Geological and Structural Mapping of the Brunei-Muara District using Unmanned Aerial Vehicle (UAV)

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"the best geologists are those who see the most rocks" (Hurst, 2012).

1. INTRODUCTION

Rocks are a primary source material to investigate the historical development of the planetary bodies, and this applies to our home planet as well, where the basic geological knowledge about the lifecycle of the Earth requires interaction with rocks. The various lithological units that have formed over the geological time are often exposed at various crustal levels on the surface, and subsurface ranks for humans to investigate. The interactions with rock outcrops have helped us to unravel, and discover the hidden secrets of our home planet. These discoveries can unfold if such interactions with the planet continue in the future. Therefore, geological field visits are an important learning, and discovery experiences for geoscientists, and particularly for field-oriented courses such as Structural Geology, Geological Mapping, Field Techniques, etc.

Several studies have suggested that field related courses have helped students to improve their understanding of geological concepts and its various processes such as ductile and brittle deformation, sedimentation, volcanism etc, which is usually missing from courses that lack field components (e.g. Elkins, 2007; Dolphin et al., 2019). However, and unfortunately, the geological field exercises have become increasingly difficult to organise because of multiple problems, and as such fieldwork activities have diminished over the years, and even completely stopped at certain places. The problems range from financial constraints, travel restrictions to temporary or permanent loss of outcrops. For example, the processes of weathering, erosion, overburden, landslides, earthquakes, flooding and urbanization can contribute to the loss of geological outcrops. However, these processes can also reveal new outcrops but again it can lead to the same cycle of outcrop exposure, erosion and ultimately the loss of crucial information. Similarly, financial constraints can shrink or altogether stop field components. Furthermore, the complex, tedious, and exhausting field approval procedures can also contribute and exacerbate such problems, and it is mostly observed to impact international field visits where immigration and fieldwork related approvals from the host countries are a winding road to ride! And although geological fieldwork remains an essential component of a typical geological curriculum, the issues raised above could limit or stop such visits, thereby limiting our access to the primary sources of geological curiosities.

Therefore, an alternative has to be explored to preserve geological outcrops, so that such information is archived, and simultaneously used to create a virtual outcrop library that could be used, and made freely available to users. This paper shows such a mission where we are collecting and preserving field data in SE Asia by conducting field visits to record details of exposed geological outcrops. We are using Unmanned Aerial Vehicles (UAV), also known as drones, which are one of the best mapping tools to explore the region, and collect information with more accuracy (see below).

In recent years, the advancements of digital technology has dramatically improved the landscape of the mapping world and this is particularly true for UAVs, which are now easily accessible and are increasingly used for mapping. Geoscientists are also using the UAVs to map the geological outcrops with more precision, and record the entire field work to convert into videos or 3D outcrop models etc. (e.g. Bemis et al., 2014; Jordan, 2015; Rocca, 2017). It is possible that UAVs with digital cameras will become one of the best friends to every field geologist in the future due to their light weight and robust ability to capture and record surface topography, geology, and canopy with accurate details. Compared to satellite images, UAVs can produce high-resolution data up to 4K resolutions and at very low cost (details are below), especially with recent models. This makes UAVs field friendly and therefore an extremely useful tool for mapping purposes (e.g. Piras et al., 2016; Mezghani et al., 2018; King, 2019). One of the best features of such an instrument is its ability to operate in areas that are often inaccessible and/or dangerous (e.g. fear of wild animals, steep slopes, etc.). Below we show our initial work in Brunei Darussalam, which is a small oil-

