COMPARATIVE INVESTIGATION OF GEOMORPHOLOGY BY AERIAL PHOTOGRAPH INTERPRETATION (API), DIGITAL AERIAL PHOTOGRAPH INTERPRETATION (DAPI) AND AIRBORNE LIGHT DETECTION AND RANGING (LIDAR) SURVEY: A CASE STUDY IN THE FORMER MA ON SHAN OPEN-PIT IRON MINE

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ABSTRACT: Aerial photograph interpretation (API) has been widely applied to the study of geomorphology, which is an essential component of natural terrain hazard study and other geotechnical projects. With the extensive archive of aerial photographs taken in Hong Kong, geomorphological features and change in landform can be well observed from API. In recent years, due to technological advancement, new remote sensing techniques enabling geomorphological studies have been evolved, which may supplement the traditional API. These techniques include digital aerial photograph interpretation (DAPI) and airborne Light Detection and Ranging (LiDAR) survey. This paper summarizes the geomorphological study of the former Ma On Shan (MOS) open-pit iron mine and the adjacent natural terrain to compare the working mechanism, data availability, strengths and weaknesses of these three contemporary landscape study methods.

Mining sites in Hong Kong indicate how human activities have altered the natural environment, but have seldom been discussed in scientific papers. The study at the former MOS iron mine provides a good example to demonstrate the application of different technologies on studying geomorphological features and change in landforms over decades, and to document the impact of human activities on natural terrain. The study concludes that the techniques can provide general information on identifying and observing key morphological features such as cut slopes, tension cracks and landslides, but each technique shows different capabilities. With the appropriate and complementary application of the three techniques, the geomorphology of a region can be described in detail for examining site development history, change in landforms and identification of natural terrain hazards.

1. INTRODUCTION

Geomorphologic studies can be conducted using various techniques. On the microscopic scale, geologists take measurements and conduct surveys in the field, as well as collecting rock samples. On the macroscopic scale, geologists have to rely on other measurement tools for geomorphological mapping. **The present paper compares the use of different tools in geomorphological mapping, including API, DAPI, and airborne LiDAR.**

API is a photogrammetric method that aerial photographs (APs) have been systematically taken from the air in Hong Kong for nearly 100 years. The use of API in geotechnical practice in Hong Kong in particular, received a boost in 1978, with the establishment of an API unit, in the Geotechnical Control Office of the Civil Engineering and Development Department (CEDD) (Ho et. al, 2006). It is considered the most traditional way of studying geomorphology; DAPI is a technique applied by practitioners and Government departments for geotechnical and geological studies in recent years. It makes use of photogrammetric software, infrared transmitter, 3D glasses, and 3D mouse to generate a digital 3D model; LiDAR is a remote sensing technology that uses laser to measure the elevation of a surface. It is widely applicable in the field of geomorphology, forestry, shoreline mapping, and site selection analysis, etc. In geomorphology, the elevation point recorded by LiDAR can help us identify geomorphological features.

There is a research gap in the lack of consensus over the choice of method to be used in geomorphologic studies. Among the 3 techniques, each respective technique has been commonly used in various geomorphologic studies. However, there has been little research using all of the 3 techniques in the same study area due to the limitation of time and capital. A systematic comparison of all 3 techniques has yet to be made.

This study will examine the three major approaches, API, DAPI, and airborne LiDAR, in studying geomorphology and its effectiveness. The geomorphologic features and changes of MOS iron-ore mining site and surrounding area over decades will be studied. Comparison of the 3 approaches will be made in regard to the demonstration of the techniques in the real case scenario.

2. LITERATURE REVIEWED

API is particularly useful in geomorphologic analysis as they capture the actual topographic features from the previous moment. In Hong Kong, API is best carried out on the high-quality low-level photography taken in 1963 if the site was undeveloped at this time, when vegetation was much less than today. "1963 low-level aerial photography is considered a reference of API with their good quality of photographs… It is also very important to view the site from a more synoptic viewpoint to establish more regional relationships, the 1964 high-level photography is useful for regional mapping purposes" (Ho et al., 2006). The APs can help identify geomorphological units in the Hong Kong landscape. Parry and Ruse (2000) stated that "the basis of developing a geomorphological model of sufficient detail to assist in Natural Terrain Hazard Study is a comprehensive API. This is extremely cost-effective, even when using experienced and hence relatively costly professionals."

Digital Aerial Photographs (DAPs) are transformed from APs by several processes. First, digital images are generated through digital cameras or scanning of films. Then, a 3D model is built after identifying its Interior Orientation (IO) and Exterior Orientation (EO) parameters, with the geo-reference information provided by ground control points. The IO describes the internal geometry of the camera at the time of image capture. IO is to establish the relationship between the camera coordinate system and the image coordinate system. IO varies with the principal point, focal length and lens distortion (Wolf and Dewitt, 2000). EO describes the position and orientation of the camera when the image was taken. The x, y and z coordinates and the omega, phi, and kappa angles (rotation along x, y and z axis) of the camera are referred to collectively as the six parameters of EO. EO enables transformation between the ground coordinate system and the image coordinate system (Wolf and Dewitt, 2000). Ground control points are to orient the stereo pairs. They are some stationary points with referenced locations, i.e., unmodified coastline, remote islands. Thus, spatial information is embedded in DAPI analysis.

