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Extracting Complex Structural Geological Data from Outcrops Using Photogrammetry: Case Studies from Ladakh, Himalaya and the South Coast, NSW

Abstract
Rendering high-definition 3D models is becoming a commonly requested task for scientific simulation, visualization and computer graphics. Many research areas generate extremely complex 3D models, such as industrial CAD models (e.g. airplanes, ships and architectures), composed of more than hundreds of millions of geometric primitives. However, these complex datasets cannot be rendered efficiently using brute-force methods on a desktop workstation. Desktop computer technology has recently reached a point where it has advanced sufficiently to calculate and process a number of photographs of an object from different perspectives to produce an accurate three-dimensional (3D) high-definition digital model. This project explores the potential applications of 3D digital models in terms of extracting complex geological data. Different methods of data acquisition and the scale of outcrops are compared between difficult to access rock outcrops in a remote High Himalayan region of Photoksar, Ladakh to more accessible, low lying coastal areas on the NSW South Coast at Bingie Bingie Point, Narooma, Wolumla and Eden. Archaeological sites and ultra-high resolution aerial photographs are also applied to the methods outlined. The application of photogrammetry at each site is assessed and compared to determine the benefit of it is applicable in any or all regions. The methods are assessed for efficiency, convenience and relevance of extracting complex structural geological data with emphasis on developing the highest quality digital 3D models possible. Any data extracted is tested for accuracy by comparing it with structural geological measurements obtained on the field by traditional methods using the trusted Field Move mobile application as a compass and clinometer equivalent. The results aim to provide a reliable and informative source of information outlining the methods used, what equipment is needed and what information can be extracted.

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Extracting Complex Structural Geological Data from Outcrops Using Photogrammetry: Case Studies from Ladakh, Himalaya and the South Coast, NSW

By

Jacob Noblett

A thesis submitted in part fulfilment of the requirements of the Honours degree of Bachelor of Science in the School of Earth and Environmental Sciences

University of Wollongong, 2015
The information in this thesis is entirely the result of investigations conducted by the author, unless otherwise acknowledged, and has not been submitted in part, or otherwise, for any other degree or qualification.

Jacob Noblett
6th April 2016
Abstract

Rendering high-definition 3D models is becoming a commonly requested task for scientific simulation, visualization and computer graphics. Many research areas generate extremely complex 3D models, such as industrial CAD models (e.g. airplanes, ships and architectures), composed of more than hundreds of millions of geometric primitives. However, these complex datasets cannot be rendered efficiently using brute-force methods on a desktop workstation. Desktop computer technology has recently reached a point where it has advanced sufficiently to calculate and process a number of photographs of an object from different perspectives to produce an accurate three-dimensional (3D) high-definition digital model. This project explores the potential applications of 3D digital models in terms of extracting complex geological data. Different methods of data acquisition and the scale of outcrops are compared between difficult to access rock outcrops in a remote High Himalayan region of Photoksar, Ladakh to more accessible, low lying coastal areas on the NSW South Coast at Bingie Bingie Point, Narooma, Wolumla and Eden. Archaeological sites and ultra-high resolution aerial photographs are also applied to the methods outlined. The application of photogrammetry at each site is assessed and compared to determine the benefit of it is applicable in any or all regions. The methods are assessed for efficiency, convenience and relevance of extracting complex structural geological data with emphasis on developing the highest quality digital 3D models possible. Any data extracted is tested for accuracy by comparing it with structural geological measurements obtained on the field by traditional methods using the trusted Field Move mobile application as a compass and clinometer equivalent. The results aim to provide a reliable and informative source of information outlining the methods used, what equipment is needed and what information can be extracted.
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# Table of Contents

1. **Chapter 1 - Introduction** ........................................................................................................ 1
   1.1. Aims and Objectives ........................................................................................................ 4

2. **Chapter 2 - Literature Review Photogrammetry** .................................................................. 6
   2.1 3D Digital Models ................................................................................................................ 7
   2.2 History of Photogrammetry ................................................................................................ 9
       2.2.1 First Generation ........................................................................................................... 11
       2.2.2 Analog Photogrammetry ........................................................................................... 11
       2.2.3 Analytical Photogrammetry ...................................................................................... 11
       2.2.4 Digital Photogrammetry ............................................................................................ 12

3. **Chapter 3 - Methodology Creating 3D Models** .................................................................... 13
   3.1 Digital Photogrammetry .................................................................................................... 13
       3.1.1 Phase 1- Reconnaissance .......................................................................................... 15
       3.1.1.2 Field equipment .................................................................................................... 16
       The equipment used in this project is outlined below ......................................................... 16
       3.1.2 Phase 2 - Photography .............................................................................................. 17
       3.1.3 Phase 3 – Photoshop ................................................................................................. 22
       3.1.4 Phase 4 – Digital Photogrammetry ............................................................................. 4
       3.1.5 Phase 5 - Photogrammetric Products ....................................................................... 11

4. **Chapter 4 - Field Work Methods and Results** ...................................................................... 13
   4.1 Project Applications .......................................................................................................... 13
4.2 Camera Calibration – Julian Rocks ................................................................. 14
4.3 Photoksar, Himalayas - High Alpine Photogrammetry ............................. 21
  4.3.1 Photoksar, Ladakh, West Himalayas (high alpine) ............................... 22
4.4 South Coast, NSW – Coastal Photogrammetry .................................... 33
  4.4.1 Bingie Bingie Point ................................................................. 35
  4.4.2 Narooma, South Coast of NSW ...................................................... 40
  4.4.3 Haycocks Point ........................................................................ 56
  4.4.4 The Pinnacles ........................................................................... 60
  4.4.5 Eagles Claw, NSW - Boat .......................................................... 64
  4.4.6 Quarantine Bay ......................................................................... 70
  4.4.7 Wolumla Cuttings ................................................................. 74
4.5 Archaeological Application ............................................................. 79
  4.5.1 The Hobbit - Mata Menge, Island of Flores, Indonesia (Drone) .... 79
  4.5.2 Evolution of Early Man – Rocklands, South Africa ......................... 86
4.6 Ultra-High Resolution Aerial Photographs – Uluru ............................ 92
5 Chapter 5 - Synthesis and Discussion ............................................... 97
  5.1 Camera Calibration ................................................................. 97
  5.2 High Alpine vs Coastal Photogrammetry ........................................... 98
  5.3 Digitization – The Photogrammetric Work Station (PWS) ........................ 101
    5.3.1 High versus Low Resolution Photographs ..................................... 102
    5.3.2 Windows 8GB RAM vs MacPro 32GB RAM .................................. 103
    5.3.3 Colour Enhanced Photographs and Image Format Compatibilities ...... 106
List of Figures

Figure 1-1: product of photogrammetry with digitised strike and dip measurements...................... 2

FIGURE 2-1: BASIC SYSTEM FUNCTIONALITY OF A DIGITAL PHOTOGRAMMETRIC WORKSTATION (SCHENK 2005). ..................... 6

FIGURE 2-2: PHASE DEVELOPMENT THROUGH HISTORY OF PHOTOGRAMMETRY ............................................................. 10

FIGURE 3-1: PHOTOGRAPHY WITH SELFIE POLE........................................................................................................... 17

FIGURE 3-2: PHOTOGRAPHY CHEAT SHEET (MERCER 2012). ............................................................................................ 19

FIGURE 3-3: SHOOTING PATTERNS RECOMMENDED BY AGISOFT (2015). ............................................................. 20

FIGURE 3-4: A FLOW DIAGRAM OF PHOTOGRAMMETRIC PRODUCTS ABLE TO BE GENERATED FROM DIGITAL 3D MODELS. ......... 12

FIGURE 4-1: LOCATION OF JULIAN ROCKS ON THE BANKS OF BOMADERRY CREEK, BOMADERRY................................. 15


FIGURE 4-3: LOCATION OF PHOTOGRAPH EXTRACTION RELATIVE TO OUTCROP AT JULIAN ROCKS. ..................................... 17

FIGURE 4-4: SCREEN IMAGE OF PHOTOSCAN HIGH-RESOLUTION 3D MODEL OF JULIAN ROCKS ............................................... 20

FIGURE 4-5: LEFT; GEOMETRY OF POINTS (P) ON A DIPPING GEOLOGIC SURFACE REFERENCED TO A HORIZONTAL PLANE. ........ 21

FIGURE 4-6 LOCATION OF SITE 1, PHOTOKSAR, LADAKH, GPS: 34°4′11.01″N, 76°50′29.25″E .................................................. 23

FIGURE 4-7: GEOLOGICAL MAP OF LADAKH, NW HIMALAYAS, INDICATING THE STUDY SITE (CORFIELD 2001, P.12) .............. 25

FIGURE 4-8: PHOTOGRAPH COMPARISON. ..................................................................................................................... 27

FIGURE 4-9: LOCATION OF PHOTOGRAPH EXTRACTION RELATIVE TO THE OUTCROP IN: ...................................................... 28

FIGURE 4-10: PHOTOGRAPH ADJUSTMENTS MADE........................................................................................................ 29

FIGURE 4-11: SCREEN IMAGE OF PHOTOSCAN HIGH-RESOLUTION 3D MODEL OF PHOTOKSAR .................................................. 32

FIGURE 4-12: GOOGLE EARTH MAP WITH YELLOW TAGS INDICATING THE LOCATION OF STUDY SITES. ...................................... 34

FIGURE 4-13: LOCATION OF PHOTOGRAPH EXTRACTION RELATIVE TO THE OUTCROP IN PHOTOSTS 1 AND 2 COMBINED. .......... 37

FIGURE 4-14: PHOTOGRAPH ADJUSTMENTS MADE........................................................................................................ 37

FIGURE 4-15: SCREEN IMAGE OF PHOTOSCAN HIGH-RESOLUTION 3D MODEL OF BINGIE BINGIE POINT. ............................. 39

FIGURE 4-16: LOCATION OF SITE 2, NAROOMA ................................................................................................................. 40

FIGURE 4-17: DIAGRAM OF COAST AND SHORELINE ZONES AND DESCRIPTIVE BOUNDARIES. ................................................ 41

FIGURE 4-18: GEOLOGICAL MAP OF THE NSW, SOUTH COAST INDICATING STUDY SITE AT NAROOMA, SURF BEACH ............ 42
List of Tables

TABLE 3-1: PHOTOGRAMMETRY BROADLY PORTRAYED AS A SYSTEMS APPROACH. ................................................................. 14
TABLE 3-2: CAMERAS TRIALLED IN THIS PROJECT. .................................................................................................................. 18
TABLE 3-3: FORMATS ACCEPTED BY AGISOFT PHOTOSCAN................................................................................................ 22
TABLE 4-1: CAMERA SPECIFICATIONS AND SETTINGS OF PHOTOSETS CAPTURED AT JULIAN ROCKS. ............................ 16
TABLE 4-2: PHOTOSHOP ADJUSTMENTS AND MODELS MADE FROM EACH PHOTOSET. .......................................................... 18
TABLE 4-3: SETTINGS AND SPECIFICATIONS USED IN PHOTOSCAN TO CREATE HIGH-DEFINITION 3D MODELS OF JULIAN ROCKS. 19
TABLE 4-4: CAMERA SPECIFICATIONS AND SETTINGS OF PHOTOSETS CAPTURED AT PHOTOKSAR, LADAKH, HIGH HIMALAYAS. 26
TABLE 4-5: PHOTOSHOP ADJUSTMENTS AND MODELS MADE FROM EACH PHOTOSET. .......................................................... 29
TABLE 4-6: SETTINGS AND SPECIFICATIONS USED IN PHOTOSCAN TO CREATE HIGH-DEFINITION 3D MODELS OF PHOTOKSAR. 31
TABLE 4-7: CAMERA SPECIFICATIONS AND SETTINGS OF PHOTOSETS CAPTURED AT BINGIE BINGIE POINT. ....................... 36
TABLE 4-8: PHOTOSHOP ADJUSTMENTS AND MODELS MADE FROM EACH PHOTOSET. .......................................................... 37
TABLE 4-9: SETTINGS AND SPECIFICATIONS USED TO CREATE HIGH-DEFINITION 3D MODELS OF BINGIE BINGIE POINT. ........ 39
TABLE 4-10: CAMERA SPECIFICATIONS AND SETTINGS OF PHOTOSETS CAPTURED AT NAROOMA, NSW. ....................... 44
TABLE 4-11: PHOTOSHOP ADJUSTMENTS AND MODELS MADE FROM EACH PHOTOSET. .......................................................... 49
TABLE 4-12: SETTINGS AND SPECIFICATIONS USED IN PHOTOSCAN TO CREATE HIGH-DEFINITION 3D MODELS OF NAROOMA. .... 51
TABLE 4-13: CAMERA SPECIFICATIONS AND SETTINGS OF PHOTOSETS CAPTURED AT HAYCOCKS POINT, EDEN, NSW. .......... 56
TABLE 4-14: PHOTOSHOP ADJUSTMENTS AND MODELS MADE FROM EACH PHOTOSET. .......................................................... 58
TABLE 4-15: SETTINGS AND SPECIFICATIONS USED IN PHOTOSCAN TO CREATE HIGH-DEFINITION 3D MODELS OF HAYCOCKS POINT. 59
TABLE 4-16: CAMERA SPECIFICATIONS AND SETTINGS OF PHOTOSETS CAPTURED AT THE PINNACLES, EDEN, NSW. ............... 61
TABLE 4-17: SETTINGS AND SPECIFICATIONS USED IN PHOTOSCAN TO CREATE HIGH-DEFINITION 3D MODELS OF THE PINNACLES. 63
TABLE 4-18: CAMERA SPECIFICATIONS AND SETTINGS OF PHOTOSETS CAPTURED AT EAGLES CLAW, EDEN, NSW. ................ 66
TABLE 4-19: PHOTOSHOP ADJUSTMENTS AND MODELS DEVELOPED FROM EACH PHOTOSET. .................................................... 68
TABLE 4-20: SETTINGS AND SPECIFICATIONS USED IN PHOTOSCAN TO CREATE HIGH-DEFINITION 3D MODELS OF EAGLES CLAW. .... 69
TABLE 4-21: CAMERA SPECIFICATIONS AND SETTINGS OF PHOTOSETS CAPTURED AT QUARANTINE BAY, EDEN, NSW.................. 71
TABLE 4-22: PHOTOSHOP ADJUSTMENTS AND MODELS DEVELOPED FROM EACH PHOTOSET. .................................................... 72
### Table 4-23: Settings and specifications used in PhotoScan to create high-definition 3D models of Quarantine Bay.

### Table 4-24: Camera specifications and settings of photo sets captured at Wolumla Road Cutting, Wolumla, NSW.

### Table 4-25: Photoshop adjustments and models developed from each photo set.

### Table 4-26: Settings and specifications used in PhotoScan to create high-definition 3D models of Wolumla.

### Table 4-27: Camera specifications and settings of photo sets captured at Mata Menge, Florese, Indonesia.

### Table 4-28: Photoshop adjustments and models developed from each photo set.

### Table 4-29: Settings and specifications used in PhotoScan to create high-definition 3D models of Mata Menge.

### Table 4-30: Camera specifications and settings of photo sets captured at Pakhuis Pass, Clanwilliam, South Africa.

### Table 4-31: Photoshop adjustments and models developed from each photo set.

### Table 4-32: High-definition 3D models of excavation sites at the Rocklands, South Africa.

### Table 4-33: Camera specifications and settings of photo sets captured at Uluru, Mutitjulu, Northern Territory.

### Table 4-34: Photoshop adjustments and models developed from each photo set.

### Table 4-35: Settings and specifications used in PhotoScan to create high-definition 3D models of Uluru.

### Table 5-1: Cameras trialled in this project and their resolution output.

### Table 5-2: Building model in Arbitrary Mode from 24MP photographs captured by the Nikon D610.
Chapter 1 - Introduction

This project evaluates methods of digital photogrammetry and applications of high-resolution 3D digital models in the extraction of geological data from virtual outcrops. Three dimensional models of outcrops are created for the purpose of extracting geological measurements remotely without any physical contact with the rock. Thompson (1958) has defined photogrammetry as the science or art of obtaining reliable measurements by means of photography. Photogrammetry as a science is among the earliest techniques of remote sensing since the invention of the photograph in the 1850s (Schenk 2005). The invention of the digital camera has progressed photogrammetry from the analogue to the digital phase (Burtch 2005). There have been rapid advances made in digital photogrammetry during recent years with the availability of faster hardware and more sophisticated software, such as powerful image processing workstations and vastly increased storage capacity (Carrivick 2013, Geological Survey of NSW 2015). Research and development efforts have resulted in operational products, such as AgiSoft Photomodeller, give a few software examples, that are increasingly being used by government organizations and private companies (ICSM 2008) to solve practical photogrammetric problems. As technologies associated with photogrammetry improve, including the increasing availability and affordability of drone aircraft carrying high resolution digital cameras, the potential applications of photogrammetric methods in fields like geology will expand and become more common place. Thus it is important that disciplines like Earth sciences stay up to date with the pace of technological advances and regularly review and test current technologies and test them against traditional methods of data collection. Currently, there are but a few recent studies regarding geological applications of photogrammetry. Recent advances in hardware and software, particularly advanced photographic positioning algorithms, mean that methods used only 5 years ago are now redundant and out-dated. Photogrammetry and three dimensional models are becoming increasingly useful in industries such as mining where visual inspection of steep mine faces is dangerous and impractical but also in recreational pursuits such as golf or trekking where people want to visualise golf courses or summit paths before attempting a shot or climb. – maybe give a link to the AgiSoft Photomodeller website where they give examples of applications?
Dr Matthew Cracknell and Dr Michael Roach have developed the most recent methods of photogrammetry for creating high-resolution digital elevation models (DEM) at the University of Tasmania. This project implements the method developed at the University of Tasmania (Cracknel et al. 2013), investigating the applications of digital photogrammetry and 3D modelling software for extracting complex geological data from outcrops that may be difficult or expensive to access. The realistic high-resolution, 3D virtual models of sites of rock outcrops give researchers the advantage of being able to “revisit” the site in a virtual sense and potentially extract more useful data, such as bedding, foliation, fold axes, slope, aspect, elevation and more from the outcrop (Cracknel et al. 2013). Dr Michael Roach from the University of Tasmania has set up an online repository of freely available models of key outcrops across Australia (see - http://www.utas.edu.au/earth-sciences/whats-new/news-item/geological-visualisation).

Figure 1-1: High-resolution 3D model, a product of photogrammetry with digitised strike and dip measurements.

Individual field applications were trialled at a number of different sites to develop and assess a number of different methods for the application of digital photogrammetry in geology. Sites include; 1) Nowra Sandstone, Bomaderry Creek, Bomaderry, to trial camera calibration in manual setting, 2) high Himalayan mountains along the Indus Suture Zone at Photoksar, Ladakh to experiment with large scale outcrop, 3) outcrops of the Wagonga Group at Narooma to trial coastal outcrop digitization, 4) several outcrops of Merimbula Group formations at Eden used in
teaching undergraduate field geology at UOW, 5) an exposure of the Mutitjulu Arkose (Uluru) in central Australia to trial aerial photography, and 6) archaeological sites at the Island of Floreses in Indonesia and at the Rocklands in South Africa to trial archaeological application. The extensive variety of geological sites was selected to assess and compare the methods used to create DEMs at each one. Methods were also varied to incorporate assessment and evaluation of using different cameras at different settings (manual versus automatic), cameras of different resolutions (high versus low), different types of weather (sunny versus cloudy), a variety of obstacles (alpine versus coastal) and to investigate what can be achieved from the results.

Dr Michael Roach states, small errors created by low resolution DEMs can significantly affect measurements from bed planes with dip estimation being more susceptible than dip orientation. Agisoft (2015) state, the accuracy of a model depends on effective image resolution of a photoset, accuracy of GPS coordinates, quality of model reconstruction and images overlap. Emphasis is made throughout the methods in this project to create the highest resolution model possible at each site by processing photosets with the highest settings achievable by PhotoScan likely to be limited by the processing power of the two computers used.

High-resolution 3D digital models were created primarily for evaluating the expediency and efficiency of their application in geology to extract structural geological data. A secondary advantage of creating high-resolution models is for addition to an online database to be freely available for future studies by creating a record of 3D outcrops, including the date the images were taken. Potential future studies include the study of rates of rock decay, downslope movement or soil erosion over time as a function of wave action, sea level rise, and rates of rock decay compared to rainfall on a particular escarpment by comparing the features of interest with those created years afterwards. In laboratory and field conditions the use for these methods is proving to be highly valuable (Gessesse et al. 2010, Morris et al. 2012, Rieke-Zapp and Nearing 2005). If climate change is real it could be especially useful to have a database to study what we have now as there may be a need for this information in the future as a result of inundated coast lines (Li et al. 2009). This present project investigates what is possible with photogrammetry and suggests potential uses for the technology. Methods are based on data extraction techniques, the appropriate software programs available and focus on determining the nature of the information that can be obtained from the results.
1.1. Aims and Objectives

The overarching aim of this project is to compare several methods of data extraction required to create 3-D models of outcrops and to identify the methods most suitable to extract geologic information from the model. Fieldwork will be at the high Himalayas near Photoksar in Ladakh and the low lying coastal outcrops along the NSW south coast. Three other sites were also incorporated to assess a variety of other applications. This project has been broken down into several achievable objectives, which include:

I. Collect necessary photographs and structural geologic information using traditional methods from selected study areas near the remote, difficult to access region of Himalayan village of Photoksar and compare with relatively easy to access regions of Narooma on the south coast of NSW.

II. Compare and contrast various cameras (Samsung Galaxy S5 versus Nikon DSLR) and camera settings (auto versus manual exposures) to determine the best method of capturing multiple images from which the Agisoft Photomodeller software will best match overlapping pixels and build the best image.

III. Examine the most efficient way to store and post-process batches of photos (IrfanView versus Adobe RawTherapee) in order to produce as much uniformity as possible between images and assessing the models produced with colour enhanced photographs versus natural colour photographs.

IV. Look at the effects of patchy cloud cover and contrasts in light and dark conditions on the ability of the software to match photos and render 3D models.

V. Produce different scale 3D models from different environments (Ladakh versus South Coast) to assess the usefulness and practicalities of photogrammetry in terms of extracting geological information.

VI. Assess results of a standard low powered computer run by Windows with 8 GB of RAM to a moderate to high powered computer, the MacPro with 32 GB of RAM.

VII. Compare the accuracy of structural geological data extracted from digital models with structural measurements recorded using traditional methods.
VIII. Evaluate the types of geologic information that can be extracted from constructed 3-D digital models and the practicalities of obtaining the data and using it in learning and teaching environments such as geological fieldtrips.

IX. Consider the advantages and disadvantages of digital photogrammetry compared with traditional methods of extracting geological information.

It is anticipated that this project will show that structural geologic data can be extracted quite readily from detailed, high-resolution 3-D digital models and can be used to compliment traditional structural geology methods. However, with studies documented by Haneberg (2006), measurements from 3-D models have an expected error related to the scale of the measurements being taken. Extracting data from 3-D digital models is also expected to be more convenient for outcrops that are difficult to access for manual measurements as seen in studies of Westboy, et al. (2006). It is also expected that working in the high Himalayas will have more implications than working on a coastal outcrop.
Chapter 2 - Literature Review Photogrammetry

The name “photogrammetry” is derived from the three Greek words phos or phot which means light, gramma which means letter or something drawn, and metrein, the noun of measure (Ghosh 1981). There is no universally accepted definition of photogrammetry (Schenk 2005). Kasser and Egles (2003) defined photogrammetry as ‘any measuring technique allowing the modelling of a 3D space using 2D images’. Geoscience Australia (1985) defines photogrammetry as a form of art and science useful for making accurate measurements by means of aerial and terrestrial photography. Photogrammetry is independent of the image type and is not restricted to photographs; it may include radar or scanning devices, for example Lidar and CT scanners. It may vary from macro scale, where planets are modelled from satellite imagery, to micro scale, where images from electron microscopes may be used to create 3D images. This present project is based solely on the acquisition of digital photographs that were processed through a photogrammetric software program (Agisoft Photoscan) at a digital photogrammetric workstation (DPW) (Figure 2-1) to recreate features selected from a number of different types of terrain and to trial different methods to create them. While the definition of photogrammetry is based on the use of film-based photographs to generate 3D imagery, models within this project were created digitally from digital photographs and are better defined for this project as digital photogrammetry.

3D viewing

CPU/OS  Graphics

Memory  Network

Storage  Periphery

Plotter

Figure 2-1: Basic System Functionality of a Digital Photogrammetric Workstation (Schenk 2005).
5 Steps of System Functionality of Digital Photogrammetry

1. Archiving: recording and storing in separate files suitable sets of digital photographs for creating 3D images.
2. Processing: formatting and adjusting visual settings of photographs if required then importing them into photogrammetric software for creating 3D images.
3. Display and Roam: the purpose of creating models is to study their visual aspects. Models can be exported as a number of different file formats and imported into other program, for example Blender, to use views such as flight and walk modes.
4. 3D Measurement: Models that are scaled or georeferenced correctly may be used to obtain a number of different measurements.
5. Super positioning: by rotating models, bedding layers can be lined up or models of different locations can be overlain for comparisons. This can also be achieved with orthophotos (perspective adjusted photographs suitable for making accurate measurements).

2.1 3D Digital Models

Complete integration of high-resolution color photographs into the 3-D models, in particular, is useful for geologic interpretation because it can convey information about non-geometric attributes such as the distribution of alteration or weathering, locations of seeps, and some variations in rock type. The result is a virtual outcrop that provides more information for geologic interpretation than an unadorned point cloud or mesh from Terrestrial laser scanners (Heno 2014).

Over the last decade Westboy (2012) has identified evidence of a technological revolution in geomatics that is transforming digital elevation modelling and geomorphological terrain analysis. The extraction of topographic data has been transformed by a new generation of remote sensing technologies. Airborne and, more recently, terrestrial laser scanning and soft-copy photogrammetry in particular, have improved the quality of digital elevation models (DEMs) by extending their spatial extent, resolution, and accuracy (Westboy 2012). Photogrammetry is the fastest and cheapest way to extract topographic data having only an error of +/- 8% (Haneberg 2006), inspiring the focus of the present project to be mainly on digital photogrammetry which is due to take over traditional methods.

High-resolution topographic surveying is traditionally associated with high capital and logistical costs, so that data acquisition is often passed on to specialist third party organisations. The high
costs of data collection are, for many applications in the earth sciences, made harder by the remoteness and inaccessibility of many field sites, rendering cheaper, more portable surveying platforms more desirable (Westboy 2012).

Traditional methods for characterising high mountain rock slopes are often constrained by accessibility and safety issues. Consequently, terrestrial remote-sensing techniques represent promising alternatives to supplement traditional rock engineering scanline or window mapping methods (Sturzenegger 2009).