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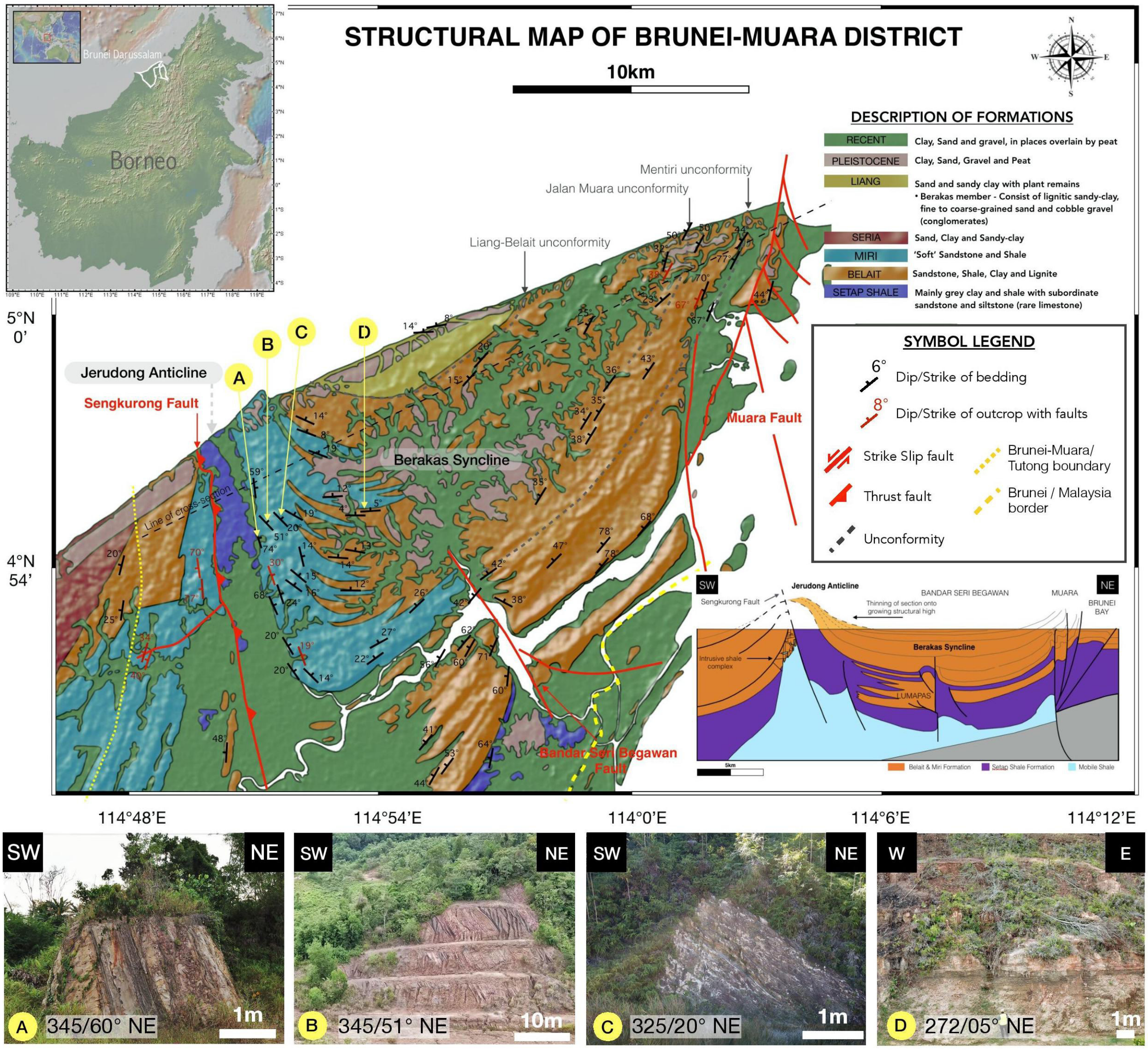

Figure 1: Above: The Geological and structural map of the Brunei-Muara district, which is modified after Wilford (1982), Morley et al. (2003), and Aaisyah et al. (2020). Field evidence of selected outcrops is shown in subsets A to D where the average dip amount of the sedimentary layers varies from steep to gentle angles.

rich country, located within the lush green forests on the north-western part of the Borneo Island (Fig. 1).