Airborne LiDAR is an integrated system composed of a laser scanner, an inertial measuring unit, global navigation satellite system (GNSS) receiver, and a reference ground station. It makes use of the remote sensing technology of multi-return signal. A pulse generator produces short, intense pulses with small angular width. Laser pulses are emitted from an aircraft and the pulses return when they are reflected by any object. A timer is started by the transmitted pulse, stopped by the received pulse. The signals help us obtain the spatial data in x-, y-, and z-direction (coordinates and elevation points) from all materials the pulses hit. For example, if the LiDAR signal hits a bare ground, it will only have 1 return signal. If the LiDAR signal hits a place with vegetation, it will have multiple return signals (i.e., the top of the trees, the branches, and the ground level) providing that there are voids in between to allow the passing of laser pulses. LiDAR data can be processed and visualized in GIS software for measurement and surface analysis (Dong and Chen, 2018).

3. MATERIALS AND METHODS

3.1 Aerial Photograph Interpretation (API)

API is considered as the most standard method in geomorphologic study. The geometry of the APs can be vertical or oblique, though vertical APs are more widely used. Information display on an aerial photograph very much depends on the emulsion and filter combinations, time of day of photography, the direction of sunlight, seasons and weather, and other human factors. In the case study, 331 APs at MOS open-pit iron mine from 1945 to 2018, were studied. APs were usually taken with a high percentage of forward overlap (for example, 60%) between photographs and 20-40% lateral overlap between flight lines. They were used, combined with a stereoscope, to project a 3-dimensional view of the selected site. Observation and interpretation of our geomorphologic study were greatly enhanced with stereoscopic projection. Not only did it enable observers to view an object in the form of a 3-dimensional model, but it also magnified APs up to 15 times with binoculars. In addition, APs constitute a complete record at the MOS open-pit iron mine. A reconnaissance cover of photography was taken in the 1940s to 1950s at the site, and high-quality coverage is provided from 1963. Though some of the photographs do not cover the site ideally, the series of photographs undoubtedly provide a detailed record of the topographic features in the past 50 years.

3.2 Digital Aerial Photograph Interpretation (DAPI)

DAPI is an alternative method to study geomorphology. It is a newly developed methodology in geomorphological mapping in Hong Kong. DAPI uses photogrammetric software to provide an aerial view of the selected site. It is equipped with an infrared transmitter, 3D glasses and a 3D mouse to view and control the image. The image contains photogrammetric data and geo-referencing information, that enable the automatic creation of stereo pairs on the digital platform. In the case study, 34 DAPs are generated from traditional APs. The 34 DAPs were reviewed in pairs using the software in the same view as stereoscope in API.

3.3 Airborne Light Detection and Ranging (LiDAR)

LiDAR is another commonly used method in geomorphologic study in the recent decades. GEO conducted two territory-wide airborne LiDAR surveys in year 2010 and 2020. The process of preparing LiDAR data includes data capturing, data processing and data quality checking. In the case study, these 2 sets of airborne LiDAR data are implemented in the geomorphologic study. Virtual deforestation was performed to remove all the signals hitting the vegetation. This generates ground models that tell the accurate topography of our terrain. A Digital Terrain Model (DTM) can show detail topographic information, like cut slopes and landslides, by knowing the zone of depression. LiDAR data are especially useful in the years that topographic landforms are covered by vegetation.

3D hill shade models were generated using ground elevation points to show the geomorphological features. In geomorphological analysis, GIS software allows us to generate vertical profiles of the selected sections. Slope angle maps can also be created by geoprocessing tools. They help us understand the change in slope in the region and analysis can be done in greater detail in a quantitative approach.

4. RESULTS

4.1 Comparative Geomorphology Technologies

Aerial Photograph Interpretation (API): API records the surface processes at the site in different years. It is an effective way to assess the land surface when there is less vegetation and good atmospheric conditions on the day of photo-taking. The low-level aerial photography from 1963 is considered a reference of API because of the high quality of photographs. These photographs are particularly good for evaluation of geomorphological features and materials including the distribution of colluvial deposits, saprolite, boulders and rock outcrop, allowing a good understanding of the active processes at the site prior to development. Moreover, the aerial photo-taking process is becoming more cost-effective with technological advancement. APs were taken by aircrafts, with more difficulties in controlling the altitude, locating the position, taking the photographs, etc. Nowadays, APs can be taken by drones. The altitude can be more easily controlled with precise GNSS location. This greatly enhances the mobilization, efficiency and accuracy, while reducing the cost of aerial photography.

However, the effectiveness of API can be limited by visibility, cloud, and adverse weather conditions. As the geometric information about physical objects is obtained from photographic images, the clarity of the photographs depends on the transparency of the medium (air) that photons pass through. Dust, water vapors and rain may block the topographic features to be captured. In years 1978, 2003, and 2009 (#23119, #CW50213, #CS25038 and #CS25039), the open-pit mining site was obstructed by cloud. Hence, we cannot clearly record the change of features in the corresponding years. Other than adverse weather conditions, another major constraint of API is the direction of sunlight. Aerial photography can only be conducted in the daytime, as features can only be captured with lighting, while the direction of sunlight also matters. For features with steep relief, they may create a shadow in the photograph. In our case study, the cut slope from photographs #28593 and #52212 cannot be clearly seen due to the shadowing effect. Thus, this limits our understanding of the relief in the shadow region in the corresponding years.

