications with many grand industrial policies since the foundation of the present regime. For example, during the Great Leap Forward (1958-1962), it is said that iron manufacturing in rural areas and large-scale water conservancy engineering project promoted at a nationwide scale have caused vast expanses of deforestation and environmental degradation (Diköter 2011). Based on our surveys in rural areas of the Loess Plateau, it was discovered that terracing of agricultural fields and check-dam construction (described below) using human power for material handling occurred during the Great Leap Forward and the Great Cultural Revolution. Apart from these artificial land modifications, the extent of soil erosion in the Loess Plateau was considered intense. The amount of annual soil runoff was estimated at 1.64 billion tons, which equals the projected value for all large rivers in the world (Shi and Shao 2000). Although there are several ways to estimate the amount of soil runoff in the Loess Plateau, the most common approach is to measure the amount and concentration of soil in the river. Another method is the automatic detection of soil runoff using a digital elevation model (DEM) (Matsunaga et al. 2009), but there is no known approach to measure the amount of long-term soil runoff calculated directly from gullies. The U-2 photographs can be used to measure and evaluate the real extent of gully erosion over the last 50 years.

The U-2 flights over the Loess Plateau (mission GRC-153) were implemented mainly along the Yellow River on 3 June 1963, soon after the upheaval of the Great Leap Forward waned. By reconstructing historic land cover/land use during this time and comparing it with present conditions, we expect to determine long-term environmental changes occurring during the latter half of the 20th century. Details of those changes have remained uncertain without having effective resources to determine historic environmental conditions.

In the remainder of the paper, we first discuss the possibilities for interpretation of the U-2 photographs, showing features such as houses, agricultural fields, crops, and check-dams detected in the actual images. Subsequently, we attempt to observe and measure the extent of gully erosion and other land cover/land use changes in the Loess Plateau by creating orthoimages

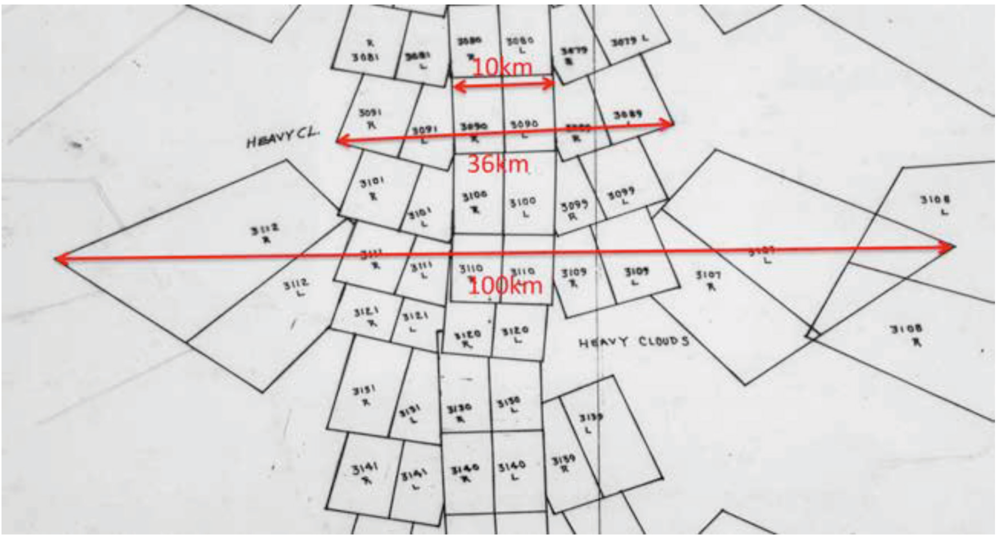


Fig. 3. Approximate land coverage of the U-2 photographs calculated from GIS.
Ryc. 3. Przybliżone Szkic pokrycie zdjęciami lotniczymi z U-2 po geometryzcji metodami GIS.

Fig. 4. An example of a high oblique U-2 photograph.
Ryc. 4. Przykladowe zdjęcie ukośne wykonanego z dużej wysokości z pokładu U-2.