The past geological investigations in Brunei are fairly limited with most of the works published with a focus on Petroleum related studies because the country accounts for about 90% of the hydrocarbon exports (Gartrell et al. 2011). The most recent, accessible and significant geological map was compiled by Wilford in 1960 and published by the the Surveyor General Brunei (Wilford, 1982). However, that was about 60 years ago, and much has changed since then. Therefore, there is a strong need to improve the geological and structural maps. Additionally, the outcrop details are largely missing from the previous studies, which is the major challenge that we are solving. More than half of the area of Brunei is still covered with thick foliage therefore aerial photographs are not that useful to uncover the rocks that are hidden under the forests, and the best alternative is to visit the exposed outcrops and film them using UAVs. This is exactly what we have been doing throughout our mission to map the exposed geological outcrops in the region, an exercise that has not been done in any part of the country. Our mission is to create a detailed geological database of the region and convert this data into a 3D model so that classroom field exercises become possible in the near future.

Therefore, the present study explores the possibility to overcome the field-related problems by the use of UAVs carrying a digital camera for an optical survey of exposed geological outcrops with the motivation to map and archive the data in Brunei Darussalam on our university website, which will serve multiple purposes. This data can be used by anyone, particularly students and researchers.

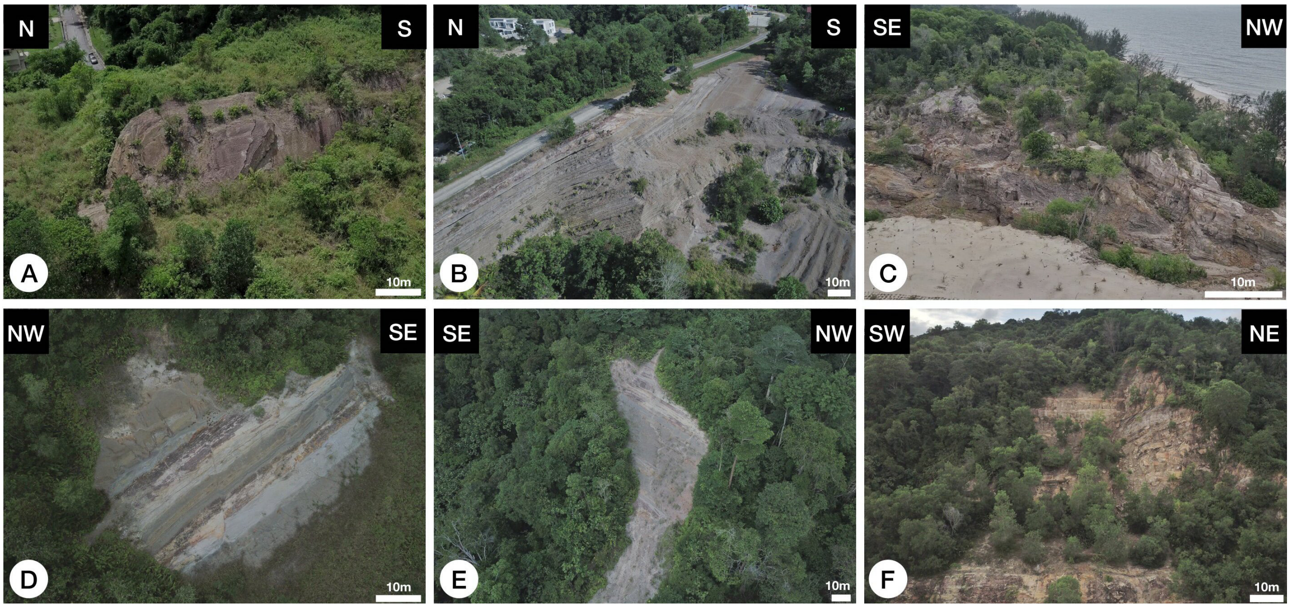

Figure 2: (A-C) Still images of large outcrops captured to show the whole overview of the outcrop that could not be achieved using hand-held cameras. (D-F) Exposed outcrops that were not accessible by foot were surveyed using the UAV by taking still images and videos.

2. REGIONAL SETTING

Brunei Darussalam is part of Borneo Island (Fig. 1), and the present tectonic setting shows that it is enclosed by active plate margins, and it belongs to the Sunda plate. On a regional scale, the Sunda megathrust fault system is the major plate boundary fault system where the Australia plate subducts under the Sunda plate (Shah et al., 2018), and encloses the Island from the south-western side. The eastern portions are marked by a number of basins that are broadly related to the active tectonic developments at the Philippine Sea and the Pacific plates.