Aerial photography requires sufficient planning beforehand. As mentioned in section 2, we use a stereoscope to create a three-dimensional model for our interpretation. In fact, the stereoscope can only make use of an overlapping region to create the 3D model. In years 1945 and 1954 (#Y00651, #Y00652, #Y02773 and #Y02774), the aerial photograph flight path was not well-planned. There is no overlapping region between two adjacent APs. Stereoscope cannot be used, and it raises difficulty for precise interpretation. We can only observe the mining site condition with our naked eye in one aerial photograph. Lastly, vegetation cover limits the effectiveness of API. In a geomorphologic study, we aim to study the form and processes of the materials on the surface of the Earth. However, vegetation covers up the bare ground surface on Earth. In the MOS iron mine case study, vegetation cover is the greatest limitation of API. As MOS iron mine is located in the MOS country park, the growth of vegetation acts as a surface barrier that shelters theground surface. Changes in geomorphological features after 2000 are hard to identify.

Digital Aerial Photograph Interpretation (DAPI): DAPI possesses the advantages of API, plus some of its own advantages due to the technology. First, DAPI has a stronger 3D visualization effect and higher resolution. The vertical contrast of DAPI is much stronger than that of API. DAPs also have a higher resolution (1800 dpi or higher) than the printed APs (200 to 600 dpi), allowing users to magnify photographs more clearly to identify subtle but important geotechnical and geological features. Second, with DAPI, it is easier to make annotations on the APs by 3D mouse. 3D mouse can draw on the 3D images shown on photogrammetric software and the drawing will appear on the digital APs. The annotation can help us delineate and record the characteristics of the features. The features delineated are geo-referenced and compatible to GIS and BIM software, reducing errors when transferring the marking from hard copy of aerial photographs to a map. Third, the synchronized comparison of APs from different years allows us to compare the change of geomorphology more systematically. Figure 1a shows the DAPs in 1963, 1982 and 2010. When we move one set of aerial photographs in the software, APs of other years will automatically move together. The red crosses at the center indicate the same location for the three years.

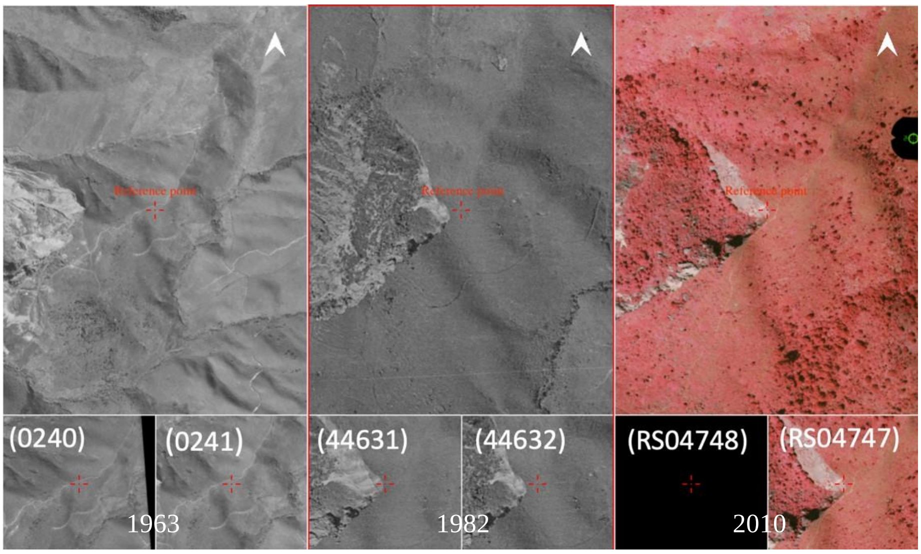


Figure 1a: Synchronized comparison of DAPs in 1963, 1982 and 2010

Figure 1b: DAPI Stereoscopic Problem

However, DAPI has the same disadvantages as API. Atmospheric condition, direction of sunlight, aerial photograph path planning and vegetation cover can also limit the effectiveness of DAPI. In addition, production of DAPI requires significant time cost and manpower. DAPI requires the presence of ground control point and a higher percentage of overlapping than API to geo-reference the image. Technicians have to input and check the coordinates, altitude and the elevation data of APs. Therefore, API can be a more effective method if we need to finish geomorphologic study in a limited time. Also, although DAPI is very helpful in 3D visualization, it cannot show a whole feature on a slope, especially in low-altitude DAPs. Taking Figure 1b as an example, even if we put each digital aerial photograph in the same direction, the feature does not collapse to form a 3D view of the feature, denoted by the orange and the red line. This is because there is a time interval between the photo-taking of #CW59057 and #CW5905. The small time interval results in a change of photo-shooting direction on the slope. This problem particularly limits the effectiveness of DAPI as user cannot move the DAPs easily during the analysis. Furthermore, DAPI requires an experienced user to manage the system and perform analysis. As DAPI is a new technology, the 3D technology involves many parameters in controlling the device. It is not easy to use for new users, at least compared to API.