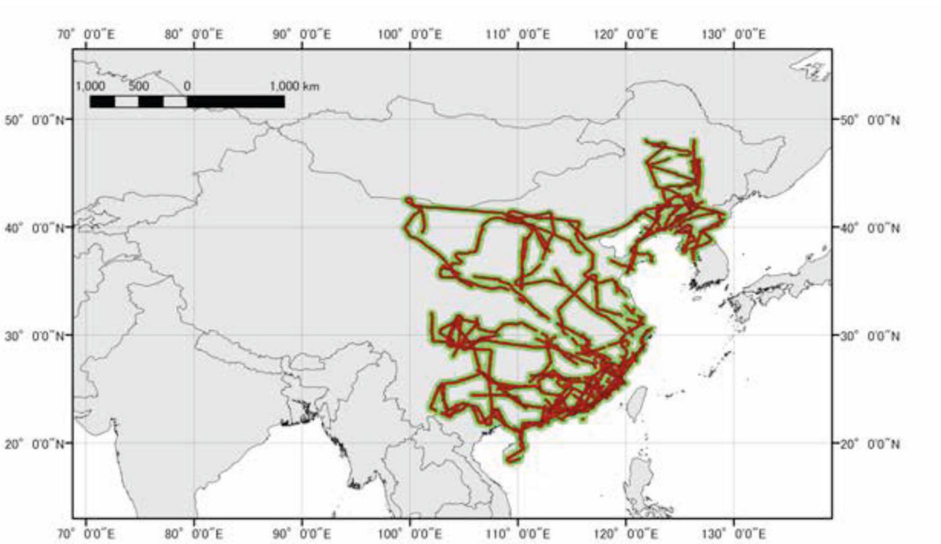
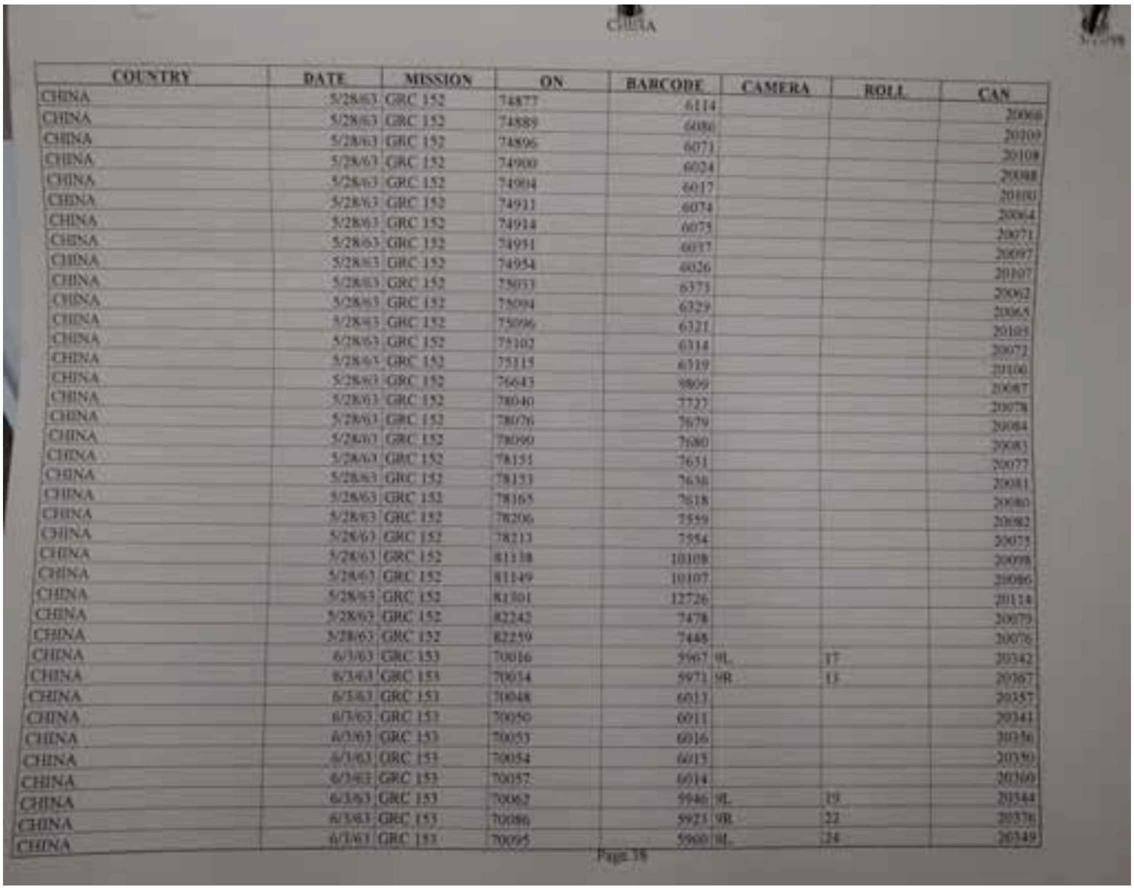


Fig. 5. The coverage of the U-2 photographs over China.
Ryc. 5. Pokrycie zdjęciami lotniczmi z U-2, wykonanymi nad terytorium Chin.