The previous geological data of Brunei Darussalam and our field studies suggest that the region is mainly composed of sedimentary beds of alternating sandstone and shale. The bedding data show a folded sequence that is represented by the Berakas syncline in the north and the Belait syncline in the south. Several faults are also mapped in the region (Fig. 1). The geological investigations presented here started in Brunei-Muara district, which is one of the administrative divisions of the country and hosts most of the population. The field area covers the Berakas syncline and the Jerudong anticline which expose rocks of the Setap Shale, Belait, Miri, and Liang Formations, along with the cover sequences of mainly Holocene sediments (Fig. 1). Morley et al. (2003) mapped three major faults in the region, which are named as Muara, Sengkurong, and the Bandar Seri Begawan faults (Fig. 1).

3. MATERIAL AND METHODS

Prior to conducting any field excursion in the region, we created a base map of the study area by updating the latest Brunei-Muara District geological maps (Wilford 1982; Morley et al., 2003). We used QGIS®

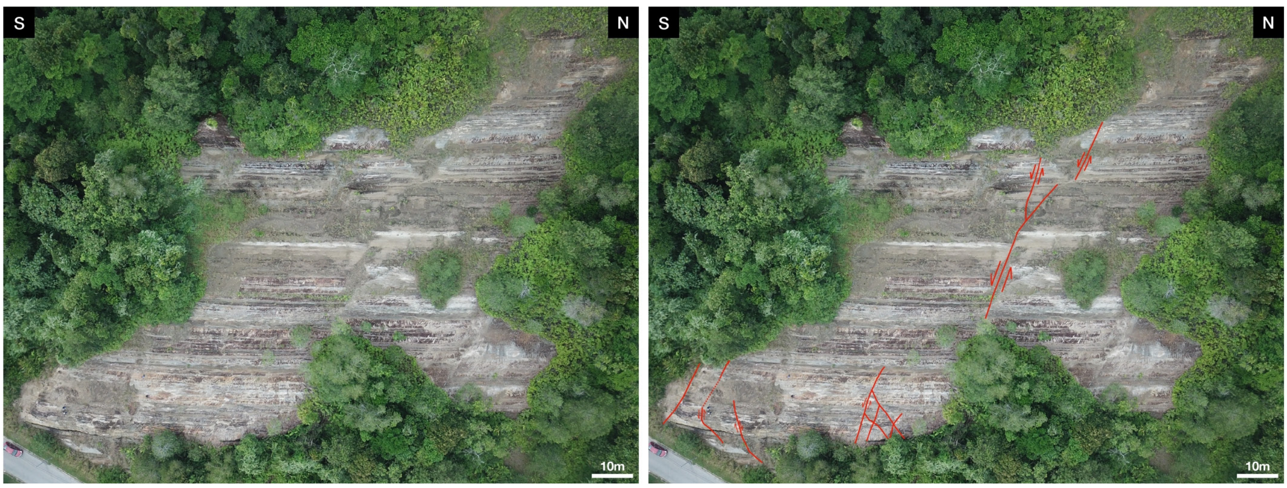

Figure 3: The high-resolution image (4000x3000 pixels) shown on left was captured by the drone, DJI Mavic Pro, and it shows high image quality with clear evidence for faulting (right side) at the "Lion King" outcrop in Jerudong, which is one of the best outcrops to study the faulted sedimentary rocks in Brunei.

Figure 4: Comparison of aerial images of the "Lion King" outcrop in Jerudong (4°53'36.25"N, 114°49'59.01"E): (A) DJI Mavic Pro (resolution: 4000x3000 pixels); (B) Ortho-photo obtained from Survey Department, Ministry of Development, Brunei (resolution: 1085x715 pixels); (C) Satellite image obtained from Google Earth Pro (2019) (resolution: 1175x758 pixels). The images from the DJI Mavic Pro produce much clearer and sharper details.

software to reproduce the map by outlining the Geological formation on a geo-referenced map. These details were then superimposed onto the terrain map of Brunei, which was obtained from GeoMapApp® to show the relief of the research area. The above steps were followed by remote-sensing reconnaissance mapping on the satellite images provided in Google Earth, where we plotted the exposed outcrop sites to be used to conduct the detailed field investigations.We also used scouting survey and from word of mouth to cover the maximum number of exposed outcrops in the region. The fieldwork was conducted from January 2019 until March 2019, and during this time we were able to map the details of a total of 115 outcrops in the Brunei-Muara District. We followed the standard mapping techniques to measure the amount of dip, dip direction, location, and other structural details. Out of the 115 outcrops that we visited, only 65 sites were digitally recorded using the UAV due to time constraints.