High-resolution digital photogrammetry provided a fast, safe, and economical characterization alternative for a fast-track rock slope remediation design project conducted under challenging conditions. Three dimensional models can be created using photographs taken from a moving aircraft or watercraft with low cost and readily available cameras and software compared to terrestrial laser scanners. The ability to export results in a variety of formats and amenable to quantitative methods such as cluster analysis or eigenvalue fabric analysis is of direct interest to engineering geologists (Haneberg 2006).

In educational settings, mapping exercises can be established during which students collect their own aerial images and then interpret them. Unlike Google Earth or regular aerial photos, structures imaged by UAVs provide greater detail at small scales (Helmke et al. 2007). Such exercises also provide students with experience in using technical instrumentation, data collection, data analysis, and interpretation being all critical career skills. The use of unmanned aerial vehicles (UAVs) is also expanding in industry, making familiarity with them a résumé skill (Helmke et al. 2007). Because of the ease of use and accessibility, they can be especially useful in undergraduate research.

The past few years have seen the rapid development and availability of UAVs. Unmanned aerial vehicles also known as “drones” are remotely operated vehicles that can be fixed-wing aircraft or helicopters. Drones provides great maneuverability, stability, and control (Carrivick et al. 2013). Low cost drones may provide the most effective method of capturing images compared to hand held photography which can encounter difficulties of access. In addition, with the ever-shrinking sizes of sensors and an expanding range of instruments, there is greater potential for use of micro UAVs (Jordan 2015).
2.2 History of Photogrammetry

Photogrammetry has increased exponentially in importance with the invention of the photograph, aeroplane and the computer. Computers initiated the current phase of digital based photogrammetry. The events that have helped to develop photogrammetry are outlined in the following timeline:

1595- First mention of photogrammetry was in the late 15th century by De Vinci using a glass pane to draw what was seen on the other side and using the picture to make measurements.

1851- After the invention of photography, the art of Photogrammetry, or Metrophotography as it was originally termed by its inventor Laussedat, was developed to be able to find the correct metrical representations of the object photographed from ordinary photographs.

1901- Invention of steriophotogrammetry in by Pulfrich.

1908- First sterioplotter in by Orel.

1930- There was a boom in aerial surveying techniques between the world wars. The techniques that were developed are still used today. The most significant developments were the analog rectification and sterioplotting instruments which became widely available. Photogrammetry was then able to establish itself as an efficient survey and mapping technique (McCaw, G., Cazalet 1932).

1950- The invention of the computer created the beginning of the 3rd generation: analytical photogrammetry.

1955- The first photogrammetrist to access a computer was Schmidt, who then went on to develop the basis of analytical photogrammetry in the 50's using matrix algebra.

1968- Several years later, in the late 60's, Brown developed the first block adjustment program.

1969- Shortly after Brown, Ackerman was the first to identify and report a new program that improved aerial triangulation by a factor of 10. This led to two major breakthroughs in photogrammetry; aerial triangulation, and analytical plotters.

1972- While Helava invented the analytical plotter in the 50's it was not broadly available until the 70's. This 20 year delay between invention and broad based production is a typical example of the history for all new developments/inventions for photogrammetry.

1990- Finally, the fourth, and most recent generation to emerge, is digital photogrammetry. Digital images are rapidly replacing the use of aerial analog photography. The use of digital images has been made possible by the availability of storage devices (which permit
rapid access to digital imagery) and by the development of special microprocessor chips that allow higher speed random access memory (RAM).

2005- The photograph was the most widely used detector system for photogrammetric applications.

2015- There are currently 14 programs available worldwide for photogrammetry where photographs are automatically orientated for the purpose of making a 3D model. After experimenting with some of these programs at the University of Tasmania it was decided that Agisoft’s program PhotoScan produces the best detail, texture and accuracy for application in geology and is easy to use. Therefore this program was used for this present project.

There are four major phases in the development of photogrammetry that are directly related to the technological inventions of photography, airplanes, computers and electronics. These are the first generation, analogue photogrammetry, analytical photogrammetry and digital photogrammetry and each is defined according to particular inventions responsible for changing the methods of photogrammetry (Figure 2-2).

Figure 2-2: Phase development through history of photogrammetry related to particular inventions changing the basic methods used in photogrammetry, (Schenk 2005, p.8).
2.2.1 First Generation

Photogrammetry had its beginning with the invention of photography by Daguerre and Niepce in 1839. The first generation, from the middle to the end of last century, was very much a pioneering and experimental phase with remarkable achievements in terrestrial and balloon photography (Moffit 1980).

2.2.2 Analog Photogrammetry

Originally, metric cameras were used to create steriopairs mostly as aerial images. If topographic measurements could be recorded simultaneously it enabled the establishment of a good ground control point network for photogrammetric use of images. Final products produced by analog photogrammetry could be used for observing elevations, making plans, constructing cross-sections and to develop contour maps (Hassani 1992). Development of the principles of optics and mechanics allowed contour lines to be traced by hand with a pencil (Wolf 1980, Kraus 1994). In analog photogrammetry the procedures and instruments require mechanical and optical manipulation. The stereo plotter is the instrument used to measure 3D positions of points in a stereo model. Aerial photographs contain date-time, altimeter data, photo number and a level bubble. Topographic measurements could be recorded simultaneously to enable better establishment of a ground control point network for photogrammetric use of images (Moffit 1980).

2.2.3 Analytical Photogrammetry

Analytical photogrammetry replaced analogue in the 1970s. Equipment was enhanced by incorporating computers that enabled the implementation of an image formula for modelling the relationship between a point and its image on the photograph (Kraus 1994, Moffit 1980). An analytical plotter established the transformation of images computationally. Digital detection was not the most widely used in photogrammetry until 2005 as analogue systems have unique properties that make it, in many cases, superior to earlier digital detectors (Schenk 2005).
2.2.4 Digital Photogrammetry

During the 1990s, the first digital photographic equipment became available. This expanded the possibilities for photogrammetric surveying. Methods were rapidly implemented by photogrammetrists who saw the possibilities of using the high-quality images which were instantly recorded in digital format extracting the need to scan analogue photographs (Hassani 1992). Automatic measurement algorithms were also implemented into their production processes. Three dimensional manual plotting is now largely replaced by new automated 3D reconstruction programs. Today a digital photographic workstation is a standard computer (Heno 2014). Current photogrammetric software is now able to calculate all of a camera’s geometric characteristics (focal length and law of optical distortion) and automatically orientate the position the camera was in at moment of capture and identify the object to be modelled because of the consistent overlap of adjacent images (Heno 2014). Recent trends towards opened-sourced software means photogrammetry is no longer a privilege for only a select few specialists at South Africa, Indonesia and Uluru in the Northern Territory.
Chapter 3 - Methodology Creating 3D Models

The method outlined is a generalized outline of terrestrial digital photogrammetry developed by incorporating the Agisoft PhotoScan user’s manual with field work achieved in this project. The method outlined in the PhotoScan user manual has been applied to a variety of different photosets outlined in Chapter 4 to experiment with the application of digital photogrammetry assessing what works and what does not. Due to the recent advances in technology in the field of photogrammetry there is no available written method for using modern equipment and software programs for terrestrial digital photogrammetry in the field of geology. YouTube tutorials and vast amounts of trial and error also assist in describing a generalized method for 3D digitization of rock outcrops. Before commencing any fieldwork tips and hints were acquired on a field tutorial run by Michael Roach. Studies from this paper incorporate the methods already practiced and investigate by Dr Roach integrating a number of new ideas and techniques.

Digital photographs are the primary source of data to create models was collected as and GPS points for georeferencing. Field measurements including strikes, dips and site dimensions were recorded to allow comparison with measurements extracted from digitized models. After running each photoset a number of times through the photogrammetric process, the most complete and sufficient model from each photoset is shown in the results. After running each photoset a number of times through the photogrammetric process, the most complete and sufficient model from each photoset is shown in the results.

Through terrestrial photogrammetry results of traditional methods for measuring structural geology are compared to any possible results extracted from new methods trialled in this project by means of photogrammetry. The main geological information for extraction from photogrammetric models is strikes, dips and field measurements of distances. Results of old and new methods are compared to assess accuracy and expediency of photogrammetry.

3.1 Digital Photogrammetry

The following method of digital photogrammetry has been developed applying the Agisoft PhotoScan user manual as the basis for the steps incorporated. The procedure has been customised accordingly to suit the photogrammetric results required. The photogrammetric process has been divided into five phases:
Phase 1 – Reconnaissance
- Site allocation
- Prerequisites
- Field equipment

Phase 2 – Photography
- Camera
- Format
- Photographic pattern

Phase 3 – Photoshop
- IrfanView: for non GPS referenced photographs
- RawTherapee: for GPS referenced photographs.

Phase 4 – Digital Photogrammetry
- PhotoScan

Phase 5 – Analysis
- Orthophoto
- PDF
- Blender
- GeoVis 3D

Table 3-1: Photogrammetry broadly portrayed as a systems approach.

<table>
<thead>
<tr>
<th>Data Acquisition</th>
<th>Photogrammetric Procedures</th>
<th>Photogrammetric Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera → Photographs</td>
<td>Hardware&lt;br&gt;- Windows 2.5GHz&lt;br&gt;- Intel dual core i7 processor&lt;br&gt;- 8GB RAM&lt;br&gt;- MacPro 3.5GHz 6-Core Intel Xeon E5 processor&lt;br&gt;- 32GB RAM</td>
<td>Photographic products&lt;br&gt;- Rectifications&lt;br&gt;- Orthophotos&lt;br&gt;- DEMs, profiles, surfaces, points&lt;br&gt;- XML&lt;br&gt;- PDF&lt;br&gt;- OBJ&lt;br&gt;- 3DS&lt;br&gt;- PSL</td>
</tr>
<tr>
<td>Scanner</td>
<td>Softcopy workstation&lt;br&gt;- Photoshop&lt;br&gt;- PhotoScan&lt;br&gt;- GeoVis 3D&lt;br&gt;- Blender</td>
<td>Output</td>
</tr>
</tbody>
</table>
3.1.1 Phase 1- Reconnaissance

3.1.1.1 Site Allocation

Prior to making a model it is necessary to consider the sites that are best suited for digital photogrammetric reconstruction. Depending on the type of study, any geological outcrop can, in some way, be reconstructed in digital form to create useful data. Digital models can be studied to investigate such things as structural data, to measure slope movement, and to measure volume of a land mass.

In this study, outcrops have been selected based on their physical appearance and location. The focus has been to extract measurements of strikes and dips from digital photogrammetric outcrops and to compare them with measurements taken on the field. It is necessary that outcrops not only display stratigraphic layering but can also be accessed and measured by traditional methods with a brunton or phone application such as field move (used in this project) so that results can be compared to test the accuracy of measurements from digitised outcrops.

For greater efficiency, it is necessary to visit the site in advance to define the elements of digitization and to decide on required resolution and accuracy of georeferencing needed. It is often necessary for the projects sponsor to be present and available for questioning.

- Access authorisations should have been investigated prior to this stage including any possible diversions of the public for a given period.
- Plan position of various measuring instruments by access limits, arranging as few as needed to save time.
- Resolution required will determine type of camera needed and its distance from object.
- It is best to arrange georeferencing points at obvious natural features likely to be long lasting. It is also necessary to have a sufficient numbers for accurate positioning.
- The number of visits may depend on budget, accessibility, weather limitations and project size.
- Depending on the complexity of the site, it may be better accomplished in parts and later put together.

Himalayan Photoksar is the first site where the digital photogrammetric method was trialled. It was selected due to its complex folded structure, but also to trial photogrammetric methods in a high alpine region. The second site selected was a coastal area at Narooma to make a direct comparison between methods in high alpine and coastal regions. Narooma was chosen as it has complex folded
structures of chert outcropped at its shores which have similar fold structures to those in the Himalayas but on a larger scale. Five different outcrops were selected to trial digitisation methods as explained further in (Chapter 3). Eight sites at Eden were trialled to create models to be displayed as learning guides for students doing the EESC 250 field geology subject. A number of other sites were chosen at different locations around the world to create a broader variety of models at different locations and with digital photographs produced from several different cameras to assess the difference between their different characteristics (such as high/low resolution). The sites were incorporated primarily to test the capabilities and limitations of Agisoft PhotoScan and what one can expect in closely replicated situations. The sites incorporated for variety included Flores Island (Indonesia), Rock Lands (South Africa), Nowra Sandstone (Bomaderry) and Uluru (Northern Territory). Sites at Flores and the Rock Lands are archaeological sites allowing assessment of photogrammetry for its application in archaeology.

3.1.1.2 Field equipment (Picture of each as appendix)

The equipment used in this project is outlined below.

- Camera: Higher resolution cameras produce better images requiring more processing power. This is ideal when few photographs are needed or pictures need to be taken from a distance. Low resolution cameras are best when there are a large number of photographs that need to be taken. This is usually where a large area is required to be covered or where there is a complex surface area involving many objects that need to be photographed at a number of angles.
- 9m selfie stick: Necessary when pictures need to be taken at a higher angle of up to 10 m.
- Boat: Necessary where outcrops need to be photographed along a shoreline or where access by land is difficult or impossible.
- Four wheel drive vehicle: Necessary for remote locations where roads are not accessible by two wheel drive vehicles.
- Unmanned aerial vehicle (UAV): Necessary for high outcrops where camera angles above 10 m are required or foot and boat access are not possible or too dangerous.
- Scale, compass and level: A good scale is an item that is large enough to be recreated in 3D and incorporated into the model so that its known dimensions can be used to give the model a scale. Straight flat objects are ideal so that they can also show the direction of north
(aligned with a compass) and made level to show the orientation of a surface horizontal to the force of gravity (aligned with leveling device).

- **GPS with altimeter**: Necessary when a model is required to be georeferenced. The high accuracy of a GPS will produce a more precisely georeferenced model. Obvious landmarks that will also be displayed in the model (but not on a vertical surface such as a cliff) should be used so that the location for each GPS point can easily be identified in the model and placed with a marker in PhotoScan in the correct position.

- **Computer with a large amount of RAM**: PhotoScan can produce models at a number of different resolutions. The higher the resolution the more accurate and detailed the model will be. The greater the amount of processing power available the higher resolution a model can produce. Anything less than 8GB of RAM will produce poor results with models created from over 20 photographs.

### 3.1.2 Phase 2 - Photography

After completion of a site plan, the photography phase should be as simple as following the plan and managing any outside constraints that may occur. Operations are carried out as planned in accordance to:

- **Geometric information**: spatial position and shape of object.
- **Physical information**: refers to properties of electromagnetic radiation, e.g. polarisation.
- **Semantic information**: meaning of an image, e.g. interpretation.
- **Temporal information**: how an object has changed over time when compared to previous images.

#### 3.1.2.1 Camera

Agisoft PhotoScan is capable of processing images shot with both metric and non-metric cameras. This means that it is possible to carry out true photogrammetric research with the help of an ordinary digital consumer-level camera. No special photogrammetry equipment is required.
**Resolution:** Agisoft PhotoScan does not set any requirements concerning the image resolution. However, it is reasonable to remember that the resolution of the input data influences the quality of the processed results. That is why it is strongly recommended to employ a camera with at least 5 MP resolution. To produce professional quality orthophotomaps it is better to opt for 12 MP resolution photography.

**Lens:** since the software applies the Brown model to simulate lens assembly, automatic calibration works perfectly well for “standard” optics (that is with 50 mm focal length (35 mm film equivalent)). To process data collected with “fish eye” lenses, you need to indicate corresponding camera type in the program settings*. The software is also capable of spherical camera data processing, providing that it implements equirectangular projection. If the source data was captured with ultra-wide angle lenses, the operation is likely to fail. In this case, one should enter calibration data to the program to achieve good reconstruction results.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Resolution</th>
<th>Megapixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial photographic camera</td>
<td>14,430 x 9,420</td>
<td>136</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>6,016 x 4,016</td>
<td>24</td>
</tr>
<tr>
<td>Panasonic</td>
<td>4,896 x 3,672</td>
<td>18</td>
</tr>
<tr>
<td>Samsung Galaxy s5</td>
<td>5,148 x 3,456</td>
<td>18</td>
</tr>
<tr>
<td>GoPro</td>
<td>4,000 x 3,000</td>
<td>12</td>
</tr>
<tr>
<td>Nikon D7000</td>
<td>3,872 x 2,592</td>
<td>10</td>
</tr>
<tr>
<td>iPhone 4s</td>
<td>3,264 x 2,448</td>
<td>8</td>
</tr>
</tbody>
</table>
3.1.2.2 Shooting

A basic knowledge of photography can assist in capturing good quality photographs. Figure 3-2 outlines visually the basic functions of camera settings. The better quality of a photoset the better the results of Agisoft PhotoScan will be. Blurry photographs and wrong ISO, F-stop and shutter speed setting can prevent correct alignment of photographs. It is possible that, after an entire day of photography at a remote site, the photosets are of no use for obtaining suitable results from PhotoScan if the setting are not adjusted correctly. If you do not have any experience in photography, or do not know how to correctly use the manual settings on a SLR camera, you would benefit from doing at least a short course in photography from a professional photographer or someone who has a good understanding in how to use the manual settings on a digital camera.

Aperture: large aperture (such as f/2.0, f/2.8) lets in more light to the camera shutter for an exposure but gives poor depth of field, while small aperture (f/11, f/16, f/22) has a smaller opening in the lens diaphragm to let in less light for a given exposure resulting in greater depth of field. The size of an aperture in a lens can either be fixed or adjustable (as in an SLR camera). Aperture size is usually calibrated in f-numbers or f-stops.

Shutter speed: or exposure time is the length of time that the film or digital sensor inside the camera is exposed to light when taking a photograph. The amount of light that reaches the film or image sensor is proportional to the exposure time. Longer exposure gives lighter photographs with any movement being blurred. Shorter exposure times produce darker photographs with motion less blurred.

ISO: The lower the ISO number, the less sensitive it is to the light which is better in sunny weather. A higher ISO number increases the sensitivity of your camera and is better in darker conditions. The component within your camera that can change sensitivity is called “image sensor” or simply “sensor”.

Figure 3-2: Photography cheat sheet (Mercer 2012).
Shooting Pattern and Planning: Note; if a feature is not overlapping in at least two photographs it will not be incorporated correctly into the model. Figure 3-3 below illustrates the basic ideas about proper shooting scenarios.

![Diagram of shooting patterns recommended by Agisoft (2015).](image)

Figure 3-3: Shooting patterns recommended by Agisoft (2015).

For the successful completion of the photo reconstruction task it is important to guarantee enough image overlap across the input dataset. In the case of aerial photography the requirement can be summarised as at least 60% of side overlap and 80% of forward overlap.

Take care with object texture and invent tricks to avoid plain/monotonous and glittering surfaces. For example, talc can be spread over a shiny surface to change it from a glittering to a dull surface. Photoscan has difficulty correctly orientating shiny surfaces.

To build a texture map of the object that has been prepared before shooting (as in the examples above) you need to capture two sets of images of the same object; one of the “natural” texture of the object and the other of the prepared object. The key point is that you need to take both sets of images from the same camera positions. This requires the organisation of a fixed set of cameras for the shoot to be successful.
To carry out any measurements based on the reconstructed model, it is important to locate at least two markers with a known distance between them. Alternatively, you can place a ruler within the shooting area.

To fulfil a georeferencing task, an even spread of at least 10 ground control points (GCPs) across the area is required to achieve results of highest quality; both in terms of the geometrical precision and georeferencing accuracy. Nonetheless, Agisoft PhotoScan is also able to complete the reconstruction and georeferencing tasks without GCPs.

**Trial and Error**

After having been familiarised with the basic camera settings and having decided on a shooting pattern, the next step is to trial some photography. Points to consider when taking photographs include:

- Go to an area that is easy to access to practise shooting; preferably similar to where you are planning your major project.
- Trial both sunny and cloudy conditions to see which settings work the best in different conditions (Figure 3-2).
- Put camera into manual mode; usually an uppercase M on the cameras scene selector.
- Adjust ISO and F-stop settings so that the object of interest has the clearest lighting and correct exposure (Figure 3-2). If you wish to study shady areas in any details, it may be best to have the sky over-exposed and burnt out so that the object of interest shows more colour and detail and less shadow effect. Shadows can also be reduced in photoshop programs (Chapter 3.1.3).
- After correct lighting settings have been selected it is time to start shooting.
- When pressing the trigger it is important to hold the camera as steady as possible (more so when there is poor lighting and when using higher ISO settings) to avoid any blurring.
- Inspect photographs closely on a large screen or computer after shooting to compare the results and see which settings worked the best.
- Go through the procedure again if the pictures could be improved in any way. Blurry photographs can ruin parts of the model alignment phase so it is important that photographs are as clear as possible.
Considerations:

- Number of workers and their ability to work together without anyone being an inconvenience.
- Number of instruments available and how to use them most efficiently.
- Weather forecast and best time of day for lighting.
- Possible presence of the general public who may need to be diverted during the shoot.
- Conformity with requirements specified, are resolution and stereoscopic overlap specifications satisfactory?

Field work for this project acquired data primarily by hand-held photography using a 7 m pole to extend the camera’s height when high angle shots were required. In areas inaccessible by foot, a boat has been used. This also provided the opportunity to compare the quality of a model created by images from a boat with images taken by hand held devices.

For more detailed and less specific guidelines and cautions on camera choice and shooting scenarios refer to Chapter 2 in Agisoft PhotoScan User Manual available at: http://www.agisoft.com/downloads/user-manuals/

### 3.1.3 Phase 3 – Photoshop

#### 3.1.3.1 Format

<table>
<thead>
<tr>
<th>Format</th>
<th>Script</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPEG</td>
<td>*.jpg</td>
</tr>
<tr>
<td>TIFF</td>
<td>*.tif</td>
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<tr>
<td>PNG</td>
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</tr>
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<td>BMP</td>
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<tr>
<td>OpenEXR</td>
<td>*.exr</td>
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<tr>
<td>Portable Bit Map</td>
<td>*.pgm</td>
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<tr>
<td>Multi-Picture Object</td>
<td>*.mpo</td>
</tr>
<tr>
<td>Norpix Sequential Files</td>
<td>*.seq</td>
</tr>
</tbody>
</table>
Photograph formatting is an essential stage of digital photogrammetry when using Agisoft Photoscan if the photographs were recorded in RAW format. If the photographs are recorded in a format compatible with photoscan (see Table 3.3) it is possible to skip to photo adjustments or upload digital photographs directly to photoscan. In this project, trials were run to test results from photographs left as their original colour and for comparison with results (3D images) created by photographs where colours were modified to emphasise the different coloured bedding layers.

3.1.3.2 IrfanView – For non-GPS referenced photographs

IrfanView is a freeware/shareware image viewer for Microsoft Windows that can view, edit, and convert image files and play video/audio files. The program is small size, fast, easy to use, and able to handle a wide variety of graphic file formats (Appendix A). It also has some image creation and painting capabilities. The software was first released in 1996. IrfanView is free for non-commercial use; commercial use requires paid registration.

IrfanView is a compact graphic viewer compatible with:

- Windows 9x, ME, NT
- Windows 2000
- Windows XP
- Windows 2003
- Windows 2008
- Windows Vista
- Windows 7
- Windows 8
- Windows 10

Its design is simple for beginners and can be powerful for professionals. A program like Adobe Photoshop (not used in this project) may be more suited for application with a Mac.

IrfanView features:

- 32 and 64 bit version
- Many supported file formats (Appendix A)
- Multi language support
- Thumbnail/preview option
- Paint option - to draw lines, circles, arrows, straighten image etc.
- Toolbar skins option
- Slideshow (save slideshow as EXE/SCR or burn it to CD)
- Show EXIF/IPTC/Comment text in Slideshow/Fullscreen etc.
- Support for Adobe Photoshop Filters
When editing photographs, most photo editing software programs will add additional data by masking a layer over the top of the original photograph increasing the file size. IrfanView recreates the photograph while incorporating the changes so that no extra data is added and each pixel carries its original file size unless compressed to a lower quality and smaller file size.

### 3.1.3.3 RawTherapee – For GPS referenced photographs.

RawTherapee provides the user with a file browser, a queue, and an image editing tab.

**File browser:** shows photo thumbnails along with a caption of the shooting information metadata. The browser includes 5-star rating, flagging, and an Exif-based filter. It can be used to apply a profile, or parts of a profile, to a whole selection of photos in one operation.

**Queue tab:** allows one to put exporting photos on hold until adjusting them in the Editor is complete. This means that CPU is fully available to the user while tweaking a photo instead of
processing photos while the user is trying to tweak new ones; which could result in a sluggish interface. Alternatively, the queue tab can be used to process photos alongside tweaking new ones if one has a CPU capable of handling the workload.

**Editor tab:** is where the user tweaks photos. While the image is opened for editing, the user is provided with a preview window with pan and zoom capabilities. A color histogram is also present offering linear and logarithmic scales, and separate R, G, B and L channels. All adjustments are reflected in the history queue and the user can reverse any of the changes at any time. There is also the possibility of taking multiple snapshots of the history queue, allowing for various versions of the image to be shown. These snapshots are not written to the sidecar file and are subsequently lost once the photo has been closed; however, work is underway to migrate the PP3 sidecar system to XMP which already supports storage of snapshots. By copying the settings used on a photograph the settings can then be pasted to other selected photos for batch conversion.

The viewing space for adjusting visual settings of a photograph in RawTherapee was found to be better than that in IrfanView.

**Input File Formats**

RawTherapee can work with both raw files from digital cameras as well as usual images. It also supports high dynamic-range, 16/24/32 bit raw DNG images.

While reading raw files RawTherapee relies on the dcraw code, but only for parsing formats; not for processing. Thus, RawTherapee supports all the formats supported by dcraw.

Additionally, RawTherapee supports the following image formats:

- JPEG
- TIFF
- PNG

Models tested for natural versus enhanced colours included Julian Rocks, Mod 2 Narooma, Mod 3 Narooma, Mod 4.5 Narooma, Mod 5 Narooma, Shale Cutting, Haycock West,
3.1.4 Phase 4 – Digital Photogrammetry

3.1.4.1 Agisoft PhotoScan

Agisoft PhotoScan was the software chosen for the photogrammetric processing of digital photographs in this project. PhotoScan uses well implemented algorithms to analyze each input image for special features in order to create a relation between the images of the entire scene (Remondino et al. 2014). It is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data that can be used in GIS applications, cultural heritage documentation, and visual effects production (Agisoft 2015). It can also be used for indirect measurements of rock outcrops of various scales (Cracknel et al. 2013). It has a wisely implemented digital photogrammetry technique enforced with computer vision methods which results in a smart automated processing system that can be managed by a new-comer to the field of photogrammetry. On the other hand, Agisoft PhotoScan has a lot to offer to a specialist who can adjust the workflow to numerous specific tasks and different types of data. For the various case studies, PhotoScan produced quality and accurate results.

3.1.4.2 Photo Preparation

The following instructions are a broad tutorial for using PhotoScan to process a single photoset in Agisoft PhotoScan Professional, version 1.2.2.