CHINA

COUNTRY	DATE	MISSION	ON	BARCODE	CAMERA	ROLL	CAN
CHINA	5/28/63	GRC 152	74877	6114			20066
CHINA	5/28/63	GRC 152	74889	6086			20109
CHINA	5/28/63	GRC 152	74896	6071			20108
CHINA	5/28/63	GRC 152	74900	6024			20088
CHINA	5/28/63	GRC 152	74904	6017			20100
CHINA	5/28/63	GRC 152	74911	6074			20064
CHINA	5/28/63	GRC 152	74914	6075			20071
CHINA	5/28/63	GRC 152	74951	6037			20097
CHINA	5/28/63	GRC 152	74954	6026			20107
CHINA	5/28/63	GRC 152	75033	6373			20062
CHINA	5/28/63	GRC 152	75094	6329			20065
CHINA	5/28/63	GRC 152	75096	6321			20105
CHINA	5/28/63	GRC 152	75102	6314			20072
CHINA	5/28/63	GRC 152	75115	6319			20106
CHINA	5/28/63	GRC 152	76643	9809			20087
CHINA	5/28/63	GRC 152	78040	7727			20078
CHINA	5/28/63	GRC 152	78076	7679			20084
CHINA	5/28/63	GRC 152	78090	7680			20083
CHINA	5/28/63	GRC 152	78151	7631			20077
CHINA	5/28/63	GRC 152	78153	7636			20081
CHINA	5/28/63	GRC 152	78165	7618			20080
CHINA	5/28/63	GRC 152	78206	7559			20082
CHINA	5/28/63	GRC 152	78213	7554			20075
CHINA	5/28/63	GRC 152	81138	10108			20098
CHINA	5/28/63	GRC 152	81149	10107			20086
CHINA	5/28/63	GRC 152	81301	12726			20114
CHINA	5/28/63	GRC 152	82242	7478			20079
CHINA	5/28/63	GRC 152	82259	7448			20076
CHINA	6/3/63	GRC 153	70016	5967	9L	17	20342
CHINA	6/3/63	GRC 153	70034	5971	9R	13	20367
CHINA	6/3/63	GRC 153	70048	6013			20357
CHINA	6/3/63	GRC 153	70050	6011			20341
CHINA	6/3/63	GRC 153	70053	6016			20356
CHINA	6/3/63	GRC 153	70054	6015			20350
CHINA	6/3/63	GRC 153	70057	6014			20360
CHINA	6/3/63	GRC 153	70062	5946	9L	19	20344
CHINA	6/3/63	GRC 153	70086	5923	9R	22	20376
CHINA	6/3/63	GRC 153	70095	5900	9L	24	20349

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Fig. 6. An example of the U-2 catalogue page (upper photo) and the information recorded in the lid of the film canister (lower photo).
Ryc. 6. Przykład strony katalogowej zdjęć wykonanych z U-2 (górne część ryciny) i informacje zapisane na pokrywie kasety filmowej (niższa część ryciny).

Fig. 7. An example of a U-2 vertical photograph.
Ryc. 7. Przykład pionowego zdjęcia lotniczego wykonanego z U-2.

of the U-2 photos and comparing them to recent high resolution satellite images.

4.1. Interpretation of features detected in the U-2 photos

Traditional side-cave dwellings called Yao Tong in the Loess Plateau were created by excavating the loess in hill slopes (Fig. 8). These dwellings are difficult to detect in satellite images and aerial photographs. Fig. 9 is a part of the U-2 photograph taken in Yulin, Shaanxi. We can detect many Yao Tong in steep slopes in the photo (see one marked by a small red circle in the figure). The large circle encompasses terraced agricultural fields, which we assumed were newly created at the time. Many of these narrow terraces were created for the most part during the Great Leap Forward and the Great Cultural Revolution using human power and material handling. These terraces are still present today, and the areas are easily distinguished from large-scale terraces created by power equipment after 1999 (Fig. 10). Using photo interpretation, we can estimate to what extent terraces were created during the Great Leap Forward.