The DJI Mavic Pro is one of the best UAVs currently on the market, and we used it for mapping of the exposed geological outcrops. It can capture high-quality images and videos up to 4K resolution at a more affordable cost (€ 700) compared to more sophisticated models such as the Wingtra drone (starting price is € 18,000). The compact size of the UAV makes it easier to carry and the interface is user-friendly. The 12-megapixel camera combined with its 3-axis mechanical gimbal allows the UAV to fly with stability and it can produce detailed data with a < 1.5 % distortion. It is also able to reach remote areas up to 7 km away from the user and this was useful to observe inaccessible outcrops. The images and videos were captured and recorded at various heights: up to the allowed height of 120 m above ground level. The aerial and cross-sectional views of the outcrops (Figs. 2–5) were mapped with ease, and it also includes the focused and detailed views. The collected visual media data was compiled and saved locally on a hard disk drive, along with the necessary geological information of each outcrop.

4. RESULTS AND DISCUSSION

The terrain map provided in Google Earth Pro shows that Brunei Darussalam is part of a folded sequence of rocks that are exposed as plunging folds. The Brunei-Muara region mainly belongs to the ~ N plunging Berakas syncline. The onshore exposed portion of the ~ NE-SW trending right limb of the fold is ~ 29 km long while as the ~ N-S trending left limb is

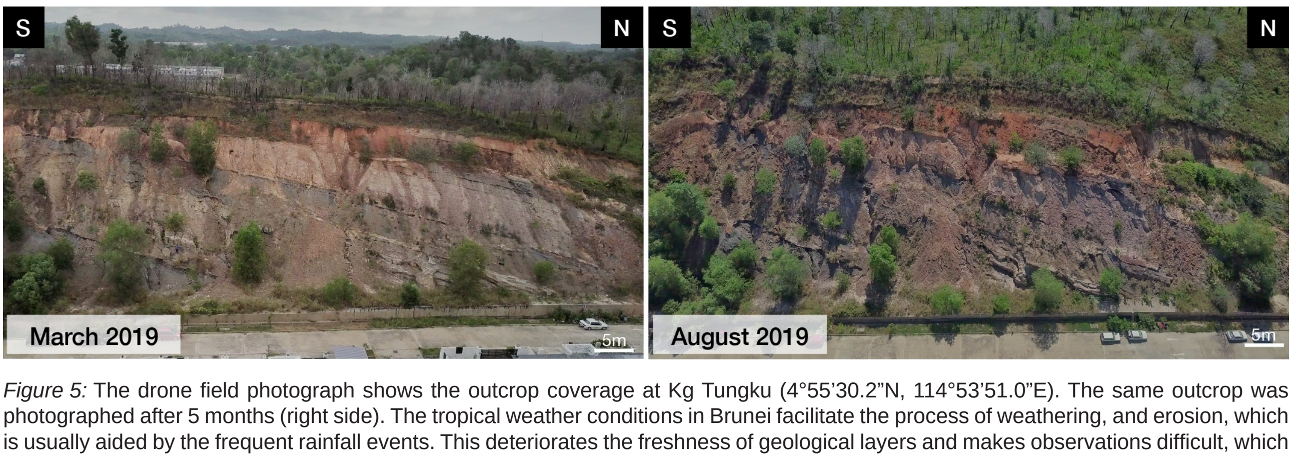

Figure 5: The drone field photograph shows the outcrop coverage at Kg Tungku (4°55'30.2"N, 114°53'51.0"E). The same outcrop was photographed after 5 months (right side). The tropical weather conditions in Brunei facilitate the process of weathering, and erosion, which is usually aided by the frequent rainfall events. This deteriorates the freshness of geological layers and makes observations difficult, which can be captured and preserved via drone footage.