1. Eliminate any blurry, out-of-focus or non-significant photos unrelated to the model from your photoset.

2. If you have GPS track data for your photos, use a program like RawTherapee or GeoSetter to geotag your photos before processing. IrfanView is a more suitable program for non-GPS tracked photos (Chapter 3.1.3).

   a. With geotagged photos, the coordinates are usually Latitude and Longitude (in degrees). Use the convert tool in the ‘ground control’ pane to convert to UTM.

   b. Never use geotagged photos as the sole source of georeferencing information. The errors in consumer grade GPS units (handheld or in camera) are too large for anything more than helping with photo alignment.
3. Agisoft PhotoScan estimates camera calibration parameters automatically. Consequently, generally there is no need to run pre-calibration procedures manually.

### 3.1.4.3 Photo Alignment

1. Load your photo set for a single model
   a. The masking tools can be used to create a mask over any features (such as the sky, people or trees) not needed in the model.

2. Align Photos Settings:
   a. Accuracy:
      i. High: is best for smaller photosets
      ii. Medium: is best for larger photosets
   b. Pair Selection:
      i. Disabled: default, works for most datasets
      ii. Generic: use this one if there is any trouble getting photos to align
      iii. Ground Control: If photos are geotagged, this will use the GPS positions to speed up processing.
   c. Advanced:
      i. Point Limit: 40,000 is the default. Smaller numbers can speed up processing, but you run the risk of not having enough points to align photos.
      ii. Constrain features by mask: You can use masks to exclude parts of the images you do not want to model, check this box if you have masks.

3. Fixing misaligned or unaligned photos
   a. After the initial pass of photo alignment there may be photos that are misaligned or unaligned. You can force the program to try again; usually this works (but not always).
i. Select all of the photos that are causing trouble, right-click and select ‘Reset Alignment’

ii. Right-click again, select ‘Align Selected Cameras’

iii. If that does not work, select a smaller batch of problem photos and try again by working in small batches.

iv. If none of that works, you need to disable or exclude the photos that will not align.

3.1.4.4 Georeferencing

1. Prepare your control point data

   a. Double-check your projection and vertical datum; do any conversions outside of Photoscan.

   b. Load your data points into Excel and delete all but the NAME, LAT (Northing), LONG (Easting), and ELEV to simplify things.

   c. Save as a text file (tab delimited).

   d. Use the Import tool in the ‘Ground Control’ pane, set the import settings, say ‘Yes to all’ when it asks to add points.

   e. If you import a larger file, you should delete any points that are not present in the photoset.

2. Set your projection with the ‘Settings’; the other settings are default.

3. Find the first photo with a ground control point.

   a. Double-click the photo to open it, zoom in on the control point, right-click on the centre of the control point marker, select ‘Place Marker’ and select the appropriate marker.

   b. Find the next photo with the same GCP as the first, set the marker.

      i. Once you have a marker placed in two photos the software starts to guess where they should be in other photos.

      ii. Right-click on the marker you have been working on, select ‘Filter Photos by Marker’. This will show just the photos that the marker is in.
iii. Click through all of the photos and place the markers.

iv. If a photo has a marker flag in it, but the GCP is not visible, you can leave it as a grey flag and it will not be used, or you can right-click on it and ‘Remove Marker’.

c. In the photos pane, select ‘Reset Filter’ to get back to the full photoset.

d. Repeat the above steps for the next two GCPs.

4. After you have three GCP markers set, you can ‘Update’ the georeferencing in the ground control pane.

a. This will roughly georeference the model and make finding the remaining GCPs easier.

b. If your first three points are close together, this may not work very well; In this case you may have to manually find and mark an additional GCP.

5. Right-click on the next GCP in the list and ‘Filter Photos by Marker’.

a. Run through all of the photos and place the markers.

b. ‘Update’ again to refine the georeferencing.

c. Repeat this step for the rest of the GCPs.

6. Double-check that all of your GCP markers are placed.

a. Right-click on all of the GCPs and ‘Filter Photos by Marker’.

b. Double-check that all of the photos have little blue flags above them in the photo pane.

c. Update one last time.

3.1.4.5 Optimize the alignment

1. Double-check that you have a camera calibration applied to all of the photos.

2. Click on ‘Optimize’ in the ground control pane.

a. Make sure the ‘Fit k4’ box is checked.
b. This optimizes the camera alignment based on the camera calibration and control points.

3. Check your error for each GCP.
   a. In the georeferencing pane, the point with the worst error is highlighted in red.
      i. You can also click on ‘View Errors’ to view the X, Y, and Z components of the error.
   b. If you have points with errors that are higher than you would like, you can uncheck the box on the left to exclude the points from the georeferencing calculations.
   c. Update the georeferencing and repeat for any other bad points if necessary.
   d. If you change or exclude a lot of points, re-optimizing is a good thing to do.

3.1.4.6 Building Dense Point Clouds

1. Settings
   a. Quality:
      i. This is the super memory intensive part of the process; photosets that are large (lots of photos) can take a long time to complete. Too many photos cause the program to run out of memory. The quality that is achievable and the time it takes depend on your processor (CPU), RAM, and video card (GPU).
      ii. High: great for smaller photosets (up to ≈150 photos)
      iii. Medium: good for larger datasets (over 150 photos)

   b. Advanced
      i. Depth Filtering: limits points that are too far from the surface. For models with a lot of vegetation, aggressive (default) may be the most suitable setting. For more flat and smooth rock surfaces the setting may be better set to moderate or mild.
3.1.4.7  Point Cloud Editing

1. If there are any points in the dense point cloud needing to be eliminated, they can be deleted manually. To do this use the ‘Rectangle Selection’, ‘Circle Selection’, or ‘Free-form Selection’ tools on the toolbar to select and delete errant points.

2. Check the bounding box (the light grey box with a red bottom) size and orientation.
   a. Use the ‘Resize Region’ and ‘Rotate Region’ tools on the toolbar if the bounding box looks like it is going to cut off any parts of the model.

3.1.4.8  Build Mesh

1. Settings
   a. Surface Type:
      i. Height Field: only builds a mesh surface orthogonal to the reference system Z-axis (i.e. no undercuts will be modelled). This is the fastest mesh procedure and excellent if DEMs are going to be your final product.
      ii. Arbitrary: Will model every nook and cranny of the object. It is best used for oblique imagery when point clouds or complex mesh surfaces are going to be the final product.

1. For geography applications, a height field would normally be modelled orthogonal to the Z-axis of the coordinate system. In Photoscan, the height field is actually modelled against the orientation of the bounding box (the light grey box with a red bottom) of the model. You can run this Python script (Align Bounding Box Tool) in the console to align the bounding box to the reference system. You will need to

   b. Source Data:
      i. Dense cloud: default, incorporates all point within the bounding box.
      ii. Sparse cloud: You could use this, however, it serves no benefit.
c. Polygon Count: The number of polygons that the model will be decimated to after processing.

i. The software has High, Medium, Low values.

ii. Or you can specify a custom number (entering 0 will not decimate the final model).

d. Interpolation

i. Enabled: default, will interpolate over small holes in the surface

ii. Extrapolation: will leave holes in the final surface where there are no dense points

e. Point Classes:

i. There is a point classification tool in Photoscan. If you used it to classify the dense point cloud, you could specify which point classes you want to use for the mesh.

3.1.4.9 Texture

1. Settings

a. Quality:

i. This is the memory intensive part of the process; photosets that are large (lots of photos) can take a long time to complete. Too many photos cause the program to run out of memory. The quality that is achievable and the time it takes depend on your processor (CPU), RAM, and video card (GPU)

ii. High: great for smaller photosets (up to ≈150 photos).

iii. Medium: good for larger datasets (over 150 photos).

3.1.4.10 Exporting DEM / Orthophotos

1. File...Export DEM...Export TIFF/BIL/XYZ...

a. Settings
i. Choose your projection.

ii. Crop invalid DEM: checked by default.

iii. No-data value: Use -9999 for ArcGIS.

iv. Pixel Size: Photoscan estimates an appropriate pixel size and can be changed to match your requirements.

v. Split in blocks: segment the DEM into X by X rasters (only needed for large datasets).

vi. Set boundaries:

1. Check the box and click ‘Estimate’, this limits extra no-data values on the edges:

   vii. Write world file: not necessary if you export a TIFF.

   viii. Choose your output location, file name, and type.

2. File...Export Orthophoto...Export JPEG/TIFF/PNG:

   a. Settings

      i. Choose your projection.

      ii. Blending mode: Mosaic (default).

      iii. Enable Colour Correction: not usually necessary; but if you need the colour to be evened out feel free to select this option.

      iv. Pixel Size: same as above.

      v. Split in Blocks: same as above.

      vi. Set boundaries: same as above.

      vii. Write world file: not necessary if you export a TIFF.

      viii. Choose your output location; file name, and type.

### 3.1.5 Phase 5 - Photogrammetric Products

PhotoScan supports model export in the following formats:

- Wavefront OBJ
- VRML
- 3DS file format
- COLLADA
Some file formats (OBJ, 3DS, VRML, COLLADA, PLY) save texture image in a separate file. The texture file should be kept in the same directory as the main file describing the geometry. If the texture atlas was not built only the model geometry is exported. (Agisoft 2015).

Figure 3.4 outlines the type of products one may hope to obtain from photogrammetric processes. Products range from simple stitching of photographs to complex, georeferenced models that cater for a large number of applications for use in geology and many other areas. A flow chart (figure 3-5) shows the way one may hope to reach such results.

Figure 3-4: A flow diagram of photogrammetric products able to be generated from digital 3d models.
Chapter 4 - Field Work Methods and Results

To test the expediency of digital photogrammetry in geology the following field sites were visited to trial photogrammetry determining the feasibility of the results obtained. Utilizing the methods outlined above from the hardware and software described a number of image processing and photogrammetric applications can be integrated to create files for export from PhotoScan. The method developed for each section is briefly outlined from the general methodology described above in Chapter 3. Tables 4.1 to 4.35 were generated from the Table of Methods (Appendix C).

4.1 Project Applications

This project has been limited to focus on the comparison of methods used for application of photogrammetry in the field of geology. Because there is little existing research utilising the more recent available technology for extracting geological measurements, two different landscapes were selected for a comparative study. The methods required in a high alpine region were compared to the methods required in a comparatively low lying coastal area. One site has been chosen for research in a high alpine region because of the difficulty of access to the study site and time constraints. Four regions (Narooma, Bingie Bingie Point, Wolumla and Eden on the NSW south coast) were chosen as the coastal research sites. Study sites were selected based on professional observations made by Dr Solomon Buckman and Associate Professor Dr Brian Jones from the University of Wollongong, 2015. The geology exposed at outcrops is presumed to be ideal for this project as there are clear stratigraphic and structural features available. Each site can also have a number of obstacles for acquiring the photographs necessary to produce the 3D images. In addition, each site was expected to produce a different type of information because of their variation in geology. The data collected was then taken back to laboratories at the University of Wollongong for analysis and comparison.

Other side studies were added to the project to test further the capabilities of PhotoScan. These included a camera tuning exercise, trials of photogrammetry for the purpose of archaeology, high resolution photographs vs low resolution photographs, natural colour of photographs vs enhanced colour of photographs, Windows with 8 GB RAM compared to a MacPro with 32 GB RAM and Photoscan exports. The coastal sites of Narooma and Eden were also used as experiments in side studies by running each as separate case studies. Sites at Eden, Bega and Bingie Bingie point were trialled as sites used to create educational media for the purpose of the EESC 250 Eden field geology subject.
The following list outlines the extent of this project in the areas that are focused on trialling the applications possible for digital photogrammetry. These are discussed in detail in Chapter 5.

- Camera Calibration
- High alpine region versus Coastal Photogrammetry
- Digitization – The Photogrammetric Work Shop (PWS)
- Archaeological application
- Extracting Structural Measurements

### 4.2 Camera Calibration – Julian Rocks

This is a small exercise required to develop familiarity with the basic functions of the Nikon (DSLR) D610 which was the primary camera used to create sets of photographs for creating models in this project. The main aim of the experiment is to practise and become familiar with operating the camera in manual mode and to understand the effects of adjusting the ISO, f-stop and shutter speed. The site chosen is known as Julian Rocks which is a small sedimentary outcrop 7 m high and 52 m long displaying a number of cross bed features that can be useful for measuring the amount of detail captured by the models. The site is only a 10 minute drive from home making it ideal for a trial and error exercise as it could be easily revisited if any errors were found or if any improvements were tried.

The quality of the photographs taken will determine the quality of the model being produced (Agisoft 2016). It is important to take advantage of the time allowed for the photography phase of photogrammetry. The quality of the phototset determines the quality of the 3D image produced from the photographs. It is important to capture the photographs correctly so there is no need to return to a site as they can be remote and returning can be costly and time consuming.

**Method**

This is a simple exercise where only the Nikon D610 is required on the field for taking photographs. The D610 has been selected to be the primary camera for the project because of its versatility in manual model and the ability to change the lens. Once captured, the photographs were taken back to the University’s photogrammetric work station, known as the spatial analysis lab to be processed through the photogrammetric method outlined in Chapter 3.
Site Details:
Photoset 1 – Julian Rocks
Date: 5th, October, 2015 at 4:30pm
GPS coordinates: 34°51’11.27”S, 150°35’41.60”E
Weather: Clear, sunny day
Cliff aspect: facing west
Modelled features: Nowra sandstone, trees, ferns, grass

![Figure 4-1: Location of Julian Rocks on the banks of Bomaderry Creek, Bomaderry.](image)

Photography

A number of shots were taken to establish the settings that work most appropriately for use in photogrammetry. Figure 4-2 shows 3 different photographs captured by 3 different ISO and f-stop settings (Table 4.1). It can be difficult to see clearly the quality of a photograph while on the field as there is only a 6.5cm viewing screen to inspect a highly resolution photograph. The simplest way to solve this problem is to zoom into the photographs while in playback mode on the cameras viewing screen and carefully inspect key details, such as colour, depth of field, focal point and lighting, which are important to the final model.
The settings adjusted are as follows:

**Aperture:** referred to as f-stop on the Nikon D610. A higher f-stop is required for a greater depth of field. Higher depth of field is important for the model as this will enable any part of the outcrop caught in the photograph to be potentially used. This will increase the model’s level of detail and accuracy (Agisoft, 2016). Any blurring in the photograph, even due to depth of field, can lead to reduced detail in parts of the model.

**ISO:** adjusting the light exposure. A burnt out sky may seem to be poor photography when shooting a landscape, however, for the requirements of photographs in photogrammetry the sky will be cut out so it is of no importance to the model. A burnt out sky can even assist when using the masking tools in PhotoScan to crop the sky out from the photographs. For darker or shadowed rocks, using a higher ISO setting may lead to a burnt sky however the rock colour can be enhanced with more detail visible in the image. It is important to get the correct balance so that any rock is not burnt out and the edges outlining the model from the sky or any other features are not blurred.

**Shutter speed:** Shorter exposure times produce darker photographs with less chance of blurring from movement. Long exposure times expose the film to light longer and create lighter images with a higher chance of blurring from any movement.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D610</td>
<td>Set 1</td>
<td>6016x4016</td>
<td>33</td>
<td>No</td>
<td>200</td>
<td>7</td>
<td>1/200</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 2</td>
<td>6016x4016</td>
<td>33</td>
<td>No</td>
<td>200</td>
<td>5.6-8</td>
<td>1/(125-250)</td>
</tr>
</tbody>
</table>
Photographic Pattern

Having clear and colourful photographs is important. If any details are not photographed they will not be included in the model. The greater the number and higher consistency of points formed in the high dense cloud the greater the overall resolution and accuracy of the final model (Agisoft 2016). The development of the point cloud is dependent on the consistency of features throughout the entire model being captured in at least two photographs to ensure sufficient overlap. Every photograph should have a minimum overlap of 50% to 60% of visual features of adjacent photographs. A set of photographs that only overlap between themselves and not with any of the photographs from the main bulk of the model will not be incorporated into the final model.

Figure 4-3: Location of photograph extraction relative to outcrop at Julian Rocks.

The aim of this exercise was to practise with the application of different settings of the D610 in manual mode. Only one photographic pattern was trialled for this model. To see more on photographic patterns refer to Chapter 3.1.2. The pattern used in this experiment is shown in Figure 4.3. This pattern was used as it has a large overlap for a relatively flat surface and captures many angles to cover the three dimensional features that require some obscure angles to capture them entirely. A total of 33 photographs were taken in RAW format.

IrfanView was used to process the single set of photographs for Julian Rocks. IrfanView program was chosen as there are no GPS tags available to be attached to exported photographs. Images were converted from NEF (RAW) to JPEG. No colour adjustments were made to photoset on. The auto enhance function was used for photoset 2 to experiment with processing photographs through PhotoScan and each individual photograph varies in colour.
Table 4-2: Photoshop adjustments and models made from each photoset.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>IrfanView</td>
<td>Mod 1, 2 &amp; 4</td>
<td>RAW to JPG</td>
<td>No</td>
</tr>
<tr>
<td>Set 2</td>
<td>IrfanView</td>
<td>Mod 3</td>
<td>RAW to JPG</td>
<td>Auto enhance</td>
</tr>
</tbody>
</table>

Photoscan settings

Four models were from the two photosets (Table 4.2).

From photoset 1, seven attempts were made to process the photoset. Three models were created successfully. There were some issues with the photo alignment phase until the setting was changed to high and all 33 images aligned correctly. Low setting was trialled first to create the density cloud. The run was successful but not completed. The medium setting was then trialled again and the trial was successful. Images were not masked. The model was completed with an extrapolated mesh so that all the gaps were filled in. The next model was run with all the same settings only this time images were masked so as to remove trees and sky that were outside the area of the outcrop and the mesh was not extrapolated so that the mesh was created only where the dense cloud was accurate. Another run was made using the same settings as model 2 but this time the density cloud setting was increased to high. The computer lacked processing power to complete the model. A final run was made with photoset 1 this time on the Mac to determine the highest resolution that can be achieved with 32 GB of RAM compared to 8 GB of RAM. The settings were the same as model 1 changing only the density cloud to ultra-high. The model was successfully created with the highest setting possible for the density cloud which is the primary control limiting a model’s resolution.

Photoset two was run once using exactly the same settings as model 2 so that the two models could be compared directly to investigate any differences between the results of photographs taken in manual mode and photographs captured in automatic and run with the auto enhance function in IrfanView.
Table 4-3: Settings and specifications used in PhotoScan to create high-definition 3D models of Julian Rocks.

<table>
<thead>
<tr>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>Photos Aligned</th>
<th># Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows, 8 GB RAM</td>
<td>No</td>
<td>Medium</td>
<td>poorly</td>
<td>33/33</td>
<td>92,387</td>
<td>Low, mod</td>
<td>2,765,344</td>
<td>Low</td>
<td>358,654</td>
<td>End</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>No</td>
<td>High</td>
<td>33/33</td>
<td>92,387</td>
<td>Low, mod</td>
<td>Medium, mod</td>
<td>7,470,087</td>
<td>High</td>
<td>1,480,628</td>
<td>10,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>No</td>
<td>High</td>
<td>33/33</td>
<td>92,387</td>
<td>Medium, mod</td>
<td>7,532,365</td>
<td>High</td>
<td>1,389,332</td>
<td>10,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 2</td>
<td>Yes</td>
<td>High</td>
<td>33/33</td>
<td>92,560</td>
<td>Medium, mod</td>
<td>7,532,365</td>
<td>High</td>
<td>1,389,332</td>
<td>10,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 3</td>
<td>Yes</td>
<td>High</td>
<td>33/33</td>
<td>92,560</td>
<td>Medium, mod</td>
<td>7,532,365</td>
<td>High</td>
<td>1,389,332</td>
<td>10,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Yes</td>
<td>High</td>
<td>33/33</td>
<td>92,560</td>
<td>High, mod</td>
<td>fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>Mod 4</td>
<td>Yes</td>
<td>High</td>
<td>33/33</td>
<td>92,560</td>
<td>Ultra-high, mod</td>
<td>19,186,725</td>
<td>High</td>
<td>19,186,725</td>
<td>20,000</td>
<td>Extrapolated</td>
</tr>
</tbody>
</table>
Results: of Julian Rocks from the Methods in Table 4.3 – see also Appendices D8 and E1

Figure 4-4: Screen image of PhotoScan high-resolution 3D model of Julian Rocks refer to Table 4-3 for model specifications. A) Model 1. B) Model 3. C) model 4.
4.3 Photoksar, Himalayas - High Alpine Photogrammetry

In many cases rock outcrops can be situated in a position where access to the rock for taking strike and dip measurements is dangerous or impossible. Examples of these areas are recognised in mountain ranges and along coastal cliff lines. For this reason, digital photogrammetry can be advantageous in acquiring strikes and dips (and other possible forms of data) by taking clear and reliable photographs (chapter 3.1.2) remotely and safely. Hasbergen (2012) outlines a method described as the three-point-method to extract geologic information from digital aerial images (Figure 4.5). This same method can be applied to vertically down orientated orthophotographs extracted from georeferenced or correctly orientated models created in this project.

![Diagram of geometry and components](image)

Figure 4-5: left; Geometry of points (P) on a dipping geologic surface referenced to a horizontal plane. Right; Components of the pole (U) to the dipping geologic surface with the coordinate directions (north, east) and elevation (z) (Hasbergen 2012, p.24).

Little information is available for application of digital photogrammetry in geology and there is no information available for extracting strikes and dips from 3D images. Therefore, it is necessary to create a method for extracting geological data from 3D images. Methods developed for photogrammetry in a mountain region were compared to methods developed for low lying coastal cliffs for creating 3D images of outcrops for the purpose of extracting complex geological data.
The sites selected for comparison were:

- Photoksar, Ladakh, West Himalayas (high alpine)
- Narrooma, South Coast of NSW (low coastal)
- Eden, NSW (low coastal)

Outline

- Acquire photographs in the Himalayan region from scree slope on the opposing side of the valley to the subject outcrop approximately 100 m in height using a Nikon D610 and a Panasonic Lumix DMC-TZ60.
- Acquire photographs from a coastal outcrop at sea-level using a Nikon D610 and a Panasonic Lumix DMC-TZ60. Photographs to be taken from the ocean by boat at site 3.
- Record structural geologic information using traditional methods from the same outcrops using the application ‘Field Move’.
- Process collected photographs from rock outcrops of interest in 3-D digital models using a software program called PhotoScan developed by Agisoft.
- Evaluate the geologic information that can be extracted from 3-D digital models
- Assess the accuracy of information extracted from digital model compared to measurements taken using traditional methods
- Compare methods of digital photogrammetry in the remote high Himalayas to low-lying coastal outcrops on the South Coast, NSW
- Consider the advantages and disadvantages digital photogrammetry compared with tradition methods of extracting geologic information

4.3.1 Photoksar, Ladakh, West Himalayas (high alpine)

Photoksar is a small Himalayan mountain village residing 22 mountain families. It is situated on the side of a large mountain where study site one is (Figure 4.6). The site was been chosen for study due to its remote locality and it being situated in a high alpine region at an elevation greater than 4,500 m requiring methods that can implemented in regions of a similar standing. Access to the site
involved a 6 hour drive from the airport at Leh, India by a Himalayan taxi driver on rough, narrow, elevated roads through numerous steep valleys between the massive Himalayan mountain ranges. Accommodation involved a two-man team of Ladakhi guides to set up and run a camp site for Dr Solomon Buckman and myself. Enough food was carried to last 4 people 9 days. Photographs were taken on foot and by car focused on an objective mountain and including some surrounding mountains. Along the base of the mountain at study site 1 where the cliffs are accessible by foot, strikes and dips were extracted manually so that their measurements could be compared to any measurements extracted digitally.

![Figure 4-6 Location of site 1, Photoksar, Ladakh, GPS: 34°4'11.01"N, 76°50'29.25"E](image)

**Regional geology of Photoksar**

There are three main units throughout the High Himalaya:

- The Crystalline Nappes, which form the Central Crystalline of the Great Himalaya and the partly extensive outliers in the Lesser Himalaya.
• The Tibetan Zone builds up the sedimentaries which overlie the Central Crystalline in the north.
• South from here there are the Synclinoria of Kashmir, Chamba and a smaller sequence known as the Indus zone.

Units studied in this project were of in the Indus Zone. The Indus zone is a complex belt consisting of several tectonic units including The Northern Zanskar Unit, Lamayuru Unit, Dras Unit, Indus Flysch and Indus Molasse. Along the boundaries of these units ophiolitic melanges and larger peridotite masses are found (Fuchs, 1981). Overall the Indus Zone is a complicated belt of flysch and volcanics that result from a squeezed ocean.

Geologically, Site 1 is on the Indian continental plate situated 84 km south west of the Indus Suture Zone. Four kilometres further to the south west of site 1 is a block of ophiolite approximately 15 km in diameter (Figure 4.7) that has been pinched out during the closing of the Tethys Ocean 55 to 35 million years ago. Between study site 1 and the ophiolite is the Lamayuru molase, a mudstone slate type melange with a number of large inclusions of cherts, ophiolites and sandstones. This is met to the north east by the folded, multicoloured limestones that have been squashed and folded underneath the ophiolite. Site 1 is at the contact where the Lamayuru molase is to the south and the multi-coloured limestones are to the north. The contact is described as a thrust fault by Fuchs (1981) that dips to the west. The Spong River flows toward the east cutting a valley perpendicular to the fold axes of the multicoloured limestones and exposing the detail and complexity of the fold structures that have formed in the region as a consequence of crustal shortening.

Research at site was used to develop a basic method for using digital photogrammetry as a means for creating georeferenced 3D images of large mountainous features. The models need to show enough detail so that as many bedding layers as possible can be clearly seen and identified. Measurement were taken on the large scale features from the digital images and compared to measurements taken in the field.
Methods

The typical alpine landscape in the Himalayan region of Ladak at Photoksar was a suitable location to trial the methods of digital photogrammetry to digitise a mountain range that is at high altitude. The valley surrounding the mountain of Photoksar was formed by the Spong River and played a key role in how photographs were taken to capture the mountain at a sufficient number of angles so that it can be recreated in 3D. The primary aim was to create a model where bedding layers can be identified and tracked through fold structures enabling strikes and dips to be measured from the 3D images.
Site Details:

Model – Photoksar
Date: 12th, June, 2015 at 12:00pm
GPS coordinates: 65°51’11.27”S, 24°35’41.60”E
Weather: Cloudy and minor showers
Cliff aspect: a corner facing south with 90 degree turn around to the west
Modelled features: Folded layers of mud stone and limestones, mountain village, river

Photography

The small digital Panasonic camera was used for photo set 1. It is not an SLR camera so photographs were captured with the cameras set to the automatic function. A number of photographs were taken with the Nikon D610 to calibrate the camera and find the settings that work most effectively for photogrammetry at site 1 due to the conditions at the time the photographs were taken. Three different sets of photographs were captured primarily to trial different patterns of photography. A forth photo set was assembled from photosets 1 and 3 to trial the creation of a model with photographs from two completely different cameras (the Nikon D610 (SLR) with the Panasonic point and shoot) (Table 4.4).