Fig. 8. Yao Tongs in a slope of the Loess Plateau.
Ryc. 8. Jaskinie mieszkalne tzw. Yao Tong, na zboczach Płaskowyżu Lessowego.

Fig. 9. An example of a low oblique U-2 photograph.
Ryc. 9. Przykład zdęcia lotniczego ukośnego wykonanego z niskiego pułapu, z pokładu U-2.

We were able to identify in part certain crops cultivated on the slopes by interpreting shadow and texture in the images. Though common millet is difficult to identify because it is sown in late May to early June, we can see other kinds of shoots of the crop clearly in the field circled with a dotted red line in Fig.11. Supposedly, the crop is either potatoes or soybeans, which are sown in April to early May in this region. In early June, many crops sown in spring are difficult to identify, but wheat sown in the autumn is maturing just prior to the harvest in late June. The field marked by a red circle in Fig. 11 was identified as wheat. Because common millet, foxtail millet, and soybeans have to be sown prior to the harvest of wheat in this region, double cropping of summer and winter crops is impossible, and wheat is cultivated mainly on north slopes and used for self-sufficiency due to climatic reasons and low yields. Most of the fields where wheat was cultivated became targets for afforestation of the Grain for Green Project after 1999 and disappeared. We can determine planting patterns during that time by distinguishing summer and winter fields seen in the U-2 images. In Fig. 11, the small trees located near rivers are jujube plantations. The area around the main stream of the Yellow River where the loess is not thick is suitable for jujube cultivation, and these plantations still exist today. Jujube plantations replaced wheat and millet and increased considerably after the Grain for Green Project because jujubes were chosen as targeted trees for afforestation in this area. We can determine the amount of jujube plantations at that time by using the U-2 images.

In Fig. 12, we can see check-dams that had been already completed at that time. A check-dam is a technological structure for agriculture and soil conservation. The structure retains and accumulates soil outflowing from the upper slopes and is constructed in valley floors for the purpose of draining water and accumulating soils used for cultivation (Fig. 13). Although check-dams emerged as early as the era of the Ming dynasty, work

Fig. 10. Agricultural terraces created using power equipment (upper photo) and by human power (lower photo).
Ryc. 10. Tarasy uprawne tworzone za pomocą urządzeń mechanicznych (górne zdjęcie) i pracy ręcznej (dolne zdjęcie).

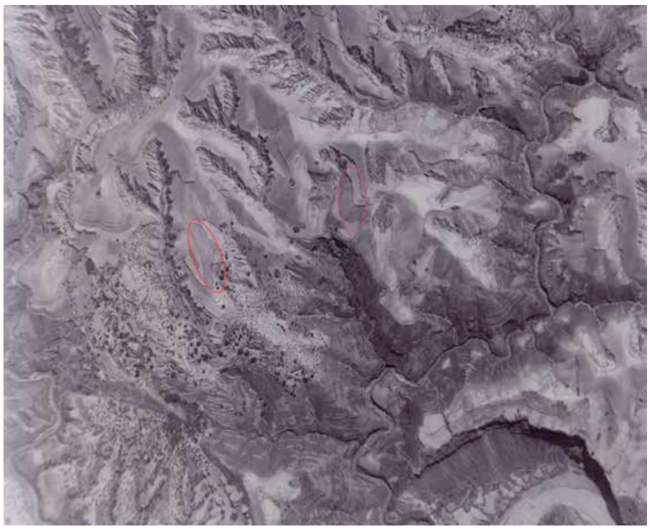

Fig. 11. An example of the U-2 photograph showing agricultural fields and jujube trees.
Ryc. 11. Przykład zdjęcia lotniczego z U-2 przedstawiającej pola uprawne i zarośla jujube.

Fig. 12. An example of the U-2 photograph showing check--dams.
Ryc. 12. Przykład zdjęcia lotniczego wykonanego z U-2, przedstawiające tamy (groble) kontrolne w obrębie doliny rzecznej, przeciwdziałające erozji.

Fig. 13. Check-dam built during the Great Cultural Revolution.
Ryc. 13. Tamy kontrolne zbudowane podczas Wielkiej Rewolucji Kulturalnej.

on the present multi-functional check-dams began during the time of the Great Leap Forward. Check-dams were constructed during and after the Great Cultural Revolution, and today they are still built, although we could not determine the number of check-dams built in recent years. Fig. 13 shows a check-dam created during the Great Cultural Revolution. According to our survey of the U-2 images, not many check-dams were built during the Great Leap Forward, and presumably, most were built after the late 1960s. Many large-scale water conservancy projects were implemented during the Great Leap Forward, and small projects such as check-dam construction for increasing agricultural production was not promoted as actively.