~ 13 km long. We collected data on both the limbs of the Berakas syncline and Jerudong anticline, which are 115 outcrop sites in total. These data were manually plotted on the map (Fig. 1). Most of the outcrops that we visited were composed of alternate layers of sand and shale lithologies with no deformation (Fig. 2). Shallow marine fossils were observed (e.g. bivalve casts, gastrapoda and ophiomorpha) that belong to Miri Formation. The amount of dip of the sedimentary layers varies from 5° to 80° (Fig. 1). Stereonet plots were used to measure the plunging amount and direction of the Berakas syncline that was measured to be 16° towards NNE and for Jerudong anticline it was 9° towards NNW. The different plunging directions of the folds are consistent with the asymmetrical folding geometry of the folded sequence, and this seems to be related to the Sengkurong fault (Fig. 1) that cuts through the fold and runs under the Berakas syncline (Morley et al., 2003).

One of the outcrops with the most prominent exposed structural features is locally known as the “Lion King” outcrop (Aaisyah et al., 2020) and it is located along the Sengkurong fault (Fig. 3). The UAV was used to take the digital details, which was used to map/trace the faults. Due to its large displacement (up to 3 m) that could not be captured using handheld cameras, the drone has proven to be a useful tool at the site. The resolution and details of the images captured using the UAV are better than the data that has been previously published or available as satellite or aerial images of the region, for example the satellite images shown on Google maps and the ortho-photos from the Survey Department of Ministry of Development, Brunei. (Fig. 4). The fault details are easy to map, and quantitative measurements from the digital coverage are possible at ease as the interactive screen provides coverage at various scales, and we can zoom further to capture outcrop details without losing the resolution.

In addition to that, fieldwork exercise shown here has demonstrated that frequent visits to geological sites in tropical rainforests should be preferred. This came to light when we visited one of the outcrops twice over a period of 5 months. Figure 5 shows such an example where photographs taken in March 2019 have recorded a much clearer picture that shows outcrop details that it has lost its sheen in August 2019. This was because of weathering, erosion, and landslides. This also proves the importance of drone mapping and preservation of field evidence in both static and video shots. This is particularly important in regions that experience frequent rains, landslides, or any other activity that erases, and sometimes destroys an outcrop (e.g. urbanization, earthquakes, etc).

5. Conclusions

The work shown above is an on-going project in Southeast Asia where we aim to survey and digitally archive the details of exposed geological outcrops using UAV. We have started this in Brunei, where we have mapped 115 outcrop locations and out of that 65 locations were captured by a drone as still images and videos. Our work has demonstrated the importance of archiving of the geological data where the preservation of outcrop details can be used in the future for education, learning, research, and other uses. It solves problems that are discussed above, and highlights the need to outline a comprehensive framework to improve the mapping courses in sciences and in other disciplines where such exercises are part of the education and learning curriculum. The data produced here provides the first drone coverage of geological outcrops in the region, and will be used to make high-resolution DEM and 3D models using SfM (Structure from motion) photogrammetry, which will further strengthen the geological mapping activities and courses. We strongly believe that recording geological outcrop data is a fundamental step towards improving of the geological maps throughout the world. The COVID-19 world has clearly shown the usability of digital media in education, learning and research. Therefore, such exercises should be done on a priority basis as it solves a number of problems that may hinder or stop geological field activities. The usage of UAVs can greatly aid in the mapping and the preservation of such digital geological data.

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7. REFERENCES

Aaisyah, D, Shah, A.A., Garcia, K., Manan, N., and Anyie, J. 2020. Evidence of Strike-Slip Faulting in Brunei Darussalam, NW Borneo. Conference Proceedings, 82nd EAGE Annual Conference &