Table 4-4: Camera specifications and settings of photosets captured at Photoksar, Ladakh, High Himalayas.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter speed (s)</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panasonic LUMIX DMC-TZ70</td>
<td>Set 1</td>
<td>4896x3672</td>
<td>109</td>
<td>yes</td>
<td>Auto</td>
<td>Auto</td>
<td>Auto</td>
<td>Mod 1-2</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 2</td>
<td>6016x4016</td>
<td>285</td>
<td>Only on 14pics</td>
<td>100</td>
<td>8</td>
<td>1/250</td>
<td>Mod 3</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 3</td>
<td>6016x4016</td>
<td>167</td>
<td>yes, some</td>
<td>100</td>
<td>9</td>
<td>1/320</td>
<td>Mod 5</td>
</tr>
<tr>
<td>Panasonic + Nikon</td>
<td>Set 4</td>
<td>As above</td>
<td>193</td>
<td>Panasonic only</td>
<td>As above</td>
<td>As above</td>
<td>As above</td>
<td>Mod 6</td>
</tr>
</tbody>
</table>
Photographic Pattern

A different photographic pattern was used for each of the photosets 1, 2 and 3 to trial the different methods that can be used to capture photographs in an alpine region. The various photographic patterns can be seen in Figure 4.9. Figure 4.9, A shows the straight line of photographs with a number of elevated photographs. Figure 4.9, B shows photographs spread out and skated through mountain range to create a 3D model including 12 km of outcrop from 285 images. Figure 4.9, C shows the multi-level height layering pattern used when capturing images with the Panasonic LUMIX DMC-TZ70.
Figure 4-9: Location of photograph extraction relative to the outcrop in: A) Photoset 3. B) Photoset 2. C) Photoset 1.
Photoshop

IrfanView and RawTherapee were both used to process photosets in this exercise using each of the programs batch conversion functions. Photoset 1 did not require photoshop as the photographs were recorded in JPEG format. IrfanView was used to process photo set 2 as there were 271 of the total 285 photographs that did not have GPS tags. No picture adjustments were made to photoset 2. Images were converted from NEF (RAW) format to JPEG. RawTherapee was required for photo sets 3 and 4 to keep the photograph GPS tags attached. RawTherapee is the preferred program to use when making image adjustments because it has a clear, large viewing pane and useful software picture controls. The image adjustments can be seen in Figure 4.10 and Table 4.5.

Figure 4-10: Photograph adjustments made. A) RAW format. B) JPG conversion with colour adjustments made in RawTherapee

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Not needed</td>
<td>Mod 1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mod 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 2</td>
<td>IrfanView</td>
<td>Mod 3</td>
<td>RAW to JPG</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mod 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 3</td>
<td>RawTherapee</td>
<td>Mod 5</td>
<td>RAW to JPG</td>
<td>Yes</td>
</tr>
<tr>
<td>Set 4</td>
<td>RawTherapee</td>
<td>Mod 6</td>
<td>RAW to JPG</td>
<td>Yes</td>
</tr>
</tbody>
</table>
PhotoScan settings

Combined, the 4 photo sets were run through Agisoft PhotoScan a total of 12 times with an outcome of 6 successful models. The settings that worked and the settings that failed can be seen in Table 4.6. Photoset one was made to trial simple photographs using the automatic function on the Panasonic LUMIX DMC-TZ70 Digital Camera. Photoset 2 trials very few photographs over a 10 km long section of mountain side (Figure 4.9,B) with a section in the middle of the model 2 km long that has a high concentration of photographs to see if the resolution of the model changes within different segments of the model depending on the photographs distance from the mountain. Photoset 3 is a set of photographs selected from the condensed 2km midsection of photoset 2. These photographs were selected to create a high resolution model of the main section of mountain under study with the MacPro 32 GB RAM (Table 4.6). Photoset 4 tested PhotoScan’s ability to create a model from photographs from two completely different cameras (different brands, lenses, resolution and mode settings).
Table 4-6: Settings and specifications used in PhotoScan to create high-definition 3D models of Photoksar.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>No</td>
<td>Medium</td>
<td>109/109</td>
<td>233,497</td>
<td>Low, mod</td>
<td>2,489,486</td>
<td>High</td>
<td>501,095</td>
<td>9,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 2</td>
<td>No</td>
<td>Medium</td>
<td>109/109</td>
<td>233,497</td>
<td>Medium, mod</td>
<td>10,084,537</td>
<td>High</td>
<td>2,027,253</td>
<td>9,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>No</td>
<td>Medium</td>
<td>Medium</td>
<td>109/109</td>
<td>233,497</td>
<td>High, mod</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 2</td>
<td>Windows, 8 GB RAM</td>
<td>Yes</td>
<td>Low</td>
<td>Medium</td>
<td>146/285</td>
<td>120,654</td>
<td></td>
<td>End</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 3</td>
<td>Yes</td>
<td>High</td>
<td>279/285</td>
<td>207,965</td>
<td>Low, mod</td>
<td>6,389,523</td>
<td>High</td>
<td>1,806,894</td>
<td>12,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>No</td>
<td>High</td>
<td>Medium</td>
<td>279/285</td>
<td>259,227</td>
<td>Medium, mod</td>
<td>24,249,184</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 4</td>
<td>Yes</td>
<td>High</td>
<td>279/285</td>
<td>259,227</td>
<td>Medium, mod</td>
<td>24,732,83</td>
<td>High</td>
<td>10,412,341</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Yes</td>
<td>High</td>
<td>279/285</td>
<td>259,227</td>
<td>High, mod</td>
<td>114,732,283</td>
<td>Low</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 3</td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 5</td>
<td>Yes</td>
<td>High</td>
<td>165/167</td>
<td>198,650</td>
<td>Medium, mod</td>
<td>15,218,740</td>
<td>High</td>
<td>8,822,516</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Yes</td>
<td>Low</td>
<td>poorly</td>
<td>94,215</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 4</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 6</td>
<td>Yes</td>
<td>Medium</td>
<td>193/193</td>
<td>231,215</td>
<td>Medium, mod</td>
<td>13,121,857</td>
<td>High</td>
<td>2,479,852</td>
<td>10,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>No</td>
<td>Medium</td>
<td>193/193</td>
<td>231,215</td>
<td>High, mod</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results: of Himalayas from the methods in Table 4.6 – see also Appendices (D9 – 11) and E(2 -3)

Figure 4-11: Screen image of PhotoScan high-resolution 3D model of Photokasar. Refer to Table 4-6 for model specifications. A) Model 2. B) Model 4. C) Model 5. D) Model 6.
4.4  **South Coast, NSW – Coastal Photogrammetry**

Outcrops of the NSW south coast span across nearly half a billion years of geological time. Stretching and compression of the earth’s crust, formation and splitting of supercontinents, and movements of tectonic plates over millions of years have produced three very different time-rock groups along the coast from Bermagui to Eden. This geo-diversity attracts researchers and students who visit every year on field trips to 'time travel', work out the range of environments recorded in the region's rocks, and trace the evolution of this place from deep ocean to stable continent.

**Stratigraphic Hierarchy (Hill, D., 1967)**

- Merrimbula Group: Group, Suite
  - Bellbird Creek Formation: Formation, beds
    - Ettrema Limestone Member: Member, phase
  - Ben Boyd Formation: Formation, beds
  - Twofold Bay Formation: Formation, beds
    - Wolumla Conglomerate Member: Member, phase
  - Worange Point Formation: Formation, beds

Rocks indicate their stories and tell how they were formed and what has happened to them during the ages that have passed since they were created. Looking at the outcrops exposed in the region, geologists can start to understand the very different past environments of their creation and the role played by the rocks forming the landscape. It is possible to also imagine the unseen changes in the earth and oceans that have left no visible rock record in this region.

Fieldwork can be time consuming and expensive and certain features may be overlooked or missed. To revisit a site can be a problem when there is no time or funding available. Visually observing a site on the field can also be limited to the angles viewed. These issues can be resolved by taking a number of photographs of an outcrop and running them through the digital photogrammetric process to create a realistic 3D model that can be viewed at any time on a computer. A 3D model also allows the ability to view the outcrop from any angle and at any distance with the
orthoperspective mode function that changes the view slightly to eradicate any distortion from the standard perspective mode having a 30 degree field of view. This is discussed in more detail later in the chapter.

Example Sites:
Because of their significance to the EESC250 field geology subject run by Dr Brian Jones (associate professor), the following sites were chosen. All of these sites are included as part of the field work to be studied by students. Each outcrop was recreated into 3D models by methods of digital photogrammetry outlined in Chapter 3. The methods used at each site vary slightly with adjustments being made to accommodate the different settings (such as lighting, photography and computer processing requirements) at each site.

Figure 4-12: Google Earth map with yellow tags indicating the location of study sites.
4.4.1 Bingie Bingie Point

While Bingie Bingie Point is not close to Eden it consists of outcrops displaying significant evidence relating to geological events that help to explain the geological setting at Eden. The plutonic rocks that occur at Bingie Bingie Point form part of the northern exposure of the Early Devonian Bega Batholith. The Bega Batholith has an outcrop area of about 9,000 square kilometres and is the largest in the Lachlan Fold Belt. It consists of more than 130 separate plutons which range in area up to approximately 1,000 square kilometres and which intrude many Late Ordovician sandstone and shale to produce contact aureoles about 1km in width. The batholith is unconformably overlain by younger Middle to Late Devonian units that can be found at Eden including the Boyd Volcanic Complex at Eagles Claw and the Merrimbula Group at Two Fold Bay.

Some of the plutons of the Bega Batholith are heterogeneous and range from mafic to felsic in composition. Most plutons contain hornblend-bearing mafic zenoliths that commonly show a very strong preferred orientation defining a foliation. These zenoliths are more common in the relatively mafic rocks. Several younger Tertiary basalt dykes also crop out at Bingie Bingie Point.

Site Details:

Date: 5\textsuperscript{th}, October, 2015 at 4:30pm
Weather: Clear sunny day
GPS coordinates: 36° 0'44.97"S, 150° 9'45.50"E
Cliff aspect: flat horizontal surface with some boulder features
Modelled features: Granite, basaltic dykes, enclaves, grass, shrubs and water.
Dimensions: length x width x height = 50 m x 20 m x 2 m

Method

The coastal outcrop has a low relief less than 2 metres high covering an area of 1,000 square metres. Because of the complexity of the geology at the site it can be overwhelming to understand the bigger picture of what is happening. By recreating the outcrop in 3D form it is then possible to zoom out from the model to get a bird’s eye view of the area. This will help to gain a faster understanding of the key geological features and how they have formed. Explanations are also made easier by being able to point out where features are precisely and more quickly than can be shown in the field.
Photography

One set of photographs was taken for this site using the Nikon D610 in manual mode. The camera was first switched to automatic mode and pointed at a number of key components in the darkest and lightest areas of the outcrop. The average of the ISO, f-stop and shutter speed was noted and an estimation was made to calculate the correct settings. From these settings the ISO was then adjusted to a slightly higher setting so that shadows were less dark (more exposed) and the sky slightly over-exposed. This adjustment was necessary because the clear sunny weather caused the shadowed areas to be automatically darker as a consequence of the large contrast between the light and shadowed areas. The final settings chosen in manual mode can be seen in Table 4.7. Photographs were recorded in RAW format.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D610</td>
<td>Set 1</td>
<td>6016x4016</td>
<td>84</td>
<td>No</td>
<td>320</td>
<td>11</td>
<td>1/320</td>
<td>Mod 1-3</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 2</td>
<td>6016x4016</td>
<td>188</td>
<td>No</td>
<td>100</td>
<td>7.1</td>
<td>1/400</td>
<td>Mod 1-3</td>
</tr>
</tbody>
</table>

Photographic Pattern

A loosely disciplined grid pattern was used to cover the area (Figure 4.13) with a total of 272 photographs being taken (Table 4.7). Adjustments were made to the grid pattern to compensate for any irregularities such as boulders, corners, crevasses and raised platforms. Care was taken when taking the photographs to capture every visible part of the selected area of rock exposure. There were no GPS points attached to the photographs.
Photoshop

IrfanView was used to process the single photoset. Photographs were converted from the RAW format to JPEG with colour, contrast and sharpness being increased by 20% (Figure 4.14, Table 4.14)

Table 4-8: Photoshop adjustments and models made from each photoset.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>IrfanView</td>
<td>Mod 1-3</td>
<td>RAW to JPG</td>
<td>20% extra</td>
</tr>
</tbody>
</table>
PhotoScan settings

The photoset was run a total of 7 times; 4 runs through Windows and 3 runs through the Mac. The photographs were run through the alignment process with 270 of 272 photographs being aligned on both machines to create a sparse density cloud. The dense cloud was first run on a medium setting with depth filtering set to aggressive. This step was successful; however, all attempts to create an arbitrary mesh failed. A second attempt was made again setting the dense cloud to medium and changing only the depth filtering to the mild setting. Again all attempts to create an arbitrary mesh failed. The dense cloud was created a third time and set to low with aggressive depth filtering. All attempts to create a mesh this time were successful with the mesh being created with 6 million faces (Model 1, Table 4.9) which is the maximum number of faces limited by the computer’s RAM.

The model was important and so the same photoset was reprocessed on the MacPro in an attempt to create the model with a higher resolution. After running the photo alignment phase, the dense cloud was set to medium with moderate depth filtering. All attempts to create a mesh were successful with 12 million faces, the maximum number of faces possible with the computer’s processing power. A final run was made with the photoset adjusting the dense cloud to high with aggressive depth filtering. This phase was successful; however, all attempts to create an arbitrary mesh failed (Table 4.9).
Table 4-9: Settings and specifications used in PhotoScan to create high-definition 3D models of Bingie Bingie Point.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Windows, 8 GB RAM</td>
<td>No</td>
<td>High</td>
<td>270/272</td>
<td>448,308</td>
<td>Medium, aggressive</td>
<td>40,904,835</td>
<td>Low</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>No</td>
<td>High</td>
<td>270/272</td>
<td>448,307</td>
<td>Medium, mild</td>
<td>34,544,371</td>
<td>Low</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>No</td>
<td>High</td>
<td>270/272</td>
<td>448,307</td>
<td>Low, aggressive</td>
<td>10,595,128</td>
<td>Custom</td>
<td>6,000,000</td>
<td>12,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>No</td>
<td>High</td>
<td>270/272</td>
<td>448,308</td>
<td>High, mod</td>
<td>10,595,128</td>
<td>Low</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 2</td>
<td>Yes</td>
<td>High</td>
<td>270/272</td>
<td>448,308</td>
<td>Medium, mod</td>
<td>37,063,941</td>
<td>Custom</td>
<td>12,000,000</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 3</td>
<td>Yes</td>
<td>High</td>
<td>270/272</td>
<td>448,308</td>
<td>Medium, mod</td>
<td>37,063,941</td>
<td>Decimated</td>
<td>8,967,030</td>
<td>9,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Yes</td>
<td>High</td>
<td>270/272</td>
<td>448,308</td>
<td>High, aggressive</td>
<td>155,925,646</td>
<td>Low</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Results:** of Bigie Bingie Point from the methods in Table 4.9 – see also Appendices D1 and E6

Figure 4-15: Screen image of PhotoScan high-resolution 3D model of Bingie Bingie Point. Refer to Table 4-9 for model specifications. A) Model 1. B) Model 2.
4.4.2 Narooma, South Coast of NSW

Narooma is a coastal town on the south coast of New South Wales, Australia. Study site 2 looks at outcrops along the coastal rock platforms from Australia Rock near the southern bar of the inlet and down south to Kangaroo Rock at the southern end of Cemetery beach. This site was chosen as it has a number of outcrops accessible by foot and displays fold structures similar to those found at study site one in the Himalayas. Five separate outcrops were digitised along the coast to run a number of different photosets with varying numbers of photographs to assess the consistency of the methods. Figure 4.17 defines terms used to explain model boundaries. Access to the site is simple requiring only a 5 minute walk from either of three car parks. At a maximum height of 7 m, the outcrops at site 2 are far smaller than the mountainous 200 m tall outcrop at site 1. Photographs were taken on foot. Because of the absence of a topographic rise opposing the outcrops a 9 m pole was used to elevate the camera for high angle shots. Some strikes and dips were taken at outcrops; however, the focus at this site was more about trialling in more detail the photogrammetric methods applied. In this section, only the method for developing 3D images of outcrops is discussed. Refer to Figure 4.16 to see the locations of the Narooma projects.

Figure 4.16: Location of site 2, Narooma, including the locations of the 5 digitized outcrops, NSW, GPS:

36°13'12.69"S, 150°8'28.87"E
Regional geology of Narooma

The geology at Narooma is described (Foster et al. 1999) to be of an accretionary prism and part of the south-eastern Paleozoic Lachlan Orogen that formed during cratonisation of the eastern margin of the Australian continent. Within this complex is the Wagonga Group that contains the Narooma Chert, Bogolo Formation (including undifferentiated chert, basalt and parautochthonous limestone units, undifferentiated turbidites) and interfingering lenses of Adaminaby Group sandstones (Powell 1983). Conodonts indicate that the lower, more massive (ribbon chert) part of the Narooma Chert ranges are Middle to Late Cambrian to Darrwilian–Gisbornian (Middle to Late Ordovician). The upper Narooma Chert consists of shale, containing Eastonian (Late Ordovician) graptolites, interbedded with chert. Where there is no deformation by later faulting, the boundary between the Narooma Chert and Bogolo Formation is gradational. At map scale, the Narooma Terrane consists of a stack of imbricate thrust slices caught between two thrust faults that juxtaposed the terrane against the coeval Adaminaby Superterrane in Early Silurian time. These slices are best defined where Narooma Chert is thrust over the Bogolo Formation. The soles of such slices contain multiple foliated cherts. Late extensional shear bands indicate a strike-slip component to the faulting. The Narooma Terrane, with chert overlain by muddy ooze, is interpreted to be an oceanic terrane that accumulated remote from land for about 50 million years. The upward increase in the terrigenous component at the top of the Wagonga Group (shale, argillite, siltstone and sandstone of the upper Narooma Chert and Bogolo Formation) records the approach of the terrane towards the Australian sector of the Gondwana margin. Blocks of chert, argillite and sandstone reflect extensional/strike-slip disruption of the terrane as it approached the transform trench along the Gondwana–proto-
Pacific plate boundary. Blocks of basalt and basalt breccia represent detritus from a seamount that was also entering the trench.

Outcrops at site 2 consist of exposed units from the Wogonga and Bogolo Formations. The focus of digital photogrammetry at this site was primarily on the chert components of each formation with a small examination of a breccia layer of the Wogonga Formation. Four models of the outcrops were created from the Wongonga Formation (three outcrops of chert to examine its variation along the coast and one outcrop of volcanic breccia to show its texture and orientation with the chert). Only one model of the outcrop was created from the Bogolo Formation displaying the ribbon chert. It was then compared to cherts of the Wogonga formation with the 3D digital visual models as they exist in the field.

![Figure 4-18: Geological map of the NSW, south coast indicating study site at Narooma, surf beach (Geological Survey of NSW, 2015).](image)

**Method**

Outcrops digitized at Narooma are of a larger scale than those in the Himalayas and so have a greater resolution. Models created of the Himalayas range from 2 km to 10 km in length compared to large scale models created at Narooma ranging from 5 m to 30 m. Without the presence of valleys
opposing the outcrops at Narooma, photographs needed to be taken up close to the rock. In comparison, distant photographs were taken from the rocks in the Himalayas. Five different sections of outcrop were digitised from Narooma (Figure 4.23, 4.24, 4.25, 4.26, 4.27) to experiment with consistency of creating models relating to small variations in the digitisation process to account for variations such as weather, camera settings, photoshop and photographic pattern. Objects were placed on the outcrops to show scale and orientation.

Site Details:

Site A – Photoset 1
Date: 19th, November, 2015 at 4:00pm
GPS coordinates: 36°12'41.08"S, 150° 8'3.03"
Weather: Cloudy and overcast
Cliff aspect: facing north with a three-dimensional rock protrusion facing all directions
Modelled features: Folded layers of chert, shrubs, water

Site B – Photoset 1
Date: 19th, November, 2015 at 4:00pm
GPS coordinates: 36°12'41.56"S, 150° 8'6.80"E
Weather: Cloudy and overcast
Cliff aspect: Flat rock platform with a vertical three-dimensional rock protrusion facing all directions
Modelled features: Folded layers of chert, water

Site C – Photoset 1
Date: 19th, November, 2015 at 4:00pm
GPS coordinates: 36°13'12.66"S, 150°8'27.78"E
Weather: Cloudy and overcast
Cliff aspect: facing south
Modelled features: Conglomerates, shrubs

Site D – Photoset 1 and 2
Date: Set 1 on 19th and set two on the 24th, November, 2015 both at 8:00am
GPS coordinates: 36°13'12.73"S, 150°8'29.06"E
Weather: partly cloudy
Cliff aspect: facing east with jagged features facing north and south
Modelled features: Folded layers of chert, shrubs, water
Site E – Photoset 1
Date: 29th, November, 2015 at 3:00pm
GPS coordinates: 36°13’49.09”S, 150° 8’35.19”E
Weather: partly cloudy
Cliff aspect: three sides facing south, east and north
Modelled features: Chevron folded chert, sand, trees, shrubs

Photography

One photoset was captured for each site except for site D for which two photosets were taken. Photoset 1 is large, consisting of 453 images, and photoset 2 is smaller, consisting of 83 images. The Nikon D610 was used to capture photographs for all photosets of the Narooma outcrops. The 9 m carbon fibre selfie pole was used at each location to acquire photographs from high angles. The number of photographs and customised camera settings chosen for each set can be seen in Table 4.10.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter Speed (s)</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D610</td>
<td>Set 1, site A</td>
<td>6016x4016</td>
<td>246</td>
<td>No</td>
<td>100</td>
<td>9</td>
<td>1/250</td>
<td>Mod 1-4</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 1, site B</td>
<td>6016x4016</td>
<td>98</td>
<td>No</td>
<td>140</td>
<td>8</td>
<td>1/250</td>
<td>Mod 1-7</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 1, site C</td>
<td>6016x4016</td>
<td>49</td>
<td>No</td>
<td>400</td>
<td>14</td>
<td>1/400</td>
<td>Mod 1</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 1, site D</td>
<td>6016x4016</td>
<td>453</td>
<td>No</td>
<td>400</td>
<td>14</td>
<td>1/400</td>
<td>Mod 1</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 2, site D</td>
<td>6016x4016</td>
<td>83</td>
<td>No</td>
<td>320</td>
<td>11</td>
<td>1/250</td>
<td>Mod 1-10</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 1, site E</td>
<td>6016x4016</td>
<td>114</td>
<td>No</td>
<td>100</td>
<td>9</td>
<td>1/250</td>
<td>Mod 1-4</td>
</tr>
</tbody>
</table>

Photographic Pattern

All photosets were captured using a scattered grid pattern from one end of the selected area to the other (Figure 4.19, 4.20). The grid patterns were captured first by walking around holding the camera and then by using the selfie pole to capture any surface missed that required the camera to be elevated.
Figure 4-19: Location of photograph extraction relative to the outcrop in: A) Photoset 1, site A. B) Photoset 1, site B. C) Photoset 1, site C
Figure 4-20: Location of photograph extraction relative to the outcrop in: A) Photoset 1, site D. B) Photoset 2, site D. C) Photoset 1, site E.
Photoshop

IrfanView and RawTherapee were both used to process photosets for sites at Narooma. Refer to Table 4.11 to follow details of photoshop processes. IrfanView was required to reformat photographs to be compatible with PhotoScan with no colour adjustments being made. RawTherapee was used for photosets requiring colour adjustments as well as for reformatting. RawTherapee is the preferred program to use when making image colour adjustments. Except for two photosets, one at site B model 5 and site D model 7 where formats were changed from RAW to TIFF to trial functionality of TIFF versus JPEG images, the images were converted from RAW to JPEG format with some different amounts of compression (Figure 4.21, 4.22, Table 4.11).

Figure 4-21: Photographs from Site A did not require any adjustments only conversion from RAW to JPG.
Figure 4-22: Photograph adjustments made. A,B) RAW to JPG conversion with extreme colour adjustments of Site B in RawTherapee. C,D) RAW to JPG conversion with auto-enhance function used of Site C in IrfanView. E,F) RAW to JPG conversion colour adjustments made of Site D in RawTherapee. G) RAW format Site E. H) Conversion to JPG with minor adjustments made in RawTherapee. I) Conversion to JPG with extreme adjustments made in RawTherapee.
### Table 4-11: Photoshop adjustments and models made from each photoset.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1, site A</td>
<td>IrfanView</td>
<td>Mod 1-4</td>
<td>RAW to JPG</td>
<td>No</td>
</tr>
<tr>
<td>Set 1, site B</td>
<td>IrfanView</td>
<td>Mod 1-3</td>
<td>RAW to JPG</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>RawTherapee</td>
<td>Mod 4</td>
<td>RAW to JPG 60%</td>
<td>Yes, extreme</td>
</tr>
<tr>
<td></td>
<td>IrfanView</td>
<td>Mod 5</td>
<td>RAW to TIF</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>RawTherapee</td>
<td>Mod 6-7</td>
<td>RAW to JPG</td>
<td>Yes</td>
</tr>
<tr>
<td>Set 1, site C</td>
<td>IrfanView</td>
<td>Fail</td>
<td>RAW to JPG</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>RawTherapee</td>
<td>Mod 1</td>
<td>RAW to JPG</td>
<td>Auto enhance</td>
</tr>
<tr>
<td>Set 1, site D</td>
<td>IrfanView</td>
<td>Failed</td>
<td>RAW to JPG</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>IrfanView</td>
<td>Failed</td>
<td>RAW to JPG 60%</td>
<td>No</td>
</tr>
<tr>
<td>Set 2, site D</td>
<td>RawTherapee</td>
<td>Mod 1-2 and 8-10</td>
<td>RAW to JPG 80%</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>RawTherapee</td>
<td>Mod 3-5</td>
<td>RAW to JPG</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>RawTherapee</td>
<td>Mod 6</td>
<td>RAW to JPG</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>RawTherapee</td>
<td>Mod 7</td>
<td>RAW to TIF</td>
<td>Yes</td>
</tr>
<tr>
<td>Set 1, site E</td>
<td>RawTherapee</td>
<td>Mod 1-2 and 4</td>
<td>RAW to JPG 90%</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>RawTherapee</td>
<td>Mod 3</td>
<td>RAW to JPG 80%</td>
<td>Yes, extreme</td>
</tr>
</tbody>
</table>

**PhotoScan settings**

Site A: Four models were successfully made from the single photoset with all photographs being masked at the start of each run before being processed through PhotoScan. Using Windows with 8 GB of RAM as the digital photogrammatic workstation, 230 of 246 photographs aligned successfully. The low setting for the density cloud is the highest achievable setting with the Windows system. Two models, one with and one without extrapolation, having a low density cloud were completed. Following assessment of the results from the Windows system, the extrapolated model was chosen as the setting to be used when processing the photoset with the MacPro 32 GB of RAM system. Two models were created with the MacPro. The first one was created in a batch process so the model could progress through each phase automatically overnight. From the first model, the workspace box was resized to crop out the outer distorted, messy parts of the model caused by lack of cloud points and over-extrapolation. The mesh in model 4 was extended to 9 million face from the high setting of 6.5 million of the batch process run (Table 4.12).