In the U-2 photographs, we can identify and interpret agricultural fields and vegetation on steep slopes and gullies extending downward from the fields. Cultivation and grazing on steep slopes greater than 25 degrees were prohibited after the start of the Grain for Green Project. Therefore, these areas are covered currently by shrubs and grasses. During that period, many steep slopes were bare of vegetation, because the land cover was lost due to grazing by goats and clearing for wood. The amount of vegetation on a slope influences the amount of erosion to a large degree. How did gully erosion progress during the last half century? How did vegetation on the slopes change before and after the Grain for Green Project? The extent of the progress of gully erosion can be measured quantitatively by comparing orthorectified U-2 images with recent high-resolution satellite images. We demonstrate a preliminary approach and the results in the following section.

4.2. Observation of gully erosion and vegetation on slopes using orthorectified U-2 photos

We created two orthogonal projection images of U-2 photographs taken on 3 June 1963 (GRC-153, photo No. 3070 Light, SW 36.89°N/110.33°E, NE 36.98°N/110.40°E; GRC-153, photo No. 3065 Light, SW 36.94°N/110.40°E, NE 37.03°N/110.46°E) in Yanchuan and Qingjian, Shaanxi Province using ERDAS IMAGINE ver.2013. We used SRTM-1 as a DEM and an orthocorrected/pansharpened WorldView satellite image taken on 15 February 2013 for ground control point (GCP) collection. Fig. 14 shows the completed ortho image and a 3D representation.

We compared two points in time (the U-2 photo and the satellite image) focusing on two examples of gullies. The first case focused on an area where the slope above the gully was cultivated in 1963 and the current vegetation is a jujube plantation (Fig. 15; 36.928°N; 110.374°E). The second case focused on a largely modified area where the slope above the gully was cultivated in 1963, but currently it consists of terraced fields with a check-dam built below the gully (Fig. 16; 36.932°N; 110.366°E). Compared to slope cultivation, the construction of terraced fields may prevent soil erosion, but there may also be a risk of losing additional soil in the construction process. In addition, terrace cultivation cannot prevent soil runoff entirely, even though the process is expected to be slower than for slope cultivation.

We delineated the extent of the gullies by digitizing polygons and calculating the area of the gully. The area of the gully in 1963 was 3355 square meters and increased to 4802 square meters in 2013, indicating that the area of the gully expanded considerably over 50 years (Fig. 15). We observed areas where the margins of the upper fields were eroded to a large degree, and land located at the center of the gully was eroded and lost. For the site shown in Fig. 16, the area of the gully was 17,521 square meters in 1963 and 18,513 square meters in 2013, showing that the gully expansion was not as extensive as in the previous areas. The rate of increase of the gully area was 43% in Fig. 15 and 5.7% in Fig. 16. The result demonstrate that rate of increase of gullies differs greatly by location.

It was expected that gully expansion could differ based on various conditions such as land use around