Airborne Light Detection and Ranging (LiDAR): For the advantages of LiDAR, it has a strong 3D visualization effect, as we can use GIS/photogrammetric software to generate a visual 3D model from LiDAR data. Better visualization may help the user understand the geomorphologic process of the site. Second, LiDAR data can remove all the signals hitting the vegetation, to build up a DTM. This will generate a ground model that gives the accurate topography of our terrain for geomorphologic study. This characteristic is very helpful in LiDAR as most of the study area are covered by vegetation after 2000. Third, we can generate a slope angle map from LiDAR data, which facilitates our analysis. LiDAR also provides quantifiable data. The elevation points are quantifiable for objective analysis.

As for the disadvantages, there is a 10-year time gap between the two LiDAR datasets. This time gap results in difficulties of detailed analysis in the change of geomorphology.

4.2 Features in Ma On Shan Open-pit Iron Mine

The study area of the research is the MOS open-pit mining site (Figure 2a & 2b). It is south to southwest of Ma On Shan and northeast to Luk Chau Shan. The area is approximately 0.73 km^2.

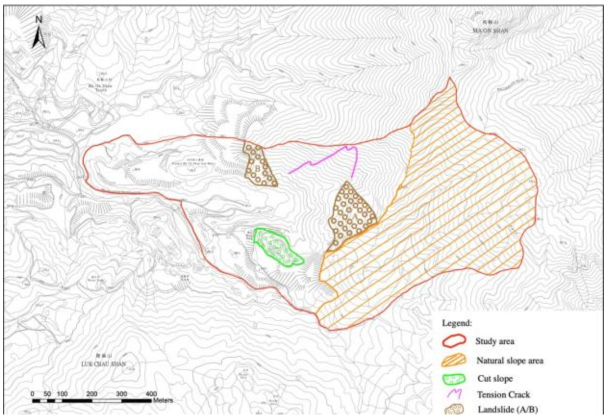


Figure 2a: Contour map showing the study area and the study features

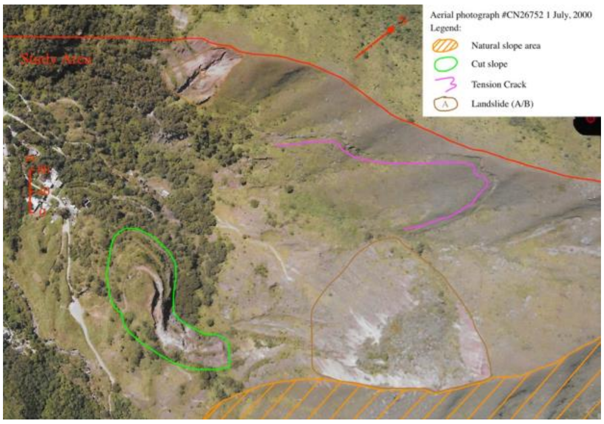
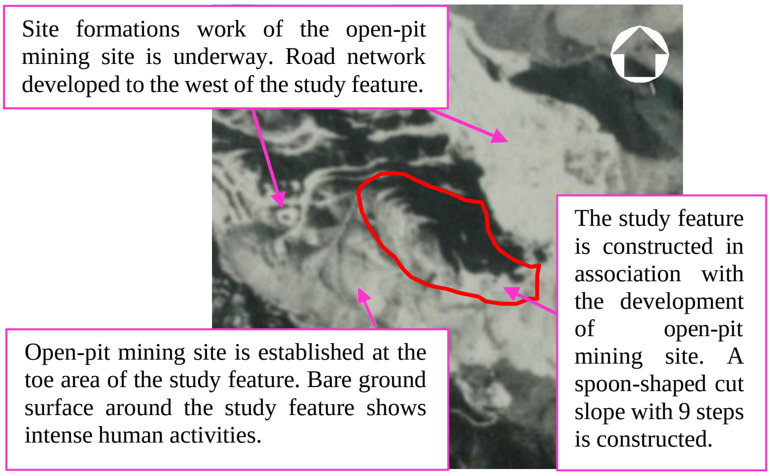


Figure 2b: Aerial Photographs showing the 4 study features

Cut slope: The spoon-shaped cut slope is one of the key features identified in the open-pit mining site. Prior to the formation of the cut slope, the general study feature area is occupied by natural landscape. The study feature was formed as spoon-shaped cut slope in association with the construction of the open-pit mining site between 1954 and 1963 (Figure 3a). Since then, there were no observable changes apparent to the study feature except dense vegetation growth. The DAPI shows no significant different result from API. From the 2010 and 2020 LiDAR data, we can identify 9 steps in the cut slope from elevation of 330m to 245m (Figure 3b). Comparatively, the 2020 LiDAR data is more capable in showing the cut slope platforms clearly in the cross section. More details are shown in the 2020 LiDAR from 290-305 mPD, probably due to the denser point density. Field study shows no sign of instability of the cut slope.


Site formations work of the open-pit mining site is underway. Road network developed to the west of the study feature.

The study feature is constructed in association with the development of open-pit mining site. A spoon-shaped cut slope with 9 steps is constructed.

Open-pit mining site is established at the toe area of the study feature. Bare ground surface around the study feature shows intense human activities.