Site B: The first coastal site modelled for this project. Ten runs were processed with the Windows system of which seven were successful. Different photosets were trialled with model 5 created with TIFF images failing at the photo alignment phase. Model 4 was created following 60% compression and excessively colour enhanced photographs to experiment with colour alterations to make contiguous stratigraphic layers of similar colour more easily distinguishable. The images were compressed to 60% of their original size. This appeared to increase the processing speed; however, fewer points were created in the dense cloud. The MacPro aligned 93 of 98 images (Table 4.12). No
masks were placed over unwanted features in the photographs. The dense cloud was created with the high, moderate setting and a custom extrapolated mesh.

Site C: Images were processed to investigate results created for a conglomerate layer. A number of attempts were made to align the images; however, 26 of 49 images was the maximum that would align (Table 4.12). It is suspected that insufficient overlap was the cause for the poor alignment results. However, from the 26 aligned photographs a sufficient model, model 1, was created to examine the application of digital photogrammetry to a conglomerate layer.

Site D: Two photosets were created for site D. Set 1 contained 453 photographs. After masking out the sky and other unnecessary features only Windows crashed and the MacPro systems aligned 403 of the photographs. Set 2 contained only 83 images of only a portion of the area captured in photoset 1. All 83 images aligned with both systems except for model 7, created from TIFF images, where 82 images aligned. The highest resolution image created was from the MacPro processed with dense cloud set to high, aggressive and a high extrapolated mesh of 6.6 million faces (Table 4.12).

Site E: Using the Windows system, a trial of both masked and non-masked images was run at the highest setting achievable of a medium dense cloud and high, extrapolated mesh from 112 images. From the results it was decided to use the non-masked images to be processed by the MacPro. Because of the complex folds of the outcrop and thin multi-coloured layers, an experiment was run to assess natural colour versus enhanced coloured images to increase ease of geologic interpretation. From the Windows system model 6 was the clearest and most realistic image (Table 4.12).

Results: of Site C from the methods in Table 4.12 – see also Appendix E9

Figure 4-23: Screen image of high-resolution 3D model of Site C Model 1. Refer to Table 4-12 for model specifications.
Table 4-12: Settings and specifications used in PhotoScan to create high-definition 3D models of Sites A to E at Narooma.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Computer</th>
<th>Model ID</th>
<th>Mask</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Textur</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1, site A</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>Yes</td>
<td>High</td>
<td>230/246</td>
<td>460,090</td>
<td>Low, mod</td>
<td>8,082,226</td>
<td>High</td>
<td>1,764,581</td>
<td>12,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 2</td>
<td>Yes</td>
<td>High</td>
<td>230/246</td>
<td>460,090</td>
<td>Low, mod</td>
<td>8,082,226</td>
<td>Custom</td>
<td>6,208,367</td>
<td>12,000</td>
<td>Extrapolated</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 3</td>
<td>Yes</td>
<td>High</td>
<td>230/246</td>
<td>460,090</td>
<td>Medium, mod</td>
<td>32,852,580</td>
<td>Low</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>Mod 4</td>
<td>Yes</td>
<td>High</td>
<td>228/233</td>
<td>476,702</td>
<td>Medium, aggressive</td>
<td>32,625,974</td>
<td>High</td>
<td>6,525,177</td>
<td>16,000</td>
<td>Extrapolated</td>
<td></td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>Mod 5</td>
<td>Yes</td>
<td>High</td>
<td>228/233</td>
<td>476,702</td>
<td>Medium, aggressive</td>
<td>32,625,974</td>
<td>Custom</td>
<td>8,960,023</td>
<td>16,000</td>
<td>Best, extrapolated</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 6</td>
<td>No</td>
<td>High</td>
<td>83/83</td>
<td>143,408</td>
<td>High, aggressive</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 1, site B</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>Yes</td>
<td>Med</td>
<td>79/98</td>
<td>97,547</td>
<td>End</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 2</td>
<td>Yes</td>
<td>High</td>
<td>90/98</td>
<td>99,877</td>
<td>Low, mod</td>
<td>3,654,321</td>
<td>High</td>
<td>744,288</td>
<td>12,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 3</td>
<td>Yes</td>
<td>High</td>
<td>90/98</td>
<td>99,877</td>
<td>Medium, mod</td>
<td>14,204,692</td>
<td>High</td>
<td>2,849,798</td>
<td>12,000</td>
<td>Not extrapolated</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 4</td>
<td>Yes</td>
<td>High</td>
<td>90/98</td>
<td>99,877</td>
<td>Medium, mod</td>
<td>14,204,692</td>
<td>High</td>
<td>2,849,935</td>
<td>12,000</td>
<td>Extrapolated, bent</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 5</td>
<td>No</td>
<td>High</td>
<td>92/98</td>
<td>87,191</td>
<td>Medium, mod</td>
<td>12,835,148</td>
<td>High</td>
<td>2,574,678</td>
<td>12,000</td>
<td>JPG 60%, Extreme colour</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 6</td>
<td>No</td>
<td>Med</td>
<td>14/98</td>
<td>7,236</td>
<td>Low, mod</td>
<td>901,926</td>
<td>High</td>
<td>2,555,310</td>
<td>13,000</td>
<td>TIFF</td>
<td></td>
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<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 7</td>
<td>No</td>
<td>Med</td>
<td>93/98</td>
<td>81,357</td>
<td>High, mod</td>
<td>51,935,219</td>
<td>Custom</td>
<td>11,920,674</td>
<td>17,000</td>
<td>Almost perfect, Extrapolated</td>
<td></td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>Mod 8</td>
<td>No</td>
<td>Low</td>
<td>19/49</td>
<td>11,449</td>
<td>End</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 9</td>
<td>No</td>
<td>High</td>
<td>18/49</td>
<td>35,820</td>
<td>End</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 10</td>
<td>No</td>
<td>Med</td>
<td>24/49</td>
<td>34,013</td>
<td>End</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 11</td>
<td>Yes</td>
<td>High</td>
<td>26/49</td>
<td>39,166</td>
<td>Medium, mod</td>
<td>7,596,465</td>
<td>High</td>
<td>1,936,592</td>
<td>12,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 1, site C</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>No</td>
<td>Low</td>
<td>403/454</td>
<td>345,089</td>
<td>Low, moderate</td>
<td>18,168,516</td>
<td>Custom</td>
<td>10,000,000</td>
<td>16,000</td>
<td>Extrapolated</td>
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<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 2</td>
<td>No</td>
<td>High</td>
<td>83/83</td>
<td>149,967</td>
<td>Medium, aggressive</td>
<td>9,139,248</td>
<td>Custom</td>
<td>5,999,999</td>
<td>12,000</td>
<td>Bad, workflow</td>
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<td>Mod 3</td>
<td>No</td>
<td>High</td>
<td>83/83</td>
<td>143,426</td>
<td>Medium, aggressive</td>
<td>8,890,841</td>
<td>Custom</td>
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<td>12,000</td>
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<td></td>
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<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 4</td>
<td>No</td>
<td>High</td>
<td>83/83</td>
<td>143,426</td>
<td>High, aggressive</td>
<td>Fail</td>
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<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 5</td>
<td>Yes</td>
<td>High</td>
<td>83/83</td>
<td>125,276</td>
<td>Medium, aggressive</td>
<td>9,195,804</td>
<td>High</td>
<td>3,678,893</td>
<td>13,000</td>
<td>Bent, not extrapolated</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 6</td>
<td>Yes</td>
<td>Med</td>
<td>83/83</td>
<td>124,910</td>
<td>Medium, aggressive</td>
<td>8,904,890</td>
<td>Custom</td>
<td>5,978,401</td>
<td>12,000</td>
<td>Extrapolated</td>
<td></td>
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<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 7</td>
<td>Yes</td>
<td>Med</td>
<td>83/83</td>
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<td>8,904,890</td>
<td>Custom</td>
<td>5,940,827</td>
<td>12,000</td>
<td>Not extrapolated</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 8</td>
<td>No</td>
<td>High</td>
<td>83/83</td>
<td>159,402</td>
<td>Medium, aggressive</td>
<td>8,886,894</td>
<td>Custom</td>
<td>6,000,000</td>
<td>14,000</td>
<td>Best, No</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 9</td>
<td>No</td>
<td>High</td>
<td>82/83</td>
<td>89,073</td>
<td>Medium, aggressive</td>
<td>6,430,866</td>
<td>Custom</td>
<td>5,999,999</td>
<td>13,000</td>
<td>Terrible, TIFF</td>
<td></td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>Mod 10</td>
<td>No</td>
<td>High</td>
<td>83/83</td>
<td>143,408</td>
<td>High, aggressive</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>Mod 11</td>
<td>No</td>
<td>High</td>
<td>111/114</td>
<td>183,011</td>
<td>Medium, aggressive</td>
<td>13,723,576</td>
<td>High</td>
<td>2,565,760</td>
<td>12,000</td>
<td>Best</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 12</td>
<td>Yes</td>
<td>High</td>
<td>112/114</td>
<td>185,593</td>
<td>Medium, aggressive</td>
<td>14,658,645</td>
<td>Custom</td>
<td>4,737,641</td>
<td>13,000</td>
<td>Rough</td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 13</td>
<td>Yes</td>
<td>High</td>
<td>112/114</td>
<td>185,593</td>
<td>High, aggressive</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Windows, 8 GB RAM</td>
<td>Mod 14</td>
<td>No</td>
<td>High</td>
<td>119/120</td>
<td>183,976</td>
<td>Medium, aggressive</td>
<td>12,969,876</td>
<td>Custom</td>
<td>5,730,665</td>
<td>12,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>Mod 15</td>
<td>No</td>
<td>High</td>
<td>111/114</td>
<td>183,011</td>
<td>High, aggressive</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>Mod 16</td>
<td>No</td>
<td>High</td>
<td>111/114</td>
<td>183,011</td>
<td>High, aggressive</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results: of Site A from the methods in Table 4.12 – see also Appendix E7

Figure 4-24: Screen image of PhotoScan high-resolution 3D model of Site A, refer to Table 4-12 for model specifications. A) Model 2. B) Model 4.
**Results**: of Site B from the methods in Table 4.12 – see also Appendix E8

Figure 4-25: Screen image of PhotoScan high-resolution 3D model of Site B, refer to Table 4-12 for model specifications. A) Model 3. B) Model 5. C) Model 4. D) Model 6.
Results: of Site D from the methods in Table 4.12 – see also Appendices E10 and E11

Figure 4-26: Screen image of PhotoScan high-resolution 3D model of Site D, refer to Table 4-12 for model specifications.
**Results:** of Site E from the methods in Table 4.12 – see also Appendices D4, E12 and E13

---

Figure 4-27: Screen image of PhotoScan high-resolution 3D model of Site E, refer to Table 4-12 for model specifications. A) Model 2. B) Model 3. C) Model 4.
4.4.3 Haycocks Point

The middle section of the Worange Formation of the Late Devonian Merrimbula Group crops out at Haycocks Point. Changes in sea level can be easily identified at the site with sediments alternating in colour as they change from mudstone to sandstone. Two photosets were made at the site. Photoset 1 was captured for a purpose unrelated to this present study. Photoset 2 was designed to capture 500 m of the rocky coastline visually displaying the orientation of bedding layers and their folded state. The coastline is very jagged with many three-dimensional features including caves, rock walls and large boulders.

Site Details:

Photosets 1 and 2 – Haycocks Point (north west)

Date: 27th, November, 2015 at 12:30pm

GPS coordinates: 36°56'54.47"S, 149°56'18.51"E

Weather: Clear sunny day

Cliff aspect: facing north

Modelled features: sandstone, mudstone, boulders, grass, shrubs, water

Photography

Photosets 1 and 2 were captured at midday on the same day and in full sunlight. Midday was chosen as the time to take the photographs so that there would be minimal shadows from sunlight around jagged features. Shadows cause outcrop discolouration that can affect the ability to follow bed layers continually along the coastline. Photographs were taken in manual mode with settings shown in Table 4.13 found to be most suited. Both photosets were captured using the same setting to assist the recognition algorithm if attempting to join the chunks together. No GPS points were recorded with the photographs.

Table 4-13: Camera specifications and settings of photosets captured at Haycocks Point, Eden, NSW.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D610</td>
<td>Set 1</td>
<td>6016x4016</td>
<td>156</td>
<td>No</td>
<td>100</td>
<td>8.0</td>
<td>1/250</td>
<td>Not run</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 2</td>
<td>6016x4016</td>
<td>318</td>
<td>No</td>
<td>100</td>
<td>8.0</td>
<td>1/250</td>
<td>Mod 1-7</td>
</tr>
</tbody>
</table>
Photographic Pattern

Due to the jagged features of the section of coastline it would not be possible to photograph all of the appropriate angles by boat required to create a complete model of the coastline. The section of coastline is accessible by foot along the platform as well as along the top of the headland allowing photographs to also be captured from a higher angle. Photographs were taken in a scattered pattern to cover as much of the visible outcrop as possible (Figure 4.28).

![Figure 4-28: Location of photograph extraction relative to the outcrop in photoset 2.](image)

Photoshop

Photoset 1 was run through RawTherapee with small adjustments made to increase colour, contrast and sharpness. The format was changed from RAW to JPEG. Photographs were not processed any further through the phases of photogrammetry due to time constraints.

Photoset two was converted into three different layouts with two different formats of JPEG and PNG (Figure 4.29, Table 4.14). The first two layouts each had a different format of PNG and JPEG with the same settings made to make a small increase to colour, contrast and sharpness settings. The third layout was created to experiment with large adjustments to increase colour, contrast and sharpness (Figure 4.29).
Figure 4-29: Photograph adjustments made. A) RAW format. B) Minor colour adjustments made in RawTherapee. C) Extreme colour adjustments made in RawTherapee.

Table 4-14: Photoshop adjustments and models made from each photoset.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>RawTherapee</td>
<td>Not run</td>
<td>RAW to JPG</td>
<td>Yes</td>
</tr>
<tr>
<td>Set 2</td>
<td>RawTherapee</td>
<td>Mod 1-2</td>
<td>RAW to JPG</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>IrfanView</td>
<td>Mod 3-4</td>
<td>RAW to PNG</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>RawTherapee</td>
<td>Mod 5-7</td>
<td>RAW to JPG</td>
<td>Yes, extreme</td>
</tr>
</tbody>
</table>

PhotoScan settings

Photoset 2 was processed through PhotoScan 9 times; 3 times with windows and 6 times on the Mac (Table 4.15). Windows was used to identify the limit of its 8 GB RAM processor processing 318 photographs of 24 megapixels with PhotoScan. Running the program with the density cloud set to medium was found to exceed the computer’s capabilities so the photoset was run twice with the cloud density to low and depth filtering set to aggressive. Only the mesh was changed with one being extrapolated and the other not extrapolated. It was found that the extrapolated model looked more complete because it filled in the gaps left behind by the non-extrapolated model. As a result, all runs using the Mac had the mesh set to be extrapolated.

Model 3 was run to trial results of PNG format photographs with those of JPEG format in models 5 and 6. The photoset for model 3 had only small adjustment made to increase the colour, contrast and sharpness. Photographs from photoset 2 for models 5 to 7 had large colour, contrast and sharpness adjustments made to see if making colours appear more different would help to make reading the visual aspects of the geology easier to read. Models 3 and 6 were decimated to create simplified models more import-friendly when transferred to other software programs such as Blender.
Table 4-15: Settings and specifications used in PhotoScan to create high-definition 3D models of Haycocks Point.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>Yes</td>
<td>Medium</td>
<td>297/318</td>
<td>388,310</td>
<td>Low,aggressive</td>
<td>9,434,970</td>
<td>Custom</td>
<td>6,000,000</td>
<td>12,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 2</td>
<td>Yes</td>
<td>Medium</td>
<td>297/318</td>
<td>388,310</td>
<td>Low,aggressive</td>
<td>9,434,970</td>
<td>Custom</td>
<td>6,000,000</td>
<td>12,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 3</td>
<td>Yes</td>
<td>Medium</td>
<td>305/306</td>
<td>471,440</td>
<td>Medium,mod</td>
<td>34,844,039</td>
<td>Custom</td>
<td>9,710,308</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 4</td>
<td>Yes</td>
<td>High</td>
<td>305/306</td>
<td>471,440</td>
<td>Medium,mod</td>
<td>34,844,039</td>
<td>Decimated</td>
<td>3,000,000</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 5</td>
<td>Yes</td>
<td>Medium</td>
<td>289/289</td>
<td>398,631</td>
<td>Medium,mod</td>
<td>38,469,465</td>
<td>Custom</td>
<td>12,000,000</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 6</td>
<td>Yes</td>
<td>Highest</td>
<td>284/284</td>
<td>262,815</td>
<td>Medium,mod</td>
<td>37,009,302</td>
<td>Custom</td>
<td>12,000,000</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 7</td>
<td>Yes</td>
<td>Highest</td>
<td>284/284</td>
<td>262,815</td>
<td>Medium,mod</td>
<td>37,009,302</td>
<td>Decimated</td>
<td>1,999,999</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
</tbody>
</table>

Results: of Haycocks Point from the methods in Table 4.15 – see also Appendices D5, D6, D7, E14 and E15

Figure 4-30: Screen image of PhotoScan high-resolution 3D model of Haycocks Point, refer to Table 4-15 for model specifications. A) Model 4. B) Model 6.
4.4.4 The Pinnacles

The Pinnacles are located to the north in Ben Boyd National Park. The Pinnacles is a formation which dates back some 65 million years when the soft white sand and its cap of red clay laid the foundations for the subsequent feature which now exists. The geology of this section is mainly sedimentary rock (ironstone and clay) laid down in the Paleogene, with some quartzite outcrops. The Pinnacles is a multi-coloured erosion gully with white sands overlaying rusty red clay. The boundary of the two colours indicates the paleo groundwater level. This boundary line can be clearly identified and shown in a single photograph; however, by recreating it as a 3D image it may be possible to extract more complex information such as angle of repose and ground erosion processes that are not possible to measure in 2D images. For example, an understanding of the formation of rills and gullies can be studies in more detail at selected sites. Wind and salt-wedging erosion can be observed around slope areas. The foliage cover can be observed, looking at the physical and thermal barriers that influence surface erosion including patterns of rainfall erosion (Figure 4.54).

Figure 4.54: Typical Puget Sound Coastal Slope Processes (Downing 1983, p.31)
Site Details:

Photoset 1 – The Pinnacles
Date: 27th, November, 2015 at 2:30pm
GPS coordinates: 36°59'30.52"S, 149°55'30.67"E
Weather: Clear sunny day
Cliff aspect: facing north
Modelled features: N/A

Photography

Images were captured with the Nikon D610. Global positioning system tags were not attached to the photographs. Because of the high light exposure on a highly reflective white surface, the ISO, f-stop and shutter speed settings in Table 4.16 worked best. The 24 megapixel images were recorded in RAW format.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D610</td>
<td>Set 1</td>
<td>6016x4016</td>
<td>177</td>
<td>No</td>
<td>100</td>
<td>10.0</td>
<td>1/400</td>
<td>Mod 1</td>
</tr>
</tbody>
</table>

Photographic Pattern

The site was photographed on foot in an attempt to capture the entire surface with a sufficient overlap. Although the selfie pole would have been useful for capturing a number of angles that were not possible on foot, so as to avoid damaging the camera when crawling under and walking through thick scrub the selfie pole was not used. The main purpose of the photographic pattern was to capture a set of images overlapping around the entire perimeter of the exposure at a distance of 2 m to 3 m from the outcrop. A number of scattered photographs were also taken to increase the percentage of image overlap (Figure 4.31).
Photoshop

While there were no GPS points recorded to the images they were converted with RawTherapee because of its favoured image enhancement display and functions. Photographs were converted from RAW format to JPEG. Some colour adjustments were made to increase contrast, colour and sharpness (Figure 4.32, Table 4.36).

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>RawTherapee</td>
<td>Not run</td>
<td>RAW to JPG</td>
<td>Yes</td>
</tr>
</tbody>
</table>
**PhotoScan settings**

With knowledge acquired from processing previous models the Pinnacles photosets was run through Agisoft PhotoScan once with a successful model developed. The settings that were used are shown in Table 4.17.

Table 4-17: Settings and specifications used in PhotoScan to create high-definition 3D models of the Pinnacles.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>MacPro</td>
<td>Mod 1</td>
<td>No</td>
<td>High</td>
<td>174/177</td>
<td>287, 884</td>
</tr>
<tr>
<td>Dense Cloud</td>
<td>#Points</td>
<td>Mesh</td>
<td>#Faces</td>
<td>Texture</td>
<td>Comments</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td>24,177,696</td>
<td>Custom</td>
<td>9,000,000</td>
<td>16,000</td>
<td>Extrapolated</td>
<td></td>
</tr>
</tbody>
</table>

**Results:** of The Pinnacle from the methods in Table 4.17 – see also Appendix E16

Figure 4-33: Screen image of PhotoScan high-resolution 3D model of the Pinnacles, Model 1. Refer to Table 4-17 for model specifications.
Eagles claw is a headland situated 1.2 km south east from the town centre of Eden on the south coast of New South Wales, Australia. Site 3 spans 3 km from outcrops at the south end of Aslings Beach following the coastline south along Two Fold Bay and around eagles claw to outcrops at the eastern end of Shelly’s Beach. This site was chosen primarily to trial methods of extracting digital photographs by boat for use in photogrammetry. The geology at this site is complex and clearly visible at the water’s edge for almost the entire shoreline of the study site. While many sections of the outcrops are accessible by foot, there are some sections that are not and make it highly difficult and dangerous to gather a set of continuous overlapping photographs covering the entire 3 km of shoreline.

**Regional Geology of Eagles Claw**

The geology of the Eagles Claw area consists essentially of a Middle Devonian sequence of the volcanic (Boyd Volcanic Complex) and sedimentary rocks (the Merimbula Group). The basal exposure of the Middle Devonian Boyd Volcanic Complex unconformably overlies the Late Ordovician Mallacoota Beds which can be seen at the north western corner of the headland towards Shelly’s Beach. In the region of the “slot” at Eagles Claw, the exposed units of the volcanic complex show a
variety of compositions, internal features and emplacement mechanisms within layers of ash units, crystal tuff layers, co-ignimbrites and a mafic lava flow. The Merimbula Group can be subdivided into the Twofold Bay Formation (base), Bellbird Creek Formation and the Worange Point Formation (top). At study site 3 of the Merimbula Group, only the Twofold Bay Formation consisting of a number of sedimentary layers is included. A volcanic plug made up of rhyolite is located at the southern end of Twofold Bay underlying the sedimentary units.

Stratigraphic Hierarchy of Eden, NSW (Hill, D., 1967)

- Merrimbula Group: Group, Suite
  - Bellbird Creek Formation: Formation, beds
    - Ettrema Limestone Member: Member, phase
  - Ben Boyd Formation: Formation, beds
  - Twofold Bay Formation: Formation, beds
    - Wolumla Conglomerate Member: Member, phase
  - Worange Point Formation: Formation, beds

Figure 4-34: Geological map of the south eastern corner of NSW (NSW Government, 1995).
**Method**

Coastal shorelines are often inaccessible by foot leaving the only options for capturing images to be by air or by water. A small aluminium boat of 4.2 m was used in this exercise to trial the potential of photogrammetry following acquisition of images by boat and to note any complications with the process. The boat was safely navigated by the captain as the images were taken during forward movement. Three kilometres of shoreline was photographed from the boat to create a continuous image of the coastline.

**Site Details:**

Date: 28\textsuperscript{th}, November, 2015 at 10:00am  
GPS coordinates: 37° 4'22.29"S, 149°55'1.20"E  
Weather: partly cloudy  
Cliff aspect: 3 km of coastline all directions favouring the east  
Modelled features: Cliff, trees and other vegetation, houses, beaches.

**Photography**

Photographs were taken by hand standing in a 4.2 m aluminium runabout to help with satiability as the boat motored forward at a speed of 20 km/hr. Pictures were captured with the Nikon D610 in manual mode with the settings outlined in Table 4.18.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photo set</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter speed (s)</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D610</td>
<td>Set 1</td>
<td>6016x4016</td>
<td>300</td>
<td>Yes</td>
<td>100</td>
<td>8</td>
<td>1/250</td>
<td>Mod 1-3</td>
</tr>
</tbody>
</table>

**Photographic Pattern**

During photography, the direction varied from slightly forward facing to perpendicular with the cliffs and then to facing slightly backwards (Figure 4.36). This pattern was repeated as the boat continued moving forwards and was necessary to capture images covering angles around jagged pieces of land sticking out from the shoreline. If photographs were captured by only taking them perpendicular to the shoreline a large number of visible outcrop would be missed. Being on a single platform boat
limits any change of elevation and, because of dangerous shallow waters, limits the minimum distance that can be reached to the outcrop. An image was captured every 10 m resulting in 300 images over 3 km.

Figure 4-35: Location of photograph extraction by boat relative to the shoreline outcrop in photoset 1.

Photoshop

The single image set was processed with RawTherapee to retain GPS tags attached to photographs once processed. Photographs were converted from RAW format to JPEG. Some colour adjustments were made to increase contrast, colour and sharpness (Figure 4.35, Table 4.19).
Figure 4-36: Photograph adjustments made. A) RAW format. B) JPG conversion with colour adjustments made in RawTherapee.