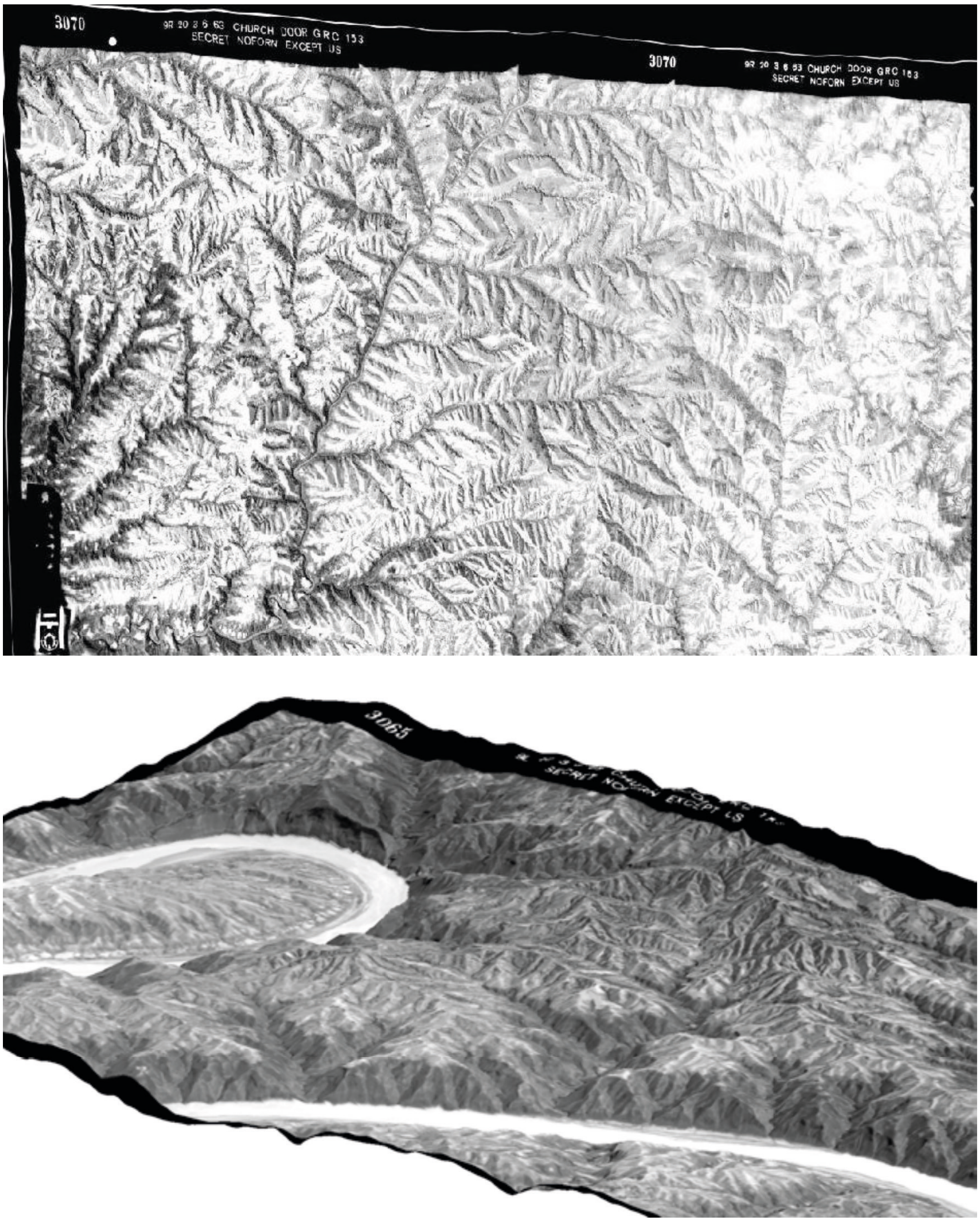

Fig. 14. Completed ortho image (upper photo) and an example of 3D representation (lower photo).
Ryc. 14. Obraz ortofoto (górna część ryciny) i przykładowa prezentacja 3D 9dolna część ryciny).

the gully, gradient of escarpment, gully vegetation, and the surrounding slopes. By examining the relationship of the extent of gully expansion with various factors using the U-2 photographs, we may find effective ways to control soil runoff in the Loess Plateau.

5. Conclusion

In this paper, we first depicted the extent of U-2 photographs acquired over mainland China, and second examined the possibility of interpretation and other utilization of the photographs; these photographs are available to the public at NARA II. The U-2 photographs depicting land use/land cover of the mid-20th century with high resolution are valuable sources for studies of the dynamics of current environmental conditions in China, given that sources for determining land cover/land use before the 1970s are quite limited. We recognized that detailed observations of land surfaces such as distribution of cave dwellings, agricultural terraces, check-dams, trees, and cultivated crops was possible, and that we could also use the photographs for quantitative analysis such as expansion of gully erosion and escarpment vegetation in the Loess Plateau.

However, we also discovered several problems associated with the use of the U-2 photographs. Similar to other aerial photographs, the time and spatial coverage of the U-2 photos are limited. Although there is vast coverage if the oblique photographs are included, the potential for quantitative analysis of oblique photographs is unknown. However, orthorectification or DEM generation of the oblique photos using recent aerial triangulation technology may be possible. Aside from the U-2 photographs, there are other aerial photographs acquired over China for reconnaissance purposes by the