Exhibition Workshop Programme, Dec 2020, pp. 1 - 5, https://doi.org/10.3997/2214-4609.202011727.
Bemis, S.P., Micklethwaite, S., Turner, D., James, M.R., Akciz, S. and Thiele, S.T et al., 2017. 'Ground-based and UAV-based photogrammetry: a multi-scale, high-resolution mapping tool for structural geology and paleoseismology', Journal of Structural Geology, vol. 69, pp.163-178, http://dx.doi.org/10.1016/j.jsg.2014.10.007
Dolphin, G., Dutchak, A., Karchewski, B. and Cooper, J., 2019. 'Virtual field experiences in introductory geology: addressing a capacity problem, but finding a pedagogical', Journal of Geoscience Education, vol. 62, no. 2, pp.114-130, http://dx.doi.org/10.1080/10899995.2018.1547034
Elkins, J.T., and Elkins N.M.L., 2007. 'Teaching geology in the field: significant geoscience concept gains in entirely field-based introductory geology courses', Journal of Geoscience Education, vol. 55, no. 2, pp. 126-132, http://dx.doi.org/10.5408/1089-9995-55.2.126
Gartrell, A., Torress, J., and Hoggmascall, N., 2011. 'A regional approach to understanding basin evolution and play systematic in Brunei – unearthing new opportunities in a mature basin', In: International Petroleum Technology Conference, 15-17 November 2011 Bangkok, Thailand. http://dx.doi.org/10.2523/15171-MS
Google Earth Pro 7.3. 2019. Lion King outcrop 4°53'36.25"N, 114°49'59.01"E. Satellite map, viewed 18 August 2020. <https://earth.google.com/web/@4.89346489,114.83302223,225.41282285a,10.00047429d,35y,275.2201h,0t,0r>
Hurst, A., cited in: Friedman, B., 2012. 'Educator seeks to nurture creativity', AAPG Explorer, January 2012, viewed 18 August 2020 <https://explorer.aapg.org/story/articleid/1776/educator-seeks-to-nurture-creativity>
Jordan, B.R., 2015. 'A bird's-eye view of geology: the use of micro drones/UAVs in geologic fieldwork and education', GSA Today, pp 50 – 52, http://dx.doi.org/10.1130/GSATG232GW.1
King, E., 2018. 'Aerial drones in mineral exploration', Geology for Investors, 12 December 2018, viewed 18 August 2020 <https://www.geologyforinvestors.com/aerial-drones-in-mineral-exploration/>
Mezghani, M.M., Mohammed Fallatah and Abdul Jaleel AbuBashait, 2018. 'From drone-based remote sensing to digital outcrop modeling: integrated workflow for quantitative outcrop interpretation', Journal of Remote Sensing & GIS, vol. 7, no. 2, http://dx.doi.org/10.4172/2469-4134.1000237
Morley, C.K., Back, S., Rensbergen, P.V., Crevello, P. and Lambiase, J.J., 2003. 'Characteristics of repeated, detached, Miocene – Pliocene tectonics inversion event, in a large delta province on an active margin, Brunei Darussalam, Borneo', Journal of Structural Geology, vol. 25, no. 7, http://dx.doi.org/10.1016/s0191-8141(02)00130-x
Piras, M., Taddia, G., Forno, M.G., Gattiglio, M., Aicardi, I., Dabove, P., Lo Russo, S. and Lingua, A., 2016. 'Detailed geological mapping in mountain areas using an unmanned aerial vehicle: application to the Rodoretto valley, NW Italian Alps', Geomatics, Natural Hazards and Risk, vol. 8, no. 1, pp. 137-149, http://dx.doi.org/10.1080/19475705.2016.1225228
Rocca, R., 2017. 'Low cost 3d mapping using a commercial drone/UAV: application in structural geology', AAPG International Conference & Exhibition, Barcelona, Spain, 3-6 April, viewed 27 April 2020 <http://www.searchanddiscovery.com/documents/2017/42054rocca/ndx_rocca.pdf>
Shah, A.A., Mohd Zhafri, Jumat, D., and Batmanathan, N.M., 2018. 'Major strike-slip faults identified using satellite data in central Borneo, SE Asia', Geosciences, vol.8, no. 5, p. 156, http://dx.doi.org/10.3390/geosciences8050156
Wilford, G. E., 1982. Geological Map of Brunei and Adjacent Parts of Sarawak, map, scale 1:152000, sheet 2, Surveyor General Brunei, Brunei Darussalam.