Table 4-19: Photoshop adjustments and models developed from each photoset.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>RawTherapee</td>
<td>Mod 1-3</td>
<td>RAW to JPG</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*PhotoScan settings*

The single photoset was processed 4 times with the MacPro from GPS referenced images. The sky and water were masked out of the images. A maximum of 205 of 300 photographs would align. Alignment was trialled with GPS tags turned on and off and results were the same whether the GPS tags were on or off. Global positioning system (GPS) tags do not appear to improve the alignment phase. The 95 photographs that did not align with any settings were all of the first 95 images captured. It is uncertain why they would not align as there appears to be sufficient overlap of the images and all settings and adjustments were the same as the 205 images that successfully aligned (Table 4.20).
Table 4-20: Settings and specifications used in PhotoScan to create high-definition 3D models of Eagles Claw.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 1</td>
<td>Yes</td>
<td>High</td>
<td>205/205</td>
<td>365,480</td>
<td>Medium,aggressive</td>
<td>28,848,703</td>
<td>Custom</td>
<td>8,999,999</td>
<td>16,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 2</td>
<td>Yes</td>
<td>High</td>
<td>205/205</td>
<td>365,480</td>
<td>High,mod</td>
<td>107,102,667</td>
<td>Custom</td>
<td>8,999,999</td>
<td>16,000</td>
<td>Best, Not extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 3</td>
<td>Yes</td>
<td>Highest</td>
<td>196/205</td>
<td>231,998</td>
<td>High,mod</td>
<td>97,102,667</td>
<td>High</td>
<td>19,532,949</td>
<td>16,000</td>
<td>Not extrapolated</td>
</tr>
</tbody>
</table>

**Results:** Of boat photographs at Eagles Claw from the methods in Table 4.20 – see also Appendices D2, D3 and E17

![Figure 4-37: Screen image of PhotoScan high-resolution 3D model of Eagles Claw, model 2. Refer to Table 4-20 for model specifications](image-url)
4.4.6  Quarantine Bay

The Late Ordovician Adaminaby Group (Mallacoota Beds) comprises an undifferentiated sequence of sedimentary strata that have a widespread occurrence in southern New South Wales and northeastern Victoria. The part of the sequence exposed at Quarantine Bay unconformably underlies a basal conglomerate of the Middle to Late Devonian Boyd Volcanic Complex. The turbidites outcrop at Quarantine Bay is the best example available within the Mallacoota Beds making it important for education and research.

Site Details:

Photoset 1 – Quarantine Bay
Date: 26th and 28th, November, 2015 both at 4:30pm
GPS coordinates: 37° 4'38.76"S, 149°53'20.55"E
Weather: Overcast
Cliff aspect: facing east
Modelled features: Turbidites, trees, shrubs, boulders, shallow rock pools

Photography

The complete photoset was captured on two different days at 4:30pm. This time was chosen because this is when the tide was low. Most of the rock platform is covered at high tide and so it was important to do the shoot at low tide. On the first day 280 of 331 photographs were taken in overcast conditions. Towards the end of the photo shoot the clouds disappeared and the sun came out permanently until sunset. This caused a significant change to the lighting at the site and so the remainder of the shot was postponed until the clouds blocked the sun out again. An attempt was made the next day to return to the site at the same time, however, the sky continued to be clear. The following day, two days after the first photo shoot, the clouds returned and it was cloudy in the afternoon. A final 51 photographs were taken to complete the photoset. All photographs were taken with the Nikon D610 in manual mode with the same ISO, f-stop and shutter speed settings as listed in Table 4.21.
Table 4-21: Camera specifications and settings of photosets captured at Quarantine Bay, Eden, NSW.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter speed (s)</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D610</td>
<td>Set 1</td>
<td>6016x4016</td>
<td>331</td>
<td>No</td>
<td>320</td>
<td>7.1</td>
<td>1/200</td>
<td>Mod 1-3</td>
</tr>
</tbody>
</table>

**Photographic Pattern**

A vague grid pattern was used to capture the 331 photographs Figure 4.38. The grid pattern is ideal when covering a large area because it the grid makes it easier to keep track of where photographs have already been taken.

![Figure 4-38: Location of photograph extraction relative to the outcrop in photoset 1.](image)

**Photoshop**

Due to no GPS tags being attached to the photographs they were manipulated with IrfanView to convert the RAW format to JPEG and to increase colour, contrast and sharpness by 20% (Table 4.22, Figure 4.39).
Figure 4-39: Photograph adjustments made. A) RAW format. B) JPG conversion with 20% increase of colour, contrast and sharpness adjustments made in IrfanView.

Table 4-22: Photoshop adjustments and models developed from each photoset.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>IrfanView</td>
<td>Mod 1-3</td>
<td>RAW to JPG</td>
<td>20% extra</td>
</tr>
</tbody>
</table>

PhotoScan settings

After uploading the photographs, the ocean, sky and distant land features were cropped out before running the photo alignment. A maximum of 269 photographs could be aligned. Of the photographs that did not align, 95% were the pictures taken facing out to the ocean. PhotoScan’s algorithms were unable to align these pictures even with the ocean masked out. This is likely caused by lack of overlap with other photographs facing the other direction. The photographs were first run with dense cloud set to medium. After successful completion of the model, the photoset was run a second time with the dense cloud set to high. Surprisingly, the model was also completed at this setting (Table 4.23). The model was processed a third time to decimate model 2 from 12 million faces to 5 million so that it could be exported into a OBJ file format and imported into Blender.
Table 4-23: Settings and specifications used in PhotoScan to create high-definition 3D models of Quarantine Bay.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 1</td>
<td>Yes</td>
<td>High</td>
<td>269/331</td>
<td>290,762</td>
<td>Medium,aggressive</td>
<td>31,577,369</td>
<td>Custom</td>
<td>8,919,392</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 2</td>
<td>Yes</td>
<td>High</td>
<td>269/331</td>
<td>290,762</td>
<td>High,aggressive</td>
<td>106,940,231</td>
<td>Custom</td>
<td>12,000,000</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 3</td>
<td>Yes</td>
<td>High</td>
<td>269/331</td>
<td>290,762</td>
<td>High,aggressive</td>
<td>106,940,231</td>
<td>Decimated</td>
<td>5,000,000</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
</tbody>
</table>

Results: of Quarantine Bay from the methods in Table 4.23 – see also Appendices D12 and E18

Figure 4-40: Screen image of PhotoScan high-resolution 3D model of Quarantine Bay, model 2. Refer to Table 4-23 for model specifications.
4.4.7  Wolumla Cuttings

Most of the Late Devonian Merimbula Group, which conformably overlies the Boyd Volcanic Complex, can be subdivided into three major stratigraphic units comprising the Twofold Bay Formation (base), Bellbird Creek Formation (middle) and Worange Point Formation (top). The Wolumla cuttings are the basal unit of the group consisting of undifferentiated conglomerate overlain by sandstone that is equivalent to the Twofold Bay Formation. These facies are of a high-energy depositional environment.

Site-A Details:

Photoset 1 - Conglomerate cutting (north)
Date: 5th, October, 2015 at 4:30pm
GPS coordinates: 36°50'49.19"S, 149°49'7.89"E
Weather: Clear sunny day
Cliff aspect: facing west
Modelled features: Successive conglomerate layers interrupted by car width ledges, trees, vegetation, grass

Site-B Details:

Photoset 2 and 3 – Shale Cutting (south)
Date: 5th, October, 2015 at 4:30pm
GPS coordinates: 36°50'59.55"S, 149°49'26.12"E
Weather: Clear sunny day
Cliff aspect: canyon type road cutting with one slope facing west and the opposing slope facing east.
Modelled features: steep rocky slopes separated by ledges and joined by a road, trees, vegetation, grass, fence
**Methods**

Road cuttings can offer a lot of visual geological information. The Wolumla cuttings show significant similarities to outcrops along the coast between Aslings Beach and Eagles Claw (Chapter 4.4.5) providing visual evidence that both outcrops belong to the Two-Fold Bay Formation. Because of the variations in colour, many of the bedding layers are clearly visible and recognisable. However, because they are spread over 30 km, it is difficult to make detailed comparisons of all the visible features that can be identified. Creating 3D images of either side of the road cutting similarities can be more easily made. Because it is easy to make comparisons, comparisons may be made that have not been thought of previously so making it more likely to make new discoveries. The focus of the Wolumla cuttings is to capture the entirety of outcrops visible with minimum change in lighting so that colours do not visually differ.

**Photography**

Two sets of photographs were taken; one from site A and one from site B. For both sites, all photographs were captured by the Nikon D610 with the same ISO, f-stop and shutter speed settings (Table 4.24). The same settings were used as there was only half an hour time different between photographing the two sites under the same light conditions.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter Speed (s)</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D610</td>
<td>Set 1, site A</td>
<td>6016x4016</td>
<td>40</td>
<td>Yes</td>
<td>110</td>
<td>8.0</td>
<td>1/250</td>
<td>Not run</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 1, site B</td>
<td>6016x4016</td>
<td>136</td>
<td>Yes</td>
<td>110</td>
<td>8.0</td>
<td>1/250</td>
<td>Mod 1-2</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>Set 2, site B</td>
<td>6016x4016</td>
<td>136</td>
<td>No</td>
<td>110</td>
<td>8.0</td>
<td>1/250</td>
<td>Mod 3</td>
</tr>
</tbody>
</table>

**Photographic Pattern**

At site A, 40 photographs were taken on foot at two different distances from the outcrop. With reference to Figure 4.41, it can be seen that the photographs were all by pointing the camera parallel to the rocky slope. The first line of photographs was taken 3 m to 4 m away from the base of
the slope and the second line of photographs was taken 14 m to 15 m away (Figure 4.41). Fewer photographs were needed on the second line as they were not required to create sufficient overlap at this distance.

**Figure 4-41: Location of photograph extraction relative to the outcrop in photoset 1, site B.**

**Photoshop**

Photographs for site A were captured to recreate a 3D image of the single-sided road cutting; however, they were not processed through the final phases of the photogrammetric work flow due to time restraints and because it lacked sufficient distinctive features.

Photographs from site B were processed into two photosets (Table 4.25, Figure 4.42):

Photoset one was processed through RawTherapee so that when the photographs were converted from RAW to JPEG format the GPS tags were kept with the photographs. Small adjustments were made to increase the strength of the colour and the contrast so that different coloured beds were more distinguishable.

Photoset 2 was processed through IrfanView so that GPS tags were removed when the format was converted from RAW to JPEG. Global positioning system tags were removed to trial the difference when compared to photoset 1 where GPS tags were kept. No colour adjustments were made to this photoset.
Figure 4-42: photograph adjustments. A) RAW format. B) JPG conversion with colour adjustments made in RawTherapee

Table 4-25: Photoshop adjustments and models developed from each photoset.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1, site A</td>
<td></td>
<td>Mod not run</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 1, site B</td>
<td>RawTherapee</td>
<td>Mod 1-2</td>
<td>RAW to JPG</td>
<td>Yes</td>
</tr>
<tr>
<td>Set 2, site B</td>
<td>IrfanView</td>
<td>Mod 3</td>
<td>RAW to JPG</td>
<td>No</td>
</tr>
</tbody>
</table>

PhotosScan settings

Three successful models were made at site B with two from photoset 1 and one from photoset 2 (Table 4.26).

The two models created from photoset 1 were processed using the same settings of a medium density cloud. The difference between the two models allowed the analysis of the difference between the extrapolated and non-extrapolated models. The primary aim of the extrapolated model was to include the road so that it could be used to identify visually the orientation of each side of the road cutting.

Only one complete model was created from photoset 2. A number of attempts were made to align photographs taken of the road cutting on both sides of the road. However, all attempts failed and the larger rock slope on the western side of the road would not align without the GPS tags.
Table 4-26: Settings and specifications used in PhotoScan to create high-definition 3D models of Wolumla Cuttings.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1, site A</td>
<td>Windows, 8 GB RAM</td>
<td>No</td>
<td>Medium</td>
<td>113/136</td>
<td>57,499</td>
<td>End</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not run</td>
</tr>
<tr>
<td>Set 1, site B</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>No</td>
<td>High</td>
<td>113/136</td>
<td>57,499</td>
<td>Medium, mod</td>
<td>9,815,454</td>
<td>Custom</td>
<td>5,829,451</td>
<td>12,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td>Set 2, site B</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 3</td>
<td>No</td>
<td>High</td>
<td>05/136</td>
<td>36,421</td>
<td>Medium, mod</td>
<td>6,845,910</td>
<td>Custom</td>
<td>5,999,999</td>
<td>12,000</td>
<td>Extrapolated</td>
</tr>
</tbody>
</table>

Results: of Wolumla Cutting from the methods in Table 4.26 – see also Appendix E19

Figure 4-43: Screen image of PhotoScan high-resolution 3D model of Wolumla Cuttings, refer to Table 4-26 for model specifications. A) Model 2. B) Model 3.
4.5  Archaeological Application

To investigate firsthand the application of digital photogrammetry in archaeology, two research sites were investigated through sets of photographs. The photographs in both cases were captured by the leading archaeologist at each site. The first site was on the island of Flores in Indonesia. Aerial photographs were taken at the site from a drone with the focus being to display the distribution of trenches that have been excavated in the area over the past 25 years. The drone captured images when the camera was aimed directly downwards (at exactly 90 degrees to the plane of the earth’s surface) and covered an area of one square kilometre. The second site was located at the Rocklands in South Africa. Two individual archaeological sites were photographed with photosets trialled using the photogrammetric process.

4.5.1  The Hobbit - Mata Menge, Island of Flores, Indonesia (Drone)

Associations of stone artefacts and fossil vertebrate remains, notably of an extinct dwarfed elephant, Stegodon florensis, have been known since the 1950s from the So’a Basin on the island of Flores (East Nusatenggara Province, Indonesia) (Hooijer, 1957; Maringer and Verhoeven, 1970; Sondaar et al., 1992; van den Bergh et al., 1996; Morwood et al., 1997; van den Bergh, 1999). The oldest stone tools so far recorded from the So’a Basin are 1.02 million year old (Brumm et al., 2010), and are thought to have been made by the putative ancestor of Homo floresiensis, the diminutive hominin that was found in 2003 in the cave Liang Bua on Flores (Brown et al., 2004; Morwood et al., 2004). In 2010 a new research project was started aiming at finding Early to Middle Pleistocene hominin fossils of the maker of the So’a Basin stone artefacts. Large-scale ongoing excavations were initiated at the site Mata Menge, in 1978. In 2015, a photogrammetric model of the site Mata Menge was constructed based on aerial photographs of the site obtained with a drone. The model is presented in a paper under review with the journal Nature (Brumm et al., in prep.). A second set of photographs taken by mobile phone from the ground of a single trench were also run through the photogrammetric process to trial recreation of a trench from phone photographs.
Site Details:

Model – Flores landscape and trench  
Date: 3rd, November, 2015 at 12:00pm  
GPS coordinates: 32° 4'18.16"S, 19° 7'48.04"E  
Weather: Partly cloudy  
Cliff aspect: photoset 1; terrain surface, photoset 2; square shaped trench  
Modelled features: Vegetation, grass plains, sandstone, mudstone and regolith  

**Method**  

The research site on the island of Flores is a savanna type landscape consisting of dry open plains with gentle sloping hills and valleys. A number of trenches have been excavated across the site over the past 25 years (Brumm et al., 2010). To map out the location of the trenches visually in high detail, a drone was used to capture aerial photographs to digitize the landscape. The model is compared to maps created from satellite images available in google earth,

A second photoset was captured on the ground to recreate a 3D image of the main trench currently in operation on the island. A mobile phone was used to capture the images to trial the potential for a simple method to create 3D images.

**Photography**  

Two photosets were captured for this exercise:  

Photoset 1 (Figure 4.45, Table 4.27) consists of 108 photographs captured by GoPro 3. The GoPro had been installed onto a drone, the DJI Phantom 2, and operated in the air to take aerial photographs. An Indonesian team was hired by Gert van den Bergh, the sites coordinator, to operate the drone and to take the photographs. The weather was partly cloudy creating patchy lighting. The initial photo set consists of 102 photographs, however, the trench in photoset 2 (the main feature to be shown in the map) was covered by a blue tarpaulin. The next day the trench was photographed again to provide an additional set of photographs with the tarpaulin removed. Six pictures were taken of the exposed trench to replace those from the original set with the blue tarpaulin. These pictures were taken at the same time of day so that shadows and lighting would be the same. The team originally stitched the 108 photographs together manually. The end result was not satisfactory...
because of the very poor 3D topographic relief. The drone photographs were then passed on to the present researcher and run through methods outlined in Chapter 3. The pictures showing the trench covered by a blue tarpaulin were kept and processed with the blue tarpaulin cropped out (Figure 4.46 versus Figure 5.2).

Table 4-27: Camera specifications and settings of photosets captured at Mata Menge, Florese, Indonesia.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter speed</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>GoPro 3</td>
<td>Set 1</td>
<td>4000x3000</td>
<td>108</td>
<td>Yes</td>
<td>100</td>
<td>2.8</td>
<td>1/250</td>
<td>Mod 1-8</td>
</tr>
<tr>
<td>Samsung s5</td>
<td>Set 2</td>
<td>5184x3456</td>
<td>47</td>
<td>No</td>
<td>125</td>
<td>8.0</td>
<td>1/160</td>
<td>Mod 1-4</td>
</tr>
</tbody>
</table>

Photoset 2 consist of 47 photographs captured by Gert van den Bergh. The pictures were taken on his mobile phone device, the Samsung Galaxy S5. Photographs were taken on the same day as the first drone launch while the tarpaulin was blocking out the majority of sunlight. The walls of the trench were photographed on automatic setting at chest height without GPS points (Figure 4.44).

**Photographic Pattern**

For photoset 1, photographs were captured by the drone in a grid pattern at a constant elevation of 30 m above the point of take-off (Figure 4.44). For photoset 2, the area surrounding the trench and the majority of the trench floor were not photographed. Photographs were captured in an assorted pattern pointing in all directions facing the trench at a distance of approximately 1.5 m to 2 m away from the trench wall.
Photoshop

Photoshop was not used on photographs in this section as images were recorded in JPEG format valid for use in PhotoScan. No colour adjustments were made to the photographs (Figure 4.45, Table 4.28).
Figure 4-45: A) Photograph from UAV in JPG format. B) Photograph inside trench capture by Samsung Galaxy S5.

Table 4-28: Photoshop adjustments and models developed from each photoset.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Not needed</td>
<td>Mod 1-8</td>
<td>Already JPEG</td>
<td>Yes</td>
</tr>
<tr>
<td>Set 2</td>
<td>Not needed</td>
<td>Mod 1-4</td>
<td>Already JPG</td>
<td>Yes</td>
</tr>
</tbody>
</table>

PhotoScan settings

The drone photographs (photoset 1) were processed through PhotoScan a total of 9 times with one attempt failing. Models 1 and 2 were the only trials run in the project using the ‘height field’ function to create a mesh. Comparisons between arbitrary and height field are made in the results (Figure 4.46). Models 1-6 were run through PhotoScan on Windows with 8 GB RAM. Models 7 and 8 were processed through PhotoScan on a MacPro 32 GB RAM (Table 4.29).

The simple phone photographs (photoset 2) were processed through PhotoScan 4 times, all on the Windows 8GB RAM system, to assess aggressive versus moderate dense cloud (models 1 and 3) and extrapolated versus not extrapolated (models 2 and 3). Model 4 is a reproduction of model 3 with a lower texture setting for export as a PDF file. Clouds cause a dark patch in model.
Table 4-29: Settings and specifications used in PhotoScan to create high-definition 3D models of Mata Menge.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>Yes</td>
<td>High</td>
<td>102/102</td>
<td>251,636</td>
<td>Medium, aggressive</td>
<td>13,535,587</td>
<td>HF, custom</td>
<td>5,998,439</td>
<td>13,000</td>
<td>Hieght field-</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 2</td>
<td>Yes</td>
<td>High</td>
<td>102/102</td>
<td>251,636</td>
<td>Medium, aggressive</td>
<td>13,535,587</td>
<td>HF, custom</td>
<td>5,996,350</td>
<td>9,000</td>
<td>distorted, cropped</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 3</td>
<td>Yes</td>
<td>High</td>
<td>102/102</td>
<td>251,636</td>
<td>Medium, aggressive</td>
<td>13,535,587</td>
<td>Custom</td>
<td>6,499,999</td>
<td>14,000</td>
<td>not extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 4</td>
<td>Yes</td>
<td>High</td>
<td>102/102</td>
<td>251,636</td>
<td>Medium, aggressive</td>
<td>13,535,587</td>
<td>Custom</td>
<td>6,499,999</td>
<td>14,000</td>
<td>Extrapolated worked best filling in cloud hole</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 5</td>
<td>Yes</td>
<td>High</td>
<td>108/108</td>
<td>272,300</td>
<td>Medium, aggressive</td>
<td>13,847,409</td>
<td>Custom</td>
<td>4,983,806</td>
<td>13,000</td>
<td>Added 6 photos, no tarpaulin</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 6</td>
<td>Yes</td>
<td>High</td>
<td>108/108</td>
<td>272,300</td>
<td>Medium, aggressive</td>
<td>13,847,409</td>
<td>Custom</td>
<td>4,983,806</td>
<td>9,000</td>
<td>cropped to square</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 7</td>
<td>Yes</td>
<td>High</td>
<td>102/102</td>
<td>272,300</td>
<td>High, aggressive</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td>Mod 8</td>
<td>Yes</td>
<td>High</td>
<td>102/102</td>
<td>251,636</td>
<td>High, aggressive</td>
<td>47,860,101</td>
<td>Custom</td>
<td>11,905,301</td>
<td>16,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>No</td>
<td>High</td>
<td>45/47</td>
<td>106,681</td>
<td>Medium, mod</td>
<td>7,194,465</td>
<td>Custom</td>
<td>5,779,974</td>
<td>13,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td>Set 2</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 2</td>
<td>No</td>
<td>High</td>
<td>45/47</td>
<td>106,681</td>
<td>Medium, aggressive</td>
<td>7,194,465</td>
<td>Custom</td>
<td>5,779,974</td>
<td>13,000</td>
<td>Not extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 3</td>
<td>No</td>
<td>High</td>
<td>45/47</td>
<td>106,681</td>
<td>Medium, aggressive</td>
<td>7,196,642</td>
<td>Custom</td>
<td>6,000,000</td>
<td>13,000</td>
<td>Extrapolated</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 4</td>
<td>No</td>
<td>High</td>
<td>45/47</td>
<td>106,681</td>
<td>Medium, aggressive</td>
<td>7,194,465</td>
<td>Custom</td>
<td>5,779,974</td>
<td>9,000</td>
<td>Not extrapolated</td>
</tr>
</tbody>
</table>
**Results:** of Drone Images at Mata Menge from the methods in Table 4.29 – see also Appendix E20

![Figure 4-46: Screen image of PhotoScan high-resolution 3D model of Mata Menge developed from drone photographs. Refer to Table 4-29 for model specifications. A) Model 1, height field. B) Model 7, arbitrary.](image-url)
Results: of Samsung Galaxy S5 Images from the methods in Table 4.29 – see also Appendix E21

Figure 4-47: Screen image of PhotoScan high-resolution 3D model of Mata Menge, trench developed from smartphone photographs. Refer to Table 4-29 for model specifications. A) Model 2. B) Model 3.

4.5.2 Evolution of Early Man – Rocklands, South Africa

For the last five years Dr Alex McKay and his team have inspected caves and open air sites around the Doring River in the eastern Cederberg area located in the south-west of South Africa. This is about 6000 km south-west from the typical Nubian belt. As part of the project, Dr McKay’s aim is to understand when, and by what routes, early modern humans left Africa. While the scientific community is increasingly certain that Homo sapiens evolved in Africa 200,000 years ago, it is still not known how long humans have remained an exclusively African species. It appears humans had entered Europe by 40,000 years ago and Australia probably 50,000 years ago, but these are, at best, youngest ages and not all are accepted (McKay, 2015). By excavating rock artefacts, McKay hopes to
answer a number of questions such as do the Nubian artefacts reflect a great migration of north-east Africans to the continent’s southern tip? Or are they the result of convergence in the face of finite possibilities? Photosets from two of the trenches currently under excavation were incorporated into this present project to assess the possible uses and benefits photogrammetry may have in the field of archaeology.

Site Details:

Model – Rocklands
Date of Photography: 5th, October, 2015 at 4:30pm
GPS coordinates: 8°42’34.73’S, 121° 0’42.80’E
Weather: Clear sunny day
Modelled Features: soil pit, sandstone cave, prehistoric rock paintings, field equipment.

Method

Three photosets from two sites A and B at the Rocklands were trialled in this exercise aimed primarily at creating 3D images of two different trenches; one at each site. The two trenches were under excavation at the time the photographs were taken. A secondary aim was to recreate and include the surrounding cave containing the recent sediment deposits covering the area where the trenches are situated and to include the rock art visible on the cave walls.

Photography

All three photosets were captured using the Nikon D7000 set to automatic mode (Table 4.30). Photographs were taken by Dr Alex Mckay, the site coordinator.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset/ Site</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikon D7000</td>
<td>Set 1, Site A</td>
<td>3872x2592</td>
<td>53</td>
<td>No</td>
<td>400</td>
<td>3.0 - 6.0</td>
<td>1/(60-500)</td>
<td>Mod 1-2</td>
</tr>
<tr>
<td>Nikon D7000</td>
<td>Set 2, Site A</td>
<td>4928x3264</td>
<td>1,133</td>
<td>No</td>
<td>400</td>
<td>3.0 - 6.0</td>
<td>1/(60-320)</td>
<td>Mod 1</td>
</tr>
<tr>
<td>Nikon D7000</td>
<td>Set 1, Site B</td>
<td>3648x2736</td>
<td>37</td>
<td>No</td>
<td>400</td>
<td>2.0 - 4.0</td>
<td>1/60</td>
<td>Fail</td>
</tr>
</tbody>
</table>
Photoset 1 from both’ sites A’ and ‘B’ were taken with the cameras resolution set to the medium setting (Table 4.30) to increase the processing speed of PhotoScan. Only a relatively small number of photographs were taken for each photoset as only the walls for the inside of the two trenches were intended to be recreated in 3D digital form from this photoset.

Photoset 2 for ‘site A’ was captured in high resolution to increase the detail of features in the model and to create a more realistic 3D image. Many photographs (1,139) were taken to create a complete 3D image of the cave and its trench and so that every surface was photographed with a sufficient overlap.

Photographic Pattern

Site A was captured with two different photosets to trial processing both a large and small photoset. Photoset 1 consisted of 53 photographs taken in a fan type sequence from 4 points; one at each side of the trench (Figure 4.48). Photoset 2 consisted of 1,139 photographs to ensure every part of the surface area intended to be recreated within the boundaries of the model was covered (Figure 4.48, B).

Site B was captured with one photoset. Photoset 1 consisted of 37 photographs in a fan pattern similar to that used for photoset 1 at site A (Figure 4.48, A).
Photoshop

Photoshop was not used on photographs in this section as images were recorded in JPEG format valid for use in PhotoScan. There were no colour adjustments made to the photographs (Figure 4.49, Table 4.31).
Figure 4-49: No photograph adjustments required as photographs were captured in JPG format.

Table 4-31: Photoshop adjustments and models developed from each photoset.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Not needed</td>
<td>Mod 1-2</td>
<td>JPG</td>
<td>No</td>
</tr>
<tr>
<td>Set 2</td>
<td>Not needed</td>
<td>Fail</td>
<td>JPG</td>
<td>No</td>
</tr>
<tr>
<td>Set 1</td>
<td>Not needed</td>
<td>Fail</td>
<td>JPG</td>
<td>No</td>
</tr>
</tbody>
</table>

PhotoScan settings

Photoset 1 at site A was run three times with all of the 53 photographs being aligned on the ‘high’ setting. The first run with the dense cloud was set to ‘medium’ and with each consecutive run the setting of the density cloud was increased until the program failed. This happened because of insufficient RAM when the setting was changed to ‘ultra-high’ (Table 4.32).