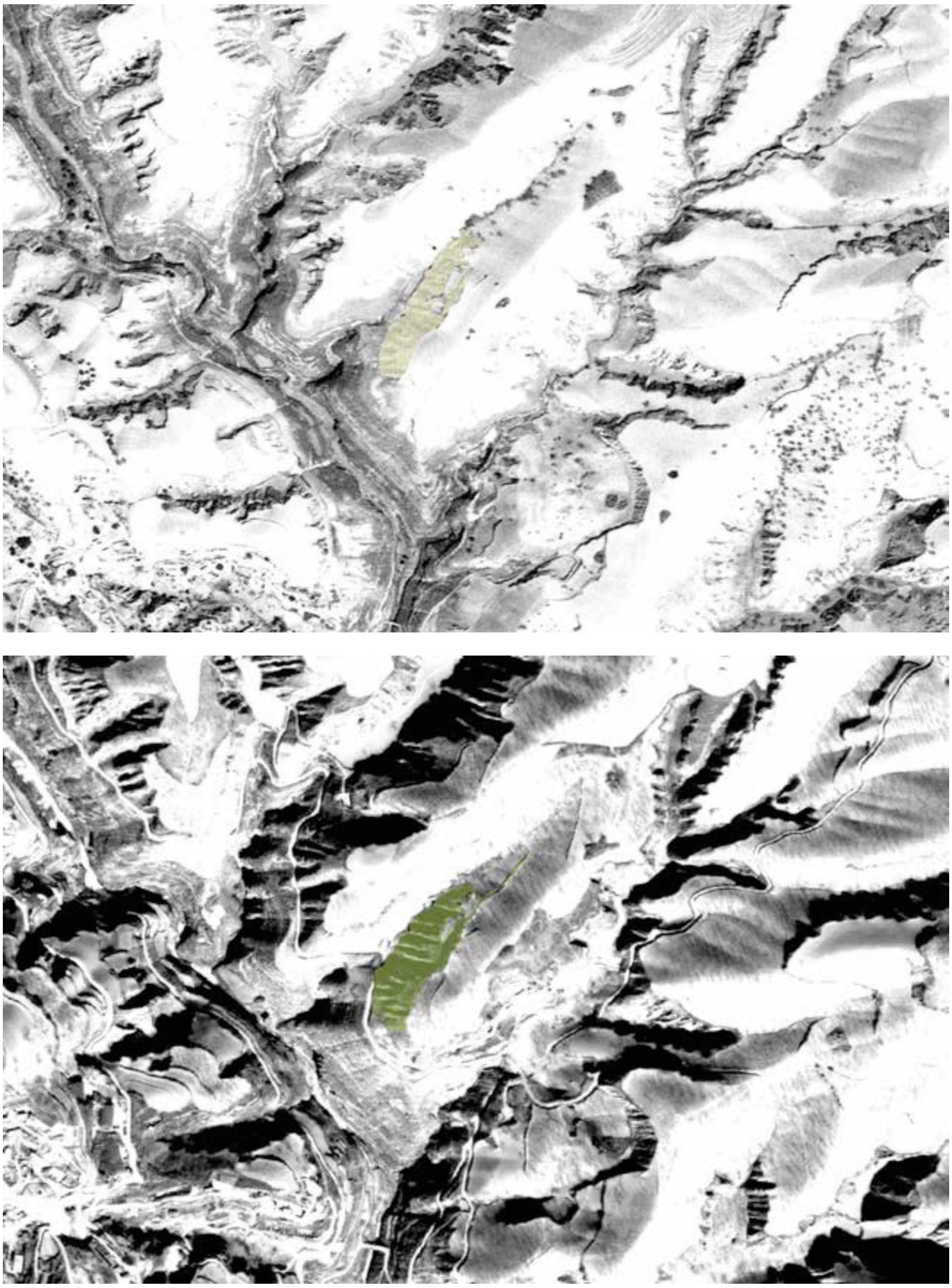

Fig. 15. Expansion of gully erosion (1963-2013).
Ryc. 15 Rozwój erozji wąwozowej w latach 1963-2013.

US Air Force in the 1940s; these photos are archived at NARA II, although their coverage is limited. Using these sources in conjunction with the U-2 photos, land cover/land use change before and after the Great Leap Forward could be clarified. We plan to investigate the coverage of other photographs for this purpose.

Various inconveniences associated with ordering the U-2 photos from NARA II also presented a problem. As mentioned in the proceeding chapters, it requires several days to investigate and search microfilm overlays and obtain the desired U-2 film. Therefore, approximately ten days to two weeks are required to investigate one mission. In order to promote academic use of the U-2 photos, these problems should be addressed to improve access to the photo catalogues.