Figure 3a: Cut slope of 1954 aerial photograph (Y02774)

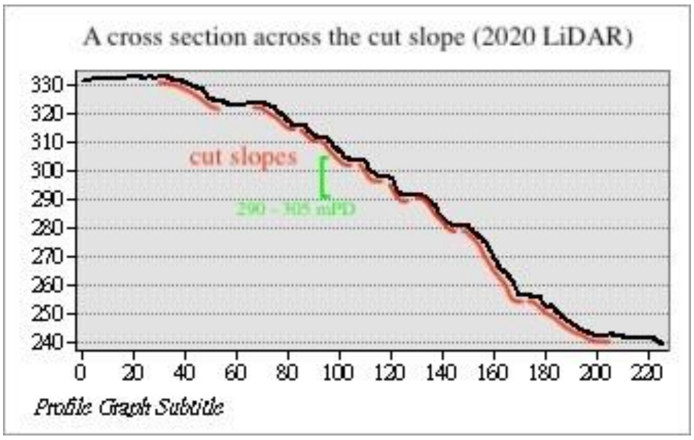
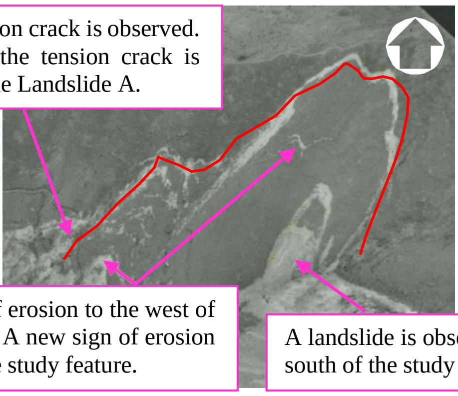


Figure 3b: Cross-section of the cut slope in 2020 LiDAR

Tension Crack: An M-shape tension crack has been observed in API since 1976. The length of the tension crack is approximately 800m, in a NE-SW trending. The tension crack was obvious in the 1976 aerial photographs (Figure 4a). It fades out in the following years and can be observed again in 2000 (Figure 4b). It was last observed in 2006. Since then, there were no observable changes apparent to the study feature except vegetation growth. The DAPI shows no significant different result from API. From the 2010 and 2020 LiDAR data, we can observe a significant drop of altitude of the ground surface at an elevation of 450m. The tension crack causes the landscape dropped by 3-4 meters (Figure 4c). The 2010 and 2020 LiDAR almost show the same result on the cross-section topography of the tension crack. From the field study, it is observed that the depth of the tension crack is approximately 3m (Figure 4d). It coincides with the result of LiDAR. The scarp of the crack consists of mainly sub-angular cobbles and boulders with a diameter of 0.2m.

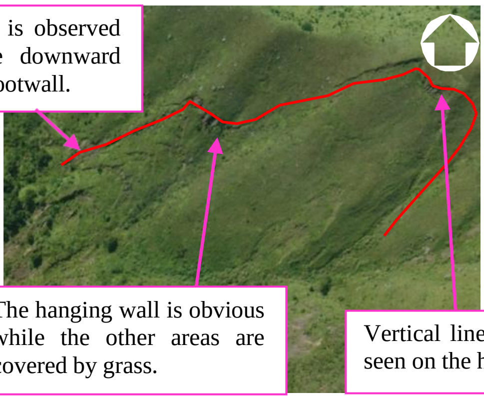


A M-shaped tension crack is observed. The east-end of the tension crack is associated with the Landslide A.

Extended signs of erosion to the west of the study feature. A new sign of erosion to the south of the study feature.

A landslide is observed to the south of the study feature.

Figure 4a: Tension crack of 1976 aerial photograph (13410)



The tension crack is observed again due to the downward movement of the footwall.

The hanging wall is obvious while the other areas are covered by grass.

Vertical lineation can be seen on the hanging wall.

Figure 4b: Tension crack of 2000 aerial photograph (CN26752)

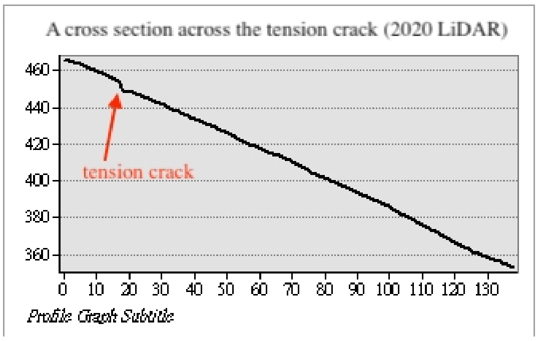
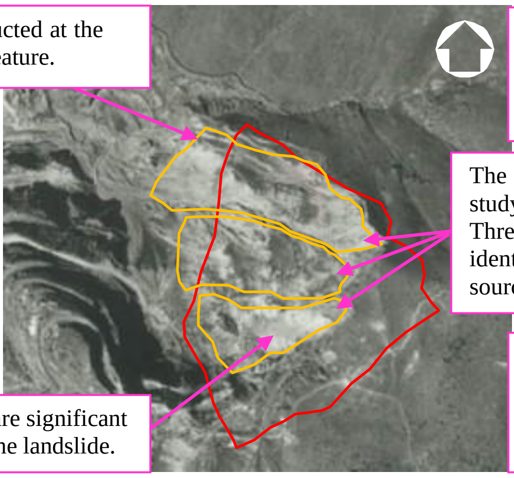