Photoset 2 at site A was run a number of times on both the Windows system with all attempts failing. The MacPro was capable of aligning and developing the photoset taking a total of 26 hours with a low quality dense cloud. Because of the excessive amount of overlap due to the dense photographic pattern the final model appeared as though it had been developed at a higher quality setting. There were almost no imperfections in the mesh making it appear very continuous (Figure 4-48 B).

Photoset 1 at site B was run a number of times at different photo alignment settings with all attempts failing (Table 4.32). Failure was due to excessive colour differences from radical changes in light exposure with the camera set in automatic mode. Photographs looking into the dark cave caused the soil in the trench to appear very dark brown. Photographs looking out towards the bright sunlight caused soil to appear a very light coloured brown. The trench also lacked variety in lines and colours that assist algorithms within PhotoScan to align the photographs.
Table 4-32: Settings and specifications used in PhotoScan to create high-definition 3D models of excavation sites at the Rocklands, South Africa.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>No</td>
<td>High</td>
<td>53/53</td>
<td>94,366</td>
<td>Medium, aggressive</td>
<td>3,128,265</td>
<td>High</td>
<td>625,434</td>
<td>12,000</td>
<td>Added in panorama</td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td>Mod 2</td>
<td>No</td>
<td>High</td>
<td>53/53</td>
<td>94,366</td>
<td>High, aggressive</td>
<td>11,444,345</td>
<td>Custom</td>
<td>5,916,067</td>
<td>12,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td></td>
<td>No</td>
<td>High</td>
<td>53/53</td>
<td>94,366</td>
<td>Ultra high, aggressive</td>
<td>37,733,171</td>
<td>Custom</td>
<td>Fail</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set 2</td>
<td>Windows, 8 GB RAM</td>
<td></td>
<td>No</td>
<td>Medium</td>
<td>1133 pics</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>To many photos</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MacPro, 32 GB RAM</td>
<td></td>
<td>No</td>
<td>Medium</td>
<td>1133 pics</td>
<td>1124/1133</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>To many photos</td>
<td></td>
</tr>
<tr>
<td>Set 1</td>
<td>Windows, 8 GB RAM</td>
<td></td>
<td>No</td>
<td>Low</td>
<td>15/37</td>
<td>85,366</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unsatisfactory</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td></td>
<td>No</td>
<td>Medium</td>
<td>16/37</td>
<td>88,512</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unsatisfactory</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Windows, 8 GB RAM</td>
<td></td>
<td>No</td>
<td>High</td>
<td>18/37</td>
<td>92,306</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unsatisfactory</td>
<td></td>
</tr>
</tbody>
</table>
Results: of Rocklands, Cave images from Table 4.32 – see also Appendices E22 and E23.

Figure 4-50: Screen image of PhotoScan high-resolution 3D model of Rocklands cave. Refer to Table 4-32 for model specifications. A) Model 2 showing open pit. B) Model 1 showing pit after back fill.

4.6 Ultra-High Resolution Aerial Photographs – Uluru

Uluru is an inselberg (Island Mountain). An inselberg is a prominent isolated residual knob or hill that rises abruptly from extensive surroundings of flat erosion lowlands. Uluru is also often referred to as a monolith, although this is a somewhat ambiguous term that is generally avoided by geologists
The remarkable feature of Uluru is its homogeneity and lack of jointing and parting at bedding surfaces, leading to the lack of development of scree slopes and soil. These characteristics led to its survival while the surrounding rocks were eroded. For the purpose of mapping and describing the geological history of the area, geologists refer to the rock strata making up Uluru as the Mutitjulu Arkose, and it is one of many sedimentary formations filling the Amadeus Basin (Young, 2002).

**Method**

Uluru has been mapped out so that the entire rock can be visualised to assist with geological research of Uluru currently underway by Dr Solomon Buckman.

**Site Details:**

Photoset - Uluru
Date: 12th, June, 2015 at 12:00pm
GPS coordinates: 25°20'41.91"S, 131° 1'57.16"E
Weather: Cloudy and minor showers
Cliff aspect: facing south around west capturing 90 degree turn
Rock type: Folded layers of mudstone and limestones

**Photography**

Aerial photographs used in this exercise were purchased from the Australian government. They are the highest resolution images processed in the project. Each photograph has a resolution of 14,430 x 9,420 which is 136 megapixels (Table 4.33). Thirty three photographs were included in the photoset.

<table>
<thead>
<tr>
<th>Camera</th>
<th>Photoset</th>
<th>Resolution</th>
<th>Number of photos</th>
<th>GPS</th>
<th>ISO</th>
<th>F-Stop</th>
<th>Shutter</th>
<th>Model ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial photograph</td>
<td>Set 1</td>
<td>9420x14430</td>
<td>33</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td>Mod 1</td>
</tr>
</tbody>
</table>
Photographic Pattern

Three different patterns were selected for this experiment to trial the different methods that could be used to capture photographs when only on foot in an alpine region. These patterns can be seen as follows (Figure 4.51):

![Figure 4-51: Location of photograph extraction relative to the outcrop in photoset 1.](image)

Photoshop

No photoshop was required as the photographs are already in JPEG format (Table 4.34). Figure 4.52 shows raw JPG aerial photograph.
Figure 4-52: No photograph adjustments made. There are 6 images shown manually overlapped.

Table 4-34: Photoshop adjustments and models developed from each photoset.

<table>
<thead>
<tr>
<th>Photoset</th>
<th>Program</th>
<th>Model ID</th>
<th>Conversion</th>
<th>Colour enhance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Not needed</td>
<td>Mod 1</td>
<td>Already JPG</td>
<td>No</td>
</tr>
</tbody>
</table>

PhotoScan settings

The photoset did not work at all with PhotoScan on Windows with 8 GB RAM. The photoset was run through PhotoScan on the Mac with 32 GB RAM and all photographs were successfully aligned. The photoset was then run through PhotoScan to test each setting of the density cloud; at low, medium and high. With 33 photographs and 32 GB of RAM, low was the only setting that would work successfully (Table 4.35).
Table 4-35: Settings and specifications used in PhotoScan to create high-definition 3D models of Uluru.

<table>
<thead>
<tr>
<th>Photo set</th>
<th>Computer</th>
<th>Model ID</th>
<th>Cropped</th>
<th>Alignment</th>
<th>#Aligned</th>
<th>Tie Points</th>
<th>Dense Cloud</th>
<th>#Points</th>
<th>Mesh</th>
<th>#Faces</th>
<th>Texture</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Windows, 8 GB RAM</td>
<td>Mod 1</td>
<td>No</td>
<td>Low</td>
<td>Fail</td>
<td>33/33</td>
<td>111, 113</td>
<td>Low, aggressive</td>
<td>20,420,357</td>
<td>Custom</td>
<td>12,000,000</td>
<td>16,000</td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>Mod 1</td>
<td>No</td>
<td>High</td>
<td>33/33</td>
<td>111, 113</td>
<td>Med, aggressive</td>
<td>76,164,285</td>
<td>Medium</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MacPro, 32 GB RAM</td>
<td>No</td>
<td>High</td>
<td>33/33</td>
<td>111, 113</td>
<td>High, aggressive</td>
<td>328,763,165</td>
<td>Medium</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results: of ultra-high resolution aerial photographs of Uluru from the methods in Table 4.35 – see also Appendix E24

Figure 4-53: Screen image of PhotoScan high-resolution 3D model of Uluru, model 1. Refer to Table 4-35 for model specifications. A) Model
Chapter 5 - Synthesis and Discussion

5.1 Camera Calibration

One of the most important aspects of creating maps (McCaw and Cazalet 1932, p454-455) and digital photogrammetric models (Agisoft 2015) from photographs is to capture a good quality photoset. Prior to commencing field work at the research locations it is important to become familiar with the equipment required for extracting data (Uysal et al. 2015). For digital photogrammetry the primary source of data is the photographs used for providing images to create the 3D images. Hence, the better the quality of the photographs the better the quality the digitized models will be. Good quality photographs are obtained by the correct use of the aperture, ISO and shutter speed functions in manual mode. For this research, the automatic setting for taking photographs was avoided as it was found to create confusion in PhotoScans photograph alignment algorithms. For this project, the Nikon D610 was the only camera available with manual mode, therefore, being the only camera used for this exercise. A rock outcrop close to home known as Julian Rocks was chosen to practise taking photographs. Using the photography cheat sheet (figure 3.2) proved an effective source of information for understanding how each of the functions in manual mode will work. Each function has a diagrammatic visual description for outlining the effect changing each setting will have.

The exercise proved to be helpful by creating a good understanding of how to use the Nikon D610 in manual mode. However, a more in depth understanding could have been developed by trialling the camera in more than one light setting of sunny weather. The basic functionality of aperture, ISO and shutter speed was understood by the end of the exercise, however, by rerunning the exercise in overcast or cloudy conditions would have helped to better prepare for a wider range of weather conditions. The weather can be unpredictable and allocated time allowed to perform field work can be limited and it is important to be prepared for any type of weather. Depending on one’s level of understanding and application of photography, doing a course in photography would be beneficial for capturing good quality photographs quickly and efficiently to create the highest quality images possible as recommended by Agisoft (2015).
5.2 High Alpine vs Coastal Photogrammetry

To initiate experimentation to assess the relevance of photogrammetry as a tool in the field of geology, a comparison was made of the application of photogrammetry in the Himalayas to photogrammetry in coastal locations. It was found that the method required for photograph extraction from each area varied according to the different environments and geography of the outcrops.

Because the Himalayas are remote means a lot of time and money was required to access the site. Two flights (one flight on a large aircraft from Sydney to New Delhi, India and a smaller aircraft from New Delhi to Leh, India) were required to reach the nearest airport at the Himalayan city of Leh at an altitude of 3,500 m. Three days of climatisation were required in Leh before being able to safely ascend to the remote high himalayan village of Photoksar where the maximum altitude reached was 5,000m. A two man team of local Himalayan guides was required to take us on the 7 hour drive from the city of Leh to the village of Photoksar and set up camp, provide food, water, local translation and local information to ensure our safety and well being in the foreign and unfamiliar landscape. This method of accessing the research area is very involved when compared to accessing the coastal areas of NSW where a 3 to 5 hour drive from home, and accommodation in a caravan park, is all that is required.

The amount of equipment required and the methods required for photographic extraction of an alpine versus coastal region must be assessed. The Himalayan mountain required only a camera to being used to capture the images (although two cameras were used at this site for experimentation of the difference in results between the cameras), an object of known size to scale the digitized image (the village of Photoksar measured on Google Earth) and an object to show the bearing of north. A smart phone to record strikes/dips and to take notes was required only to gather information to confirm the accuracy of geological measurements extracted from the photogrammetric models. Capturing the photographs involved walking along the scree slopes on the opposing side of the valley to the mountain being photographed. One hour was required to capture 167 photographs. Photographs were captured 200 mm to 300 m from the outcrop by walking along the scree slope at one elevations for 1.6km. Photographs were taken every 10 metres to 20 metres apart horizontally to digitize 2.1 km of the mountain side (Figure 4.9, A). All photographs were taken with the camera pointing directly at the mountain. As an addition to this photoset, a second set of photographs was captured of a more distant slope opposing the mountain 1-3 km from the outcrop on the side of a larger, more distant valley. A car was driven along a poorly maintained dirt road stopping every 100-200m to take 4 photographs in a fan pattern (Figure 4.9, B). One hundred and
eighteen photographs were taken in total and combined with the 167 images to form a photoset of 285 images (Table 4.4). The combined set of photographs produced a digitized image of 14 km of cliff line. The detail of the model formed from this photoset is much lower than the detail that can be seen in the model produced from the first photoset. A separate set of photographs was taken with the Panasonic to capture the same 2 km of mountain side as the first set of images from the Nikon (Figure 4.9). Results between the two images were very similar. The Nikon was preferred due to its versatility of control using the settings available in manual mode.

The coastal outcrops were photographed using only the Nikon D610 as it was the preferred camera from experiments run in the Himalayas. Two 2 m long pieces of dowel with a diameter of 2 cm were used to create a scale and orientation in the models, however, their diameter was found to be too small to create an effective scale. A square piece of drift wood 5 cm x 5 cm x 60 cm was used in the models created for Narooma and were large enough to be digitized to create a valid scale and orientation. As the travel to coastal outcrops was much less involved, more convenient and less costly than travelling to Photoksar, a total of eleven outcrops were photographed and digitized. As outlined in chapter 4 each outcrop was digitized to experiment with what is possibilities and to assess the capabilities of extracting complex geological data. A number of different methods were used to extract the photographs from the rocky outcrops including walking around by foot as in the Himalayas, using a 9m selfie pole to capture elevated angles and taking photographs from the water by boat moving along the shoreline. Taking photographs by foot is ideal for convenience when accessing distant outcrops or for a difficult approach (such as narrow or steep terrain similar to accessing the base of the Pinnacles or Haycocks Point) as less equipment is required. However, camera angles are limited when traversing on foot, and assessment of whether every critical angle can be covered by this method alone should be carefully considered. Haycocks Point, the Pinnacles, Quarantine Bay, Wolumla cuttings and site C at Narooma are examples of the models that can be created by capturing photographs exclusively on foot (Appendices E1, E9, E14, E15, E16, E18 and E19). As shoreline outcrops are rarely opposed by an elevated land mass it is often not possible to capture high angled images without the assistance of specialised equipment. To solve this problem a 9m selfie pole has been used at a number of outcrops including sites A, C and E at Narooma and Bingie Bingie Point (Appendices E7, E8, E10, E11, E12, E13 and E6). Photographs were first taken on foot and then the selfie pole was used to fill in the gaps by setting the camera to take a photograph every 15 seconds while walking around. It was important to keep the camera as steady as possible while each shot was taken to avoid blurring with 15 seconds to move inbetween each take. These methods worked very well where there is a continual rock platform to walk on. The shoreline outcrop at Eagles Claw did not have a continual platform along the shoreline. To extract
photographs from this type of terrain a 4.2 m aluminium runabout was used to create a versatile photographic platform on the water. With nearly any outdoor photogrammetric project (unless in a protected cave) the weather has to be considered. When using a boat or unmanned aerial vehicle (UAV) the weather becomes a bigger factor by limiting the days of which these methods can be used so more time with respect to the number of days allowed for a project may be required. Any winds above 10 to 15 knots can be consider impracticle for a UAV or boat from experience on the field, creating to much movement resulting in blurred images. Large sea swell and rain are also not ideal for photography by boat. Results of GPS referenced photographs by boat at Eagles Claw proved successful with 2.5km of coastline being digitized with only one trial being run. Photgraphs from an aditional 1 km of coastline from the same photoset would not stitch together at all for reasons unknown.

This research has made clear that the best methods of photogrammetry will be determined by the altitude and the nature of the terrain but camera operations and methods for creating a scale for reference are likely to be the same. For example, the Himalayan landscape requires a lot of hiking with out the requirement of boats or 9 m selfie poles where as the coastal areas do require them. However, methods of operation of the camera and using objects for scale remain the same for both regions.

Studies by Gini et al. (2013), Remondino et al. (2014), Ryan et al. (2015) and Uysal et al. (2015) reveal that development of new platforms and sensors and improvement of data acquisition devices such as UAV technology has the potential to replace all methods of photography in both regions. From UAVs almost any required angle can be captured providing the weather will permit UAVs to operate safely. Automated photographic patterns can be planned and calculated by modern UAV operating systems. However, operating a UAVs is not only limited by weather but also by battery power. Large, high input solar panels and a number of secondary batteries would be required to allow consistant use of a UAV at remote areas such as Photoksar where there is no locally generated electricity.

Different regions will have different access issues. For example, alpine regions are more costly and required more time and money for preperation and execution where the coastal areas proved more accessible. Each region has its dangers and the high alpine regions require serious consideration as emergency response can take a number of hours and even days to arrive depending on weather and snow conditions. Coastal areas also have a number of dangers
elating to high cliffs and dangerous waters; however, reliable medical care is much closer and more promptly accessible.

To perfect the method of photogrammetry in both regions the methods outlined in this project could be repeated and adjusted by revisiting the same location a number of times and by compensating for any error found in previous photorealistic 3D representations made (Gini 2013). Improvements may include capturing areas not photographed previously shown as imperfections in high-resolution 3D images or by adding and subtracting photographs to create sufficient overlap, or to reduce the number of photographs to increase processing speed. Blurred photographs should be replaced and better weather or more suitable times of day may be chosen to create photosets of better or more consistent lighting. By recapturing entire photosets with different ISO, aperture and shutter speed settings can also help to increase the quality of the final model by eliminating shadows or any excessive exposure.

5.3 **Digitization – The Photogrammetric Work Station (PWS)**

Methods for processing photographs through the photogrammetric work station (PWS) were the same for all sets of photographs from both alpine and coastal regions. Variations in methods were determined by the number of images in a photoset, the resolution of photographs, the amount of image adjustment required, the desired output resolution and the final product to be exported. The number of photographs was the main variable in this project so as to determine the maximum settings that could be used to create the highest resolution possible. For this reason the same camera was used for 18 out of the 27 photosets processed (Appendix C). Other variables that determined the maximum setting to be used in PhotoScan that were trialled in this project include the resolution of photographs and the processing power of the computer being used. Dahl (2004) explains that the speed of a computer system is primarily determined by the amount of random access memory (RAM) with the type of computer processor and graphics cards within the computer also influencing the computers speed. A number of experiments were run to assess and compare the computers’ processing capacities with PhotoScan by; high versus low resolution photographs, Windows with 8GB RAM versus Macintosh with 32GB RAM and natural versus enhanced photographs.
5.3.1 High versus Low Resolution Photographs

A number of experiments were run using different types of cameras that captured photographs at different resolutions. A significant finding is that the resolution of an image has as much significance for the maximum settings to be used in PhotoScan and its processing speed as the number of photographs within the photoset. For example, Appendix B outlines that the number of photographs determines the RAM required to process a photoset for 12 MP images. Findings in Table 5.1 show that by doubling the number of megapixels (MP) and halving the number of photographs, photosets of 24 MP would comply with RAM and quality settings (see Appendix B) calculated with 12 MP images. Chapter 4 discusses the dense cloud quality setting as the controlling factor behind the output resolution of the final model with the alignment and mesh settings working on any setting providing the dense cloud is not too high. For example, the photoset at Julian Rocks used as the subject for the camera calibration exercise (see Chapter 4.2) contained 33 photographs captured with the Nikon D610 with a resolution of 6,016 x 4,016 pixels (24 MP) (table 5.1). When the photoset was processed through PhotoScan on the Windows system, photogrammetric work station (PWS) comprising 8GB RAM the maximum dense cloud that could be created was at the ‘medium’ setting producing 7,532,365 points (table 4.3). Photoset 1 at South Africa of trench 1 using the Nikon D7000 had a resolution of 3,264 x 2,448 pixels (8 MP) (table 4.29) contained 53 photographs. This photoset was processed through the Windows 8GB Ram PWS also, however, was capable of processing at a maximum setting of ‘high’ dense cloud producing 11,444,345 (table 4.29) points. With the photoset captured by the Nikon D7000 in South Africa containing 20 photographs more than that of the photoset captured by the Nikon D610, the Nikon D700 was able to run at a higher quality dense cloud setting consisting of more matched points in the dense cloud.

A second example can be identified between the 33 aerial photographs captured of Uluru at a resolution of 14,430 x 9,420 pixels (136 MP) (table 5.1) and again being compared with the photoset of Julian Rocks where 33 images were captured by the Nikon D610 with a resolution of 6,016 x 4,016 pixels (24 MP) (table 5.1). Both photosets were run this time using the MacPro 32GB RAM as the Windows 8GB RAM system failed to process the 136 MP images at any setting. The highest setting achieved by the 136 megapixel aerial photographs was at the low dense cloud setting producing 20,420,357 (table 4.35) points. The highest quality setting achieved with PhotoScan by the 24 megapixel images was an ultra-high dense cloud which is three settings higher producing 19,186,725 points (table 4.3). While the dense cloud settings are of much higher quality setting for Julian Rocks, similar to the results of the previous example for the Windows 8 GB system, the number of points produced is again very similar defining a relationship between the number of photographs and the
resolution where lower resolution photographs and higher settings are equal to higher resolution photographs and lower settings.

When planning to digitize an outcrop, the choice of resolution should be considered in accordance with the number of camera angles required or the distance the camera is away from the subject. If the surface is detailed and relatively flat then fewer angles may be needed. The results in chapter 4 (Appendix C) show that the resolution of photographs will digitize the details more efficiently although a high powered computer is required. If the images are captured from a large distance (such as the aerial images of Uluru (Chapter 4.6)) digitized details will be similar to lower resolution photographs captured closer to the outcrop. If an outcrop has many bends, corners and hidden surfaces, or images can only be taken close to the subject, then a large number of angles may be required so a camera capturing photographs at a lower resolution should be used (example Site D, Figure 4.20,A,B).

<table>
<thead>
<tr>
<th>Camera</th>
<th>Resolution</th>
<th>Megapixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial photographic camera</td>
<td>14,430 x 9,420</td>
<td>136</td>
</tr>
<tr>
<td>Nikon D610</td>
<td>6,016 x 4,016</td>
<td>24</td>
</tr>
<tr>
<td>Panasonic</td>
<td>4,896 x 3,672</td>
<td>18</td>
</tr>
<tr>
<td>Samsung Galaxy s5</td>
<td>5,148 x 3,456</td>
<td>18</td>
</tr>
<tr>
<td>GoPro</td>
<td>4,000 x 3,000</td>
<td>12</td>
</tr>
<tr>
<td>Nikon D7000</td>
<td>3,872 x 2,592</td>
<td>10</td>
</tr>
<tr>
<td>iPhone 4s</td>
<td>3,264 x 2,448</td>
<td>8</td>
</tr>
</tbody>
</table>

5.3.2  Windows 8GB RAM vs MacPro 32GB RAM

A model with a low dense cloud commonly has blurred and poorly defined lines where the same model produced with a high dense cloud will have clearer more easily defined lines in-between colours (Figure 5.1). This is particularly important when attempting to trace out stratigraphic layers to make geological assessments of boundaries where it can be difficult to distinguish between similar colours which are made more distinguishable by higher quality 3D models.
Initially, high-resolution 3D models were developed by processing photosets with PhotoScan using a Windows 2.5GHz Intel dual core i7 processor with 8GB RAM. From results in chapter 4, it is evident the Windows computer had enough processing power to produce models from all photosets aside from the 33, 136MP ultra-high resolution aerial photographs of Uluru, photoset 1 from site D at Narooma containing 453 photographs of 24MP and photoset 2 of trench 1 in South Africa which contained 1,139 photographs of 16 MP. All other photosets could produce 3D models with Photoscan. However, any photosets captured by the Nikon D610 (24MP) containing more than 200 photographs (Table 5.2) could only be processed to a maximum dense cloud setting of low. According to the developers of PhotoScan, the higher the settings that a photoset can be produced at, the more accurate the model will be (Agisoft 2015) with low settings not ideal for models requiring data acquisition of strikes and dips. This is also evident when observing the difference between a model developed by a high and a low setting of the dense cloud (Figure 5.1).

To overcome the issue of low quality high-resolution 3D models developed by the Windows system, models were reprocessed by a MacPro consisting of 3.5GHz 6-Core Intel Xeon E5 processor running with 32GB of RAM which has four times the amount of RAM of the Windows system. Table 5.2 outlines the maximum performance output of each computer relative to the number of photographs contained in
each photoset captured by the Nikon D610. Models created by the Windows 8 GB RAM system consisting of photosets with 33 to 136 photographs of 24 MP could be created with up to a medium dense cloud and photosets with 228 to 290 photographs of 24 MP could be created with a low dense cloud (Table 5.2). A photoset containing 453 photographs of 24 MP exceeded the computer’s capacity to complete the first phase of aligning the photographs at any setting. The photoset containing 453 photographs also initially exceeded the processing capabilities of the MacPro. However, by adjusting the tie point and match point limits to half of the original default setting and by turning pair selection from ‘default’ to ‘generic’, the alignment worked and a 3D image was successfully created (Table 4.12). The same scenario is described in Chapter 4.5.2 with the 1,139 photographs of 14 MP in photoset 2 at site A at the Rocklands, South Africa (Table 4.32). This was the highest number of photographs to be stitched into a single high-resolution 3D model in this project. Each of the dense cloud settings limited by the Windows system could be processed to a minimum of one setting higher with the MacPro. From the MacPro photosets containing 228 to 290 photographs of 24 MP could be processed at a dense cloud setting of medium. Photosets with 83 to 205 photographs of 24 MP could be processed at dense cloud setting of high and where the Windows system could process 33 photographs of 24 MP at a ‘medium’ setting the MacPro could process 33 photographs at ‘ultra-high’. The MacPro was also able to process the 136MP aerial photographs at a low dense cloud and also photosets of 453 images with 24 MP and 1,139 images with 14 MP setting where the 8GB RAM Windows system was unable to process any of these photosets (Appendix C).

Table 5-2: Building Model in Arbitrary Mode from 24MP Photographs Captured by the Nikon D610.

<table>
<thead>
<tr>
<th>Location</th>
<th>Images</th>
<th>Max Windows 8GB RAM</th>
<th>Max Macintosh 32GB RAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Julian rocks</td>
<td>33</td>
<td>Medium</td>
<td>Ultra-High</td>
</tr>
<tr>
<td>Site D(2), Narooma</td>
<td>83</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Site B, Narooma</td>
<td>98</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Site E, Narooma</td>
<td>114</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Wolumla Cuttings</td>
<td>136</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Eagles Claw</td>
<td>205</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Site A, Narooma</td>
<td>228</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Quarantine Bay</td>
<td>269</td>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td>Bingie Bingie Point</td>
<td>272</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Photoksar</td>
<td>285</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Haycocks Point</td>
<td>290</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Site D(1), Narooma</td>
<td>453</td>
<td>Fail</td>
<td>Fail</td>
</tr>
</tbody>
</table>
In conclusion, it is highly beneficial to have the highest powered computer possible to produce the highest quality models possible in order to gain the greatest accuracy possible. This is important when the models are required for extracting geological measurements. The web page http://www.agisoft.com/support/tips-tricks/ created by Agisoft (2015) provides tables under the heading ‘Memory Requirements Tips’ (Appendix B) and is similar to Table 5.2. Appendix B shows how the approximate memory consumption peaks depend on the processing stage, settings of dense cloud quality used and the number and resolution of images (or, simply, the limitations of PhotoScan which depends on the available RAM). Tables in Appendix B are based on images having a resolution of 12MP. Table 5.2 is based on images of 24MP, therefore, if the number of photographs are doubled in Table 5.2 an equal comparison can be made to the ‘Build Model (Arbitrary mode)’ table in Appendix B suggesting the tables are nearly identical. This suggests Appendix B to be a reliable source for planning the size of desirable photosets in accordance with the dense cloud quality required.