[Acknowledgement] This study was supported by JSPS KAKENHI Grant (No.15H05131 and No. 24240115).

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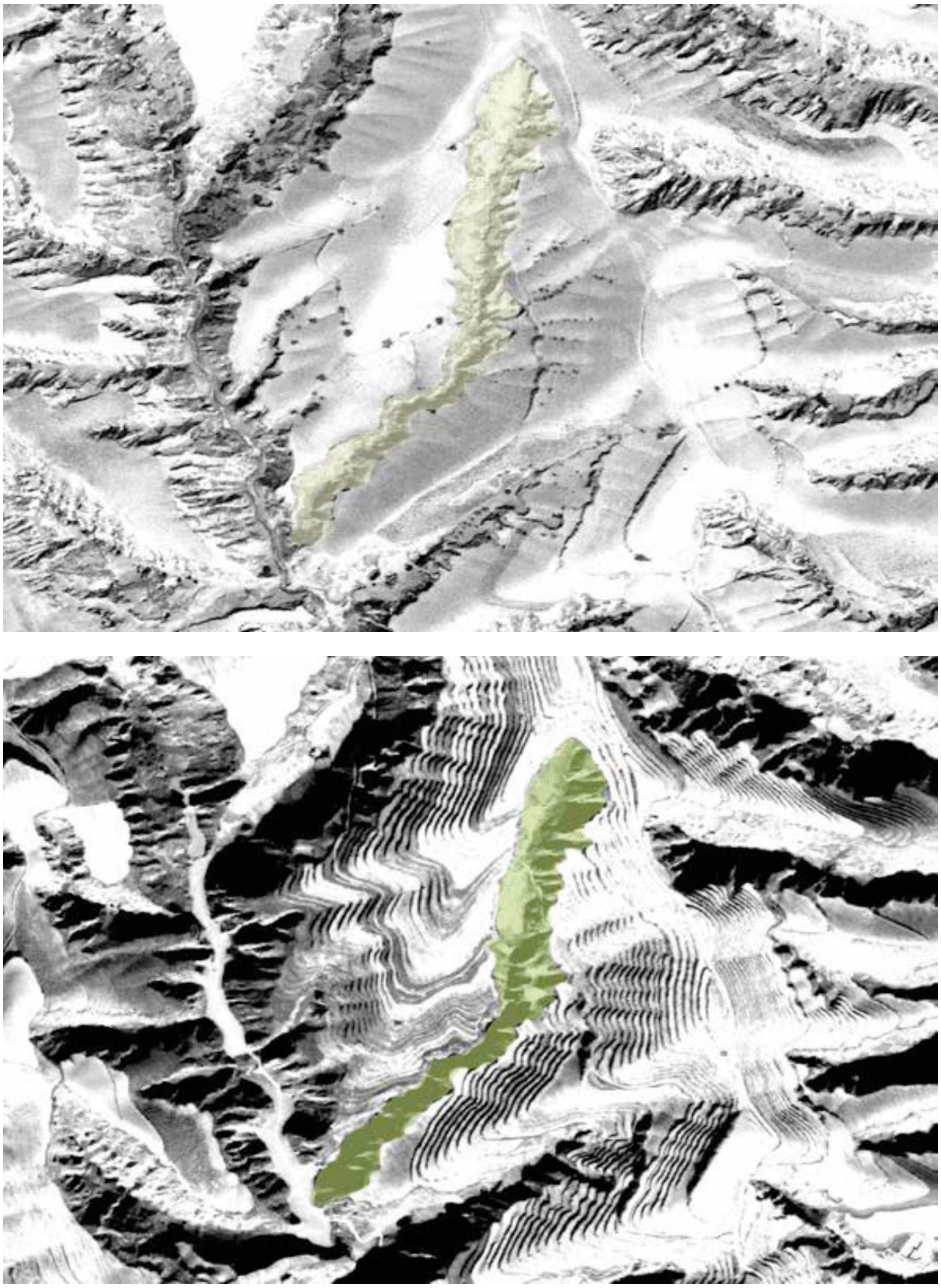

Fig. 16. Gully erosion and land modification (1963-2013).
Ryc. 16. Erozja wąwozowa i modyfikacja stoków wąwozów przeciwdziałających erozji (1963-2013).

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Otrzymano: 1 lipca 2016
Zaakceptowano: 12 grudnia 2017
Article first received: July 1. 2016
Accepted: December 12.2017