Figure 4c: Cross-section of tension crack in 2020 LiDAR

Figure 4d: Field photography of the tension crack

Landslide A: Landslide A was first discovered as 3 landslides in 1963 (Figure 5a), possibly due to open-pit mining activities. In 1976, the landslides enlarged and combined into a triangular-shaped landslide - Landslide A (Figure 5b). There was an obvious change in the location for landslide A. It has been retreated backward reaching the ridge in the subsequent years. Since 1997, there were no observable changes apparent to the study feature except dense vegetation growth. From the DAPI, it is observed that there is a significant change of location for Landslide A. By tracking the upper edge of the landslide, it is discovered that the landslide has retreated 120 m in the past 50 years (Figure 5c). From the 2010 and 2020 LiDAR data, we can observe the surface of rupture at an elevation of 470m - 430m. There is accumulation of debris at an elevation of 430m - 420m. The 2010 and 2020 LiDAR almost show the same result on the cross-section topography of Landslide A, indicating that there is no obvious change in extent or morphology of the landslide between those 10 years. The bare slope surface with no vegetation growth observed in field study indicates erosion activities. The tension cracks are subparallel to one of the slope faces of Landslide A (Figure 5d).

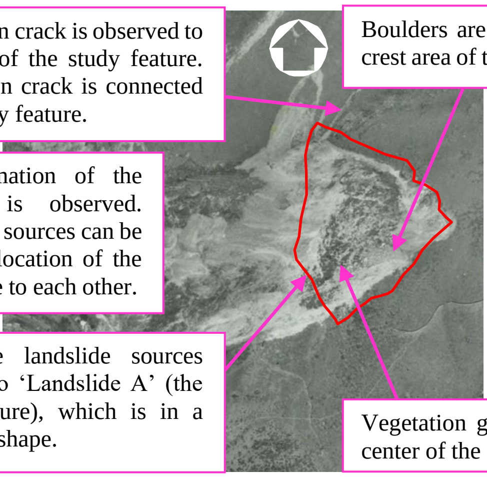


Roads are constructed at the toe of the study feature.

The prior formation of the study feature is observed. Three landslides sources can be identified. The location of the sources are close to each other.

Signs of erosion are significant at the surface of the landslide.

Figure 5a: Landslide A of 1963 aerial photograph (Y10308)



The tension crack is observed to the north of the study feature. The tension crack is connected to the study feature.

Boulders are observed at the crest area of the study feature.

The three landslide sources combine to ‘Landslide A’ (the study feature), which is in a triangular shape.

Vegetation growth at the center of the study feature.

Figure 5b: Landslide A of 1976 aerial photograph (13410)

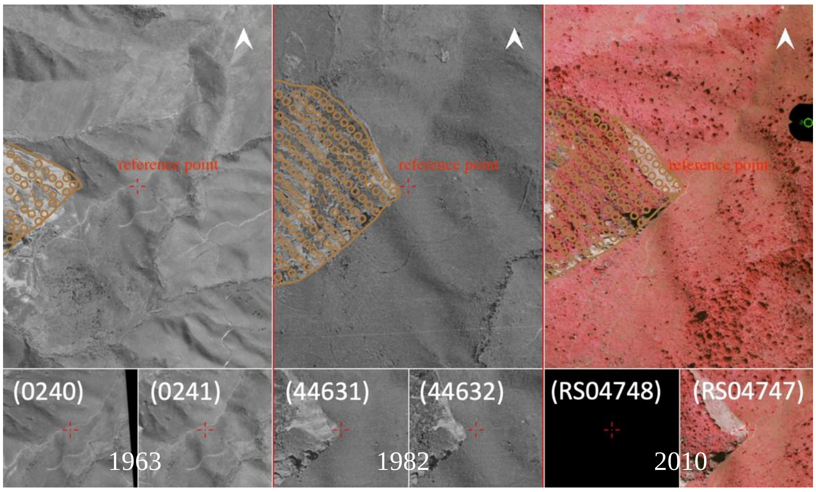


Figure 5c: DAPI of Landslide A in 1963, 1982 and 2010

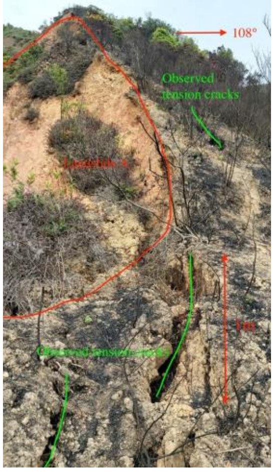


Figure 5d: Field Photograph of Landslide A

Landslide B: Landslide B was observed since 1963 in association with the construction of cut slope (Figure 6a). Significant slope failure has occurred in 1963 to 1976. Since then, there were no observable changes apparent to the study feature except vegetation growth. From the DAPI, it is observed that there is a minor change of location for Landslide B. Landslide B has retreated around 5 meters backward in the past 50 years (Figure 6b). From the 2010 and 2020 LiDAR data, we can observe the surface of rupture at an elevation of 360m - 330m. There is accumulation of debris at an elevation of 330m - 325m (Figure 6c). The 2010 and 2020 LiDAR almost show the same result on the cross-section topography of the tension crack. From the field study, due to the limitation of accessibility, we cannot walk close to Landslide B for slope evaluation. It is observed that part of Landslide B is covered by vegetation, however, there are many loose rock fragments on the slope, which indicates the occurrence of past instability of the slope (Figure 6d).

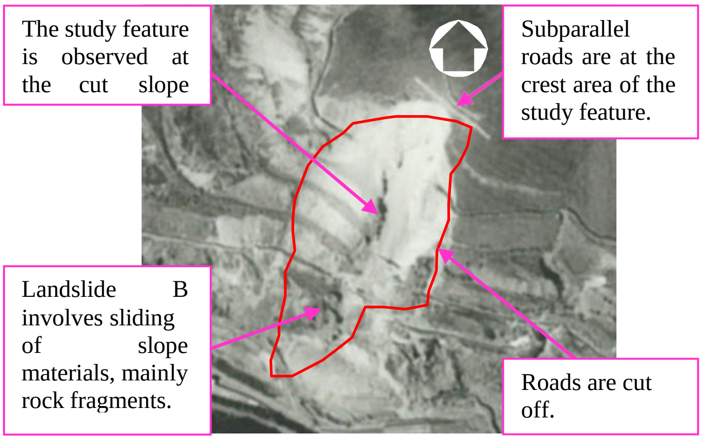


Figure 6a: Landslide B 1963 aerial photograph (Y10308)

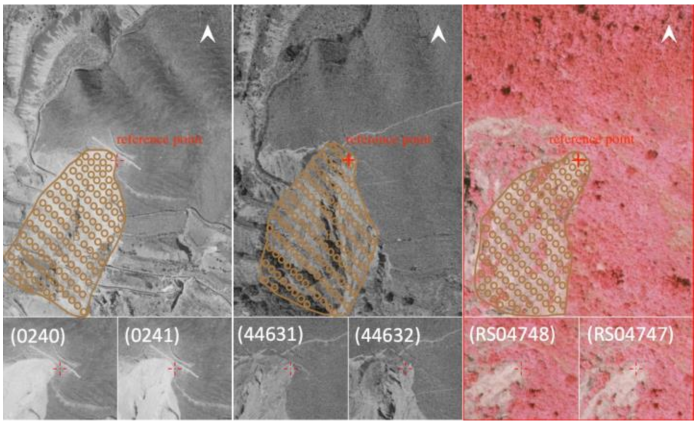


Figure 6b: DAPI of Landslide B in 1963, 1982 and 2010

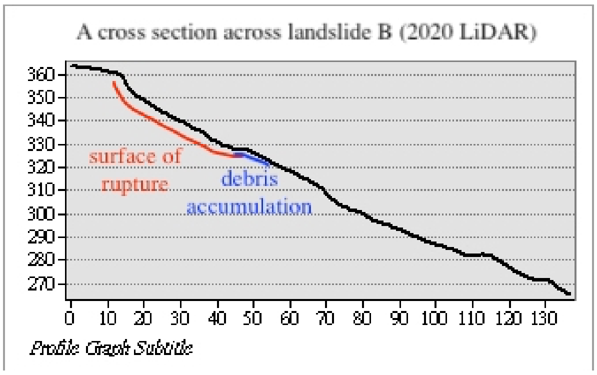


Figure 6c: Cross-section of Landslide B in 2020 LiDAR

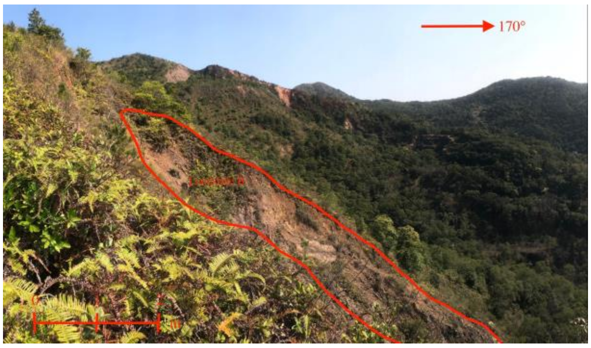


Figure 6d: Field Photograph of Landslide B

Natural Slope: Natural slopes refer to a natural area that is unmodified by human activities. In the case study, the natural slope east of the MOS iron mine was selected as a comparison of surface changes with the aforementioned geomorphological features. From API and DAPI, steady slopes were observed with no significant alteration over the previous 55 years; the landscape was covered by dense vegetation canopy. No natural terrain landslide was observed at the natural slopes. From the 2020 LiDAR data, a constant slope of gradient 1 in 1.39 is recorded. There is no obvious convex or concave break-in-slope along the section. The comparison has shown that the undisturbed natural terrain in MOS open-pit mining site region has been stable over the past years. The 4 features discussed are significantly contributed by human mining activities in the past decades.

Table 1: Summary of the significant observation of the study features by API, DAPI, LiDAR and field study

	API	**DAPI**	**LiDAR**	**Field study**
Cut slope	Constructed with site formation work (6 steps)	Indifferent	Number of steps (9 steps)	No instability
Tension crack	Clearly observed in 1976 & 2000 aerial photographs	Indifferent	Vertical displacement of scarp clearly observed	Indifferent
Landslide A	3 landslide sources combined into 1 landslide	Significant backward retreat	Surface of rupture observed	Bare slope surface, Existence of tension crack
Landslide B	Instability associated with cut slope	Minor backward retreat	Surface of rupture observed	Existence of loose rock fragments on slope

5. DISCUSSION

5.1 Comparison of the Geomorphologic Study Methods

This section compares the 3 geomorphologic study methods, API, DAPI and LiDAR by considering different parameters. The comparison is mainly based on the results of the case study in the former MOS open-pit iron mine. The determination of ranking of each parameter can be used as a reference of future choice of method in geomorphologic study. However, the ranking is not necessarily proportional and is subject to the experience of the users.

Completion of data: First, API; Second, DAPI; Third, LiDAR. API and DAPI share the same source of data, as DAPI is transformed from API originally. API contains records as early as 1945 in the study area and has a continuous photogrammetric record since 1973. However, digital photograph acquisition is not assured as technical problems may occur in transforming APs to DAPs, or the DAPs are not able to be geo-referenced due to insufficient overlapping in photograph coverage. Airborne LiDAR only contains data in years 2010 and 2020. It is hard to do a continuous evaluation of a feature with a 10-year data gap.

Visualization: First, LiDAR; Second, DAPI; Third, API. By using LiDAR data, a 3D DTM can be generated using ground elevation points or a 3D digital surface model by using all data points. The 3D model can be rotated or flipped on a computer program. It is best to observe the study area in 3D from different angles. For DAPI, it also generates a 3D model in the computer for display and delineation of features. However, ground features may be concealed by vegetation. Lastly, for API, although API can be visualized in 3D by stereoscope, the resolution is controlled by the quality of printers. It is also difficult to view the 3D images simultaneously by a group of people.

Easiness to use: First, API; Second, LiDAR; Third, DAPI. API can be conducted with the naked eye and stereoscope, no software is needed to conduct API analysis. The skill of examining aerial photography is not hard either as users only need to move adjacent APs together to look around the study area. For LiDAR, we need to employ remote sensing and GIS software to do the analysis and to generate models or maps. Lastly, professional photogrammetric and GIS software and high-end computer hardware are required for DAPI.

Cost: First, API; Second, DAPI. Third, LiDAR. All three methods are very effective in geomorphologic study in different aspects: for example, API and DAPI are effective in land surface evaluation while LiDAR is effective in building DTM. However, for the cost, API is comparatively cheaper while DAPI and LiDAR are more expensive in data acquisition and data analysis. APs used in the study are taken from manned aircraft by the Lands Department. On the other hand, in addition to the cost of aerial photograph acquisition, DAPI requires significant time cost and manpower to process the DAPs. The photogrammetric software and computer hardware are also costly. For LiDAR, especially the territory-wide airborne LiDAR surveys, expensive state-of-the-art LiDAR equipment is required to achieve the high accuracy and data density. The mobilization cost is also high.

Portability: First, DAPI and LiDAR; Third, API. DAPs and LiDAR data are some information that can be transferred through soft disk, which is quite portable and transferrable. However, to conduct API, we need to select and borrow APs, which are some printed copies, from the Aerial Photograph Library of the CEDD. Stereoscope is also required to view the aerial photographs.

Table 2: Summary of the comparison of the 3 techniques with different aspects

Aspects	**API**	**DAPI**	**LiDAR**
Completion of data	1	2	3
Visualization	3	2	1
Easiness to use	1	2	3
Cost	1	2	3
Portability	3	1	1

Remarks: 1 is the best, 3 is the worst

5.2 Improvements of Geomorphologic Studies Methods

To improve the geomorphologic studies, the users have to be familiar with the aim and scope of the study so that they know what features they should pay special attention to. Users need to understand the background and the history of the study area to make in-depth investigation. API, DAPI and LiDAR record facts from previous times, and the conclusion depends on the user's interpretation of those facts. More practice is also needed for users to make reasonable judgements. In addition, continuous investigation from different years can help us make reasonable judgement on doubtful feature. Besides, an integrated use of all available information including APs, DAPs and LiDAR data in the analysis could be helpful in geomorphologic study as each of them has its own benefits. For example, API can be conducted as a preliminary study because it is more cost-effective. Then, DAPI can be used for annotation and comparative analysis of DAPs from different years while LiDAR data can provide ground information and enable quantitative analysis. The incorporation of all different techniques maximizes the benefits of each approach. Geomorphology is a process of time and features seldom appear in sudden. When we look through the study area with continuous records, we can usually find some hints for the occurrence and evolution of features. This approach could be helpful for users to make justifiable interpretation on irresolute landform. With the advancement in drone LiDAR techniques, we can collect more frequent site-specific LiDAR data in the future to reduce the time gap and help us understand the geomorphological change of an area.

6. CONCLUSION

In conclusion, this project covers the three techniques of studying geomorphology, API, DAPI and LiDAR. Each technique has its own benefits and limitations. API is an effective way to conduct preliminary geomorphologic study, especially as there is extensive archive of aerial photographs in Hong Kong. DAPI and LiDAR give more in-depth observation on the features and provide accurate geo-spatial information. We should take advantages of the different techniques to optimize their strengths and minimize individual limitations in our study.

The study showcases some examples of human alteration of natural landscape in the past. The result can be incorporated to the geomorphologic study of other study areas, not limited to mining sites, in Hong Kong. With the appropriate and complementary application of the three techniques applied in the study, the geomorphology of a region can be described in detail for examining site development history, change in landforms and identification of natural terrain hazards.

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