5.3.3 Colour Enhanced Photographs and Image Format Compatibilities

As a side study, photographs were duplicated into a number of different photosets to experiment with variations in colour and format. Extreme colour adjustments were made at sites B (Figures 4.22,A,B and 4.25,A,C) and E (Figures 4.22,G,I, 4.27,A,B, Appendices E12, E13) at Narooma and also at Haycocks Point (Figures 4.29,A,C, 4.30,A,B, Appendices E14, E15, D5, D6) in Eden to assess whether the colour adjustments would assist in making it easier to distinguish between different coloured stratigraphic layers of high-resolution 3D models. It is evident that the different coloured stratigraphic layers of the colour enhanced models are more easily distinguished. However, as the colours are very different to how they appear in reality, the general comprehension of the model is made more difficult. Batch processing photographs through photo shop programs does work successfully and is a viable option when digitizing 3D models with the photogrammetric process outlined in this project. Colour enhanced models may not be beneficial in all geological presentations, however, they do show potential in making geological interpretation easier and may be suited for certain projects where bedding layers are required to be more distinguishable.

PhotoScan will import several different image formats (Table 3.3). The most common to be used are JPG, PNG and TIF. It is uncertain whether JPG or PNG format images can create the highest quality models and more experiments are needed to make an accurate and final decision. It can be suggested that both PNG and JPG are compliant formats and it is recommended that TIF images be
avoided if possible. Images in JPG format are the preferred format as JPG files require approximately 60% of the disk space compared to PNG files from the same photosets.

Photosets of JPG, PNG and TIF were each trialled to assess if either one will produce better quality models. All except three photo sets were run in JPG format as was recommended by Dr Michael Roach at the University of Wollongong (2015). Photoset 2 at Haycocks Point (Chapter 4.4.3) was captured in RAW format and converted into PNG and JPG format. Models 3 and 4 were created by PNG images and compared to models 5 and 6 which were created by JPG images (Table 4.14). From the PNG images 305 of the 318 images aligned when compared to JPG where 284 of the 318 aligned (Table 4.15). More images were successfully aligned by PNG images with nearly double the number of tie points being created compared to the JPG images. However, an extra 20,000 points where formed in the JPG dense cloud when compared to the PNG dense cloud (Table 4.15). Overall there was no distinguishable difference when observing the final 3D models (Figures 4.30,A,B, Appendices E14, E15, D5, D6). Photoset 1 from site B and photoset 2 from site D at Narooma each had conversions into both TIF and JPG format images (Table 4.11). The models produced from the JPG images at both sites developed normal, well replicated models with 90 out of 98 images aligning at site B and 83 out of 83 images aligning at site D (Table 4.12). When the two photosets were processed with the TIF images both models failed having unusual formations (Figures 4.25,B, 4.26,C). Photoset 1 at site B had only 14 of the 98 TIF images align and site D had 82 of the 83 TIF images align. It may be possible to manipulate the TIF images to create adequate models however, JPG and PNG format images have proven to be less problematic and therefore less time consuming.

5.4 Archaeological Application

Photogrammetry has recently seen increased use in archaeological studies as it allows rapid and cost-effective formation of models of archaeological sites, excavation surfaces, and individual finds (Gonzalez-Aguilera, Munoz-Nieto et al. 2009; Sturzenegger and Stead 2009; Lerma, Navarro et al. 2010; De Reu, Plets et al. 2013; Ashton, Lewis et al. 2014; De Reu, De Smedt et al. 2014; Magnani 2014, Olson, Gordon et al. 2014’ Stal, Van Liefferinge et al. 2014; Fisher, Akkaynak et al. 2015). The advantages are numerous.

In cave sites, complex sedimentation processes are sensitive to the physical structure of the cave and can be time consuming to map with traditional total station methods. The combination of photogrammetry and rectification to local or global grid systems also allows the integration of time
lapse sequences spanning the period and process of excavation into the broader cave model. Figure 4-48 shows images of two 3D models: A) created at the peak of pit excavation and B) the cave floor on completion of pit back fill.

Figure 5-2: A Figure created by Dr Gert van den Bergh including model 5 (Figure 4-44,B) created in this project, for publication in the first edition of Nature Paper 2016.
Also, in caves, photogrammetry can be used as a tool to archive and preserve rock art, allowing the creation of models and virtual tourism that limits the need for large numbers of visitors to sensitive locations (Figure 4-48,B).

In open air sites, photogrammetry from local flyovers by unmanned aerial vehicles (UAVs) can be used to develop high-resolution local terrain models across which sediment bodies and artefact distributions can be mapped (Figure 5.2). This allows the integration of geological and archaeological data, and also allows the creation of time-series studies of the effects of processes, such as erosion, on both land-surfaces and the archaeological debris which rests on them. Figure 5.2 is a Figure that was created to be published in the first Nature Paper of 2016 (Brumm et al. in prep) including a high-resolution 3D photogrammetric digital elevation model created in this paper.

Three dimensional (3D) LiDAR scanning of individual artefacts in the field is often impractical given constraints on the portability and operating conditions required by most scanning systems. Yet in-field recording of artefacts with traditional ‘metric and characteristic-systems’ is invariably insufficient to capture all detail of current and potential interest. In-field photogrammetry allows the creation of a digital archive of artefact forms which allow for subsequent (ex-field) analysis of shape and other characteristics of interest. Photogrammetry can thus reduce the analytic constraints that arise from finite field time.

### 5.5 Extracting Structural Geological Data With PhotoScan

PhotoScan provides a number of built in measuring tools to measure distance, area and volume for georeferenced 3D models. However, measurements cannot be stored or exported in anyway and required the installation of PhotoScan software to be utilized in this way. PhotoScan provides a number of options for exporting files from high-resolution 3D models created by PhotoScan in different formats (Table_). After investigating the options of file formats available for export four formats were selected to be analysed and assessment in this project to investigated methods available for extracting geological measurements from high-resolution 3D models. The formats selected were Google Earth KMZ files, 2D orthophotos, 3D PDF documents and OBJ files to be imported into Blender.
5.5.1 KMZ Files and GeoVis 3D Developed by Dr Michael Roach

Anon (2015) points out that KMZ stands for Keyhole Markup language Zipped. It is a compressed version of a KML (Keyhole Markup Language) file. The KMZ file extension is for a placemark file used by Google Earth and can only be created by PhotoScan from georeferenced 3D models. KMZ files can contain placemarks featuring a custom name, the latitudinal and longitudinal coordinates for the location, and 3D model data. KMZ files can be opened by Google Earth, or unzipped with a compression utility, such as WinZip on Windows, MacZip for Macintosh users, and Zip and UnZip for UNIX systems.

Roach (2015), developed an interactive gaming platform called GeoVis 3D. GeoVis 3D requires KMZ files containing georeferenced 3D model data to be imported. After a KMZ file is imported into the software program a number of tools are provided to make strike and dip measurements which are then plotted on a stereonet. Measurement options include point, multi-point and neighbouring point measurements, lineation by digitising two successive points, best fit plane requiring selection of a minimum of three points to trace out a bedding plane, and multi-line to place coloured annotations on the models surface. The measuring tools can be used for interaction with the model’s surface only. The measurements made by the GeoVis 3D measuring tools can be exported into a Microsoft Excel file. An instruction manual written by Roach is provided with the software. The following examples outline the results obtained from the GeoVis 3D interface of one alpine and one coastal 3D model developed by PhotoScan and exported as a KMZ file. Stereonets produced

Figure 5-3: Top; bedding layer identified by difference in colour on a corner of the outcrop. Middle; points selected to trace out bedding plane. Bottom; A number of best fit planes can be made to measure the average.
When strikes and dips of the Zanskar Limestones and Lamayuru Shales are plotted on the stereonet of field measurements and are compared with the stereonet of strikes and dips extracted from the 3D model many similarities can be identified (Figure 5.4). As the results of the stereonets from the Himalayan experiment shown in Figure 5.4 are very similar, there is strong evidence to suggest extracting strikes and dips from high-resolution 3D models created from photographs capture by walking around the mountain on land has high potential to be a valid method for extracting reliable structural geological measurements.

Figure 5-5: Top; identified exposed bedding planes for placing ‘best fit planes’. Middle; points selected to mark out bedding plane. Bottom; A number of best fit planes can be placed to measure the average.
Figure 5-6: Top, Middle: A number of ‘best fit planes’ are placed on the 3D model in GeoVis 3D created in PhotoScan. Bottom: Stereonet and legend for measurements extracted on the field using the phone application, field move. Field measurements for stereonet were taken from the same positions as 3D measurements.
When strikes and dips of the folded chert that are plotted on the stereonet of field measurements are compared with the stereonet of strikes and dips extracted from the 3D model many similarities can be identified (Figure 5.6). As the results of stereonets from the outcrop of folded chert shown in Figure 5.6 are very similar, there is strong evidence to suggest that extracting strikes and dips from high-resolution 3D models created from photographs captured by walking around the coastal outcrop on land and using the 9 m selfie pole without physical contact to measures exposed bedding planes has high potential as a valid method for extracting reliable structural geological measurements.

### 5.5.2 Orthophotograph

An orthophoto is a high-resolution image also referred to as a digital orthophoto or orthophoto mosaics from created by raw aerial survey photography and digital image capture that has been geometrically corrected or 'ortho-rectified' such that the scale of the photograph is uniform and utilised in the same manner as a map. An ortho-photograph can be used to measure true distances of features within the photograph (Spatial Solutions 2015).

![Figure 5-7: Top: High-resolution digital orthophoto mosaic of Haycocks Point captured from front view of PhotoScan 3D model. Middle: High-resolution digital orthophoto mosaic of Haycocks Point captured from top view of PhotoScan 3D model. Bottom: Google Earth image for comparison (Google Earth 2015).](image-url)
High-resolution digital orthophoto mosaics were captured from several 3D models created in PhotoScan (Appendices D(1-12)). High-resolution digital orthophoto mosaics captured from high-resolution digital 3D models of Haycocks Point (Figure 5.7) and Quarantine Bay (Figure 5.8) were used to assess their practical uses. Jones (2015) found the high-resolution digital orthophoto mosaics suitable for marking out fold axis interpretations on the coastal outcrops which are incorporated in annual field exercises. The image interpretations can then be shown to students to assist with explanations in the class room. Studies by Doneus (2001) and Welch et al. (2002) suggest that by calculating a scale for the digital orthophoto mosaics accurate measurements can be made from the images.

![Figure 5-8: High-resolution digital orthophoto mosaic of Quarantine Bay.](image)

### 5.5.3 Animated Three Dimensional PDF Files

Animated 3D PDF (portable document format) files provide a broad range of interactivity, as opposed to 2D images and movies, as the perspective can be chosen and varied. Unlike the animated 3D PDF file, almost all other software applications providing these functions require the installation of specific software (van de Kamp 2014). By exporting high-resolution 3D models from PhotoScan into an animated 3D PDF file (Figures 5.9, 5.10, Appendicies E(1-24)) possibilities were discovered to be available to analyse, illustrate and describe complex structural geological and archaeological data. This is accomplished by animating 3D mesh models of static land formations with the help of the 3D animation software. The main advantage is that 3D PDF files do not require additional software to be installed for modern operating systems as most systems have Adobe software pre-installed. However, there are disadvantages: the files are limited by resolution as 3D PDF files are not yet capable of being exported at the resolution of the original 3D model created in PhotoScan (Figures 4.4, 4.11, 4.15, 4.23, 4.24, 4.25, 4.26, 4.27, 4.30, 4.33, 4.37, 4.40, 4.43, 4.46, 4.47, 4.50, 4.53), older, slower computers have a high amount of lag when attempting to manipulate 3D models within the animated PDF files, the tools for
making measurements are limited to straight lines, circles, angles and 3D comments, and georeferenced information is not recognised (meaning, therefore, that any measurements made are not geographically orientated with GPS coordinates). The following examples, one of geology and one of archaeology applications, reveal how the animated 3D PDF files can be utilized in these fields.

Example 1: Bingie Bingie Point, NSW, South Coast geological application.

Figure 5-9: Screen image of Bingie Bingie Point animated PDF file with 3D measurements in centimetres (Appendix E6).

Example 2: Rocklands, South Africa archaeological application.

Figure 5-10: Screen image of Mata Menge animated PDF file with 3D comments of trench sites (Appendix E6).
5.5.4 Blender

Blender is a professional free and open-source 3D computer graphics software product used for modelling, rigging, animation, simulation, rendering, compositing and motion tracking, video editing and game creation. Advanced users employ Blender’s API for Python scripting to customize the application and write specialized tools (Blender Foundation, 2015). To import high-resolution 3D models into blender, the 3D models were first required to be exported from PhotoScan in OBJ file format after having decimated the mesh to 3 million faces and reducing the texture to a setting no greater than 9,999 (Chapter 3.1.5). The Blender software is complex and tutorials in the operation of the program may be required before proficiency is achieved. Appendix G outlines the control functions available for operating the program. Once a PhotoScan generated mesh has been imported into the program many operations are possible; from expanding the thin mesh into a block to give it a cubic appearance making it look as though the land formation has been neatly cut out in a prism and raised out of the earth (Figure 5.11) to implementing physics and giving life-like interactive animated motion to the static mesh.

Figure 5-11: Bingie Bingie Point high-resolution 3D model OBJ file import into Blender and modified.
Blender was originally implemented into the project as an attempt to 3D print high-resolution digital 3D land formations. The mesh created in PhotoScan of Bingie Bingie Point (Chapter 4.4.1, Figure 4.15) was selected for the experiment. It required almost 7 days of YouTube tutorials and trial and error experiments with smaller models to expand the Bingie Bingie Point mesh into a rectangular block. The Blender file of the Bingie Bingie Point block model was then exported as a STL file required for 3D printing. The STL file was processed for 3D printing at the University of Wollongongs Engineering 3D printing laboratory, however, the attempt failed as the block model had not been programmed with a 3D density. More time was required to program the 3D block with a density, so the experiment was aborted to focus on directions more suited to extracting geo-orientated structural measurements. Other functions, such as model lighting, sculpting and texture rendering were experimented with to assess the program’s potential for future projects. By applying physics 3D models in Blender tectonic simulations can be created for crustal processes including volcanism, plate tectonics, land surface erosion processes, human intervention to land structures and many more. Animated simulations of walk through tours can be created as well as creating figures such as people or geological instruments to give models recognisable features for scale.
Chapter 6 - Conclusion and Recommendations

The advances made in terms of the algorithms that match various photos from various camera sources by Agisoft Photoscan and other photogrammetry programs has made making high-resolution digital 3D models much simpler and potentially added a new and easy way in which geologists can extract more geological information from the outcrop. It is possible to extract accurate geological data such as bedding plane, foliation and fold axis orientations from detailed three-dimensional digital models of geological outcrops. The main conclusions drawn from this study are as follows:

- It can be concluded that 3D models of different scales can be used to extract important structural data from both large mountain sides (small scale) to detailed outcrops (large scale) as the application of digital photogrammetry has proven to be successful for all study sites and rock types trialled in this project from large Himalayan Mountains to small isolated coastal outcrops. This is useful in remote regions like the Himalaya where it is difficult to access the field site. Models from the south coast of NSW of individual outcrops and were also used to extract structural data that matched the field measurements well. These local models would be particularly useful for teaching purposes, enable large cohorts of students access before and after visiting key geological sites and the ability to check their field observations.

- A key finding of this study is the importance of developing as high a resolution model as possible initially by capturing as much of the outcrop as possible from as many orientations as possible with greater image overlap ensuring more complete models. The use of a high-resolution DSLR camera when initially capturing the images will give the potential to create a high resolution model. Lower resolution images from smart phones will certainly produce a model but it will be limited by the resolution of the camera and doesn’t allow for manual settings image capture. It was found that high resolution images captured with a DSLR camera gave the best results in terms of having the potential to produce extremely detailed, high-resolution 3D models.

- Using manual settings on a DSLR provided consistency between overlapping images that helped the software identify and match overlapping pixels. The ideal manual settings vary depending on light conditions of the day and partly cloudy days or full sunshine with heavy shadows were not ideal in terms of obtaining consistency between overlapping images. Overcast days provide the perfect lighting without the development of strongly contrasting shadows which is ideal for photogrammetry. Shadows created by sunlight were found to assist
PhotoScans alignment algorithms in creating a greater depth of field with rock detail, especially with lower resolution photosets.

- Both IrfanView and RawTherapee proved to be successful image editing programs for reformatting images from RAW format into PNG and JPG files. However, photographs reformatted with IrfanView would lose any attached GPS coordinates. Photographs converted into TIF format proved consistently problematic in 3 separate photosets at the photograph alignment phases in PhotoScan for reason unknown. RawTherapee proved to be more user friendly than IrfanView for making image colour, contrast and sharpness adjustments.

- Experiments of photosets run by two different computers systems (Windows 8 GB of RAM to MacPro 32 GB of RAM) confirmed (Figure 5.2, Appendix B) to be accurate with processing power creating a very large difference in the amount of detail and resolution of 3D models produced. This is an important factor as recommended by Agisoft (2015) as higher settings require greater RAM to produce more accurate and detailed 3D models. This is of great significance for the required application of models produced in this project as models are created specifically for the purpose of extracting measurements where the highest accuracy obtainable is required.

- There are a wide variety of possible model output types from which measurements can be extracted. High-resolution 3D models created in PhotoScan can be exported as KMZ files, PDF files, digital orthophoto mosaics and OBJ files. Each type of file proved to be useful in some way for geological application. From the production of GeoVis 3D by Dr Michael Roach, KMZ files were found to be the most appropriate type of file to be exported and used for extracting complex geological data. GeoVis 3D requires 3D models to be imported as as KMZ files. Two models created in this project, one of a large Himalayan Mountain and one of a small coastal outcrop were analysed in GeoVis 3D. Strike and dip measurements made on the field were plotted in stereonets and compared to stereonets of strikes and dips extracted from the high-resolution 3D models created with PhotoScan. Measurements extracted from GeoVis 3D were found to be very similar to measurements extracted on the field. 3D PDF files are the most versatile due to the widespread use of PDF related software.

- 3D models produced are found to be a new comparative technology that has the ability to change the way in which field geology is carried out. It is still necessary to test and compare the capabilities of different systems, in order to further assess the accuracies of final products and be aware in the choice of the system, which should be the most suitable for the survey purpose.
The ease at which high-resolution digital models can be created now compared to only 5 years ago (Westboy 2012) has the potential to change the way in which field geology is carried out. More emphasis may be put on capturing digital images of the outcrop and its orientation with only a few structural measurements for ground trothing due to the ability to extract more data points from the digital model any time after the field visit. It enables measurements to be taken on a computer from difficult or dangerous to access or cliffs or open cut walls. Creating detailed, high definition virtual models that are located and orientated accurately could change the way in which field geology is approached. A strong example of this is with the Two-Fold Bay Formation being able to compare two 3D models. The 3D models can be used to construct and check stratigraphic logs recorded by students on the day. The ability to virtually revisit a site after the fieldwork has been completed allows students to check their recorded observations in the case that they have conflicting observations with other people in their group. A calibrated 3D model also allows students to measure the true thickness of unit outcrops and check against their own field measurements. Sometimes it is impossible to measure the true thickness of a unit because the contacts are not accessible with a tape measure whereas 3D models enable those measurements to be made. If all the bedding information that is included in a stratigraphic log is added to the 3D models it can open a wide range of possibilities to how easily complex geological data can be read.


Gosh, S., 1981. History of Photogrammetry, Laval University, Canada.


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Koppel, P., 2015. Agisoft PhotoScan: Point Cloud accuracy in close range configuration.


Li, X., 2009. GIS Analysis of Global Impacts from Sea Level Rise, Photogrammetric Engineering and Remote sensing, University of Kansas, USA.


Schenk, T., 2005. Introduction to photogrammetry, Department of Civil and Environmental Engineering and Geodetic Sciences, The Ohio State University, USA.


Westoby, M., Et al., 2012. ‘Structure-from-Motion’ photogrammetry: A low-cost, effective tool for geoscience applications, Institute of Geography and Earth Sciences, Penglais Campus, Aberystwyth University, UK.


Appendix A - Supported file formats in IrfanView

<table>
<thead>
<tr>
<th>Extension</th>
<th>Format Name</th>
<th>Read</th>
<th>Save</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Graphic formats:**

- ANI, CUR: Animated Cursor | X |
- AWD*: Artweaver format | X |
- B3D*: BodyPaint 3D format | X |
- BMP, DIB: Windows Bitmap | X | X |
- CAM*: Casio digital camera format (JPG version only) | X |
- CLP: Windows Clipboard | X |
- CPT: CorelDraw Photopaint format (CPT version 6 only) | X |
- CRW/CR2*: Canon RAW format | X |
- DCM/ACR/IMA*: Dicom/ACR/IMA file format for medical images | X |
<table>
<thead>
<tr>
<th>Format</th>
<th>Description</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCX</td>
<td>Multipage PCX format</td>
<td>X</td>
</tr>
<tr>
<td>DDS*</td>
<td>Direct Draw Surface format</td>
<td>X</td>
</tr>
<tr>
<td>DJVU, IW44*</td>
<td>DjVu File Format</td>
<td>X</td>
</tr>
<tr>
<td>DXF*</td>
<td>Drawing Interchange Format, CAD format</td>
<td>X</td>
</tr>
<tr>
<td>DXF, DWG, HPGL, CGM, SVG*</td>
<td>CAD Formats (Shareware PlugIns)</td>
<td>X</td>
</tr>
<tr>
<td>ECW*</td>
<td>Enhanced Compressed Wavelet</td>
<td>X</td>
</tr>
<tr>
<td>EMF</td>
<td>Enhanced Metafile Format</td>
<td>X</td>
</tr>
<tr>
<td>EPS, PS, PDF, AI*</td>
<td>PostScript Formats (Ghostscript required)</td>
<td>X</td>
</tr>
<tr>
<td>EXR*</td>
<td>EXR format</td>
<td>X</td>
</tr>
<tr>
<td>FITS*</td>
<td>Flexible Image Transport System</td>
<td>X</td>
</tr>
<tr>
<td>FPX*</td>
<td>FlashPix format</td>
<td>X</td>
</tr>
<tr>
<td>G3*</td>
<td>Group 3 Facsimile Apparatus format</td>
<td>X</td>
</tr>
<tr>
<td>GIF</td>
<td>Graphics Interchange Format</td>
<td>X</td>
</tr>
<tr>
<td>HDR*</td>
<td>High Dynamic Range format</td>
<td>X</td>
</tr>
<tr>
<td>HDP, JXR, WDP*</td>
<td>JPEG-XR/Microsoft HD Photo format</td>
<td>X</td>
</tr>
<tr>
<td>Format</td>
<td>Description</td>
<td>Icon Library formats</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>ICL, EXE, DLL</td>
<td>Icon Library formats</td>
<td></td>
</tr>
<tr>
<td>ICO</td>
<td>Windows Icon</td>
<td></td>
</tr>
<tr>
<td>ICS*</td>
<td>Image Cytometry Standard format</td>
<td></td>
</tr>
<tr>
<td>IFF, LBM*</td>
<td>Interchange File Format</td>
<td></td>
</tr>
<tr>
<td>IMG*</td>
<td>GEM Raster format</td>
<td></td>
</tr>
<tr>
<td>JP2, JPC, J2K*</td>
<td>JPEG 2000 format</td>
<td></td>
</tr>
<tr>
<td>JPG, JPEG</td>
<td>Joint Photographic Experts Group</td>
<td></td>
</tr>
<tr>
<td>JLS*</td>
<td>JPEG-LS, JPEG Lossless</td>
<td></td>
</tr>
<tr>
<td>JPM*</td>
<td>JPEG2000/Part6, LuraDocument.jpm</td>
<td></td>
</tr>
<tr>
<td>KDC*</td>
<td>Kodak digital camera format</td>
<td></td>
</tr>
<tr>
<td>Mac PICT, QTIF*</td>
<td>Macintosh PICT format (<em>Apple Quicktime required</em>)</td>
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</tr>
<tr>
<td>MNG, JNG*</td>
<td>Multiple Network Graphics</td>
<td></td>
</tr>
<tr>
<td>MRC*</td>
<td>MRC format</td>
<td></td>
</tr>
<tr>
<td>MrSID, SID*</td>
<td>LizardTech's SID Wavelet format</td>
<td></td>
</tr>
<tr>
<td>DNG, EEF, NEF, MRW,</td>
<td>Digital camera RAW formats (Adobe, Epson, Nikon, Minolta, Olympus, Fuji, Kodak, Sony, Pentax, Sigma)</td>
<td></td>
</tr>
<tr>
<td>ORF, RAF, DCR, SRF/ARW, PEF, X3F,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>File Format</td>
<td>Description</td>
<td>RW2</td>
</tr>
<tr>
<td>Format</td>
<td>Description</td>
<td>X</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------</td>
<td>---</td>
</tr>
<tr>
<td>SFW*</td>
<td>Seattle Film Works format</td>
<td>X</td>
</tr>
<tr>
<td>SGI, RGB*</td>
<td>Silicon Graphics format</td>
<td>X</td>
</tr>
<tr>
<td>SIF*</td>
<td>SIF format</td>
<td>X</td>
</tr>
<tr>
<td>SWF, FLV*</td>
<td>Macromedia Flash format</td>
<td>X</td>
</tr>
<tr>
<td>TGA</td>
<td>Truevision Advanced Raster Graphics Adapter (TARGA)</td>
<td>X X</td>
</tr>
<tr>
<td>TIF, TIFF</td>
<td>Tagged Image File Format</td>
<td>X X</td>
</tr>
<tr>
<td>TTF*</td>
<td>True Type Font</td>
<td>X</td>
</tr>
<tr>
<td>TXT</td>
<td>Text (ASCII) File (as image)</td>
<td>X</td>
</tr>
<tr>
<td>VTF*</td>
<td>Valve Texture format</td>
<td>X</td>
</tr>
<tr>
<td>WAD*</td>
<td>WAD3 Game format</td>
<td>X</td>
</tr>
<tr>
<td>WAL*</td>
<td>Quake 2 textures</td>
<td>X</td>
</tr>
<tr>
<td>WBC, WBZ*</td>
<td>Webshots formats</td>
<td>X</td>
</tr>
<tr>
<td>WBMP*</td>
<td>WAP Bitmap format</td>
<td>X</td>
</tr>
<tr>
<td>WebP*</td>
<td>Weppy file format</td>
<td>X X</td>
</tr>
<tr>
<td>WMF</td>
<td>Windows Metafile Format</td>
<td>X</td>
</tr>
<tr>
<td>WSQ*</td>
<td>Wavelet Scaler Quantization format</td>
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<tr>
<td>Format</td>
<td>Description</td>
<td>Active</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>XBM*</td>
<td>X11 Bitmap</td>
<td>X</td>
</tr>
<tr>
<td>XCF*</td>
<td>GIMP file format</td>
<td>X</td>
</tr>
<tr>
<td>XPM*</td>
<td>X11 Pixmap</td>
<td>X</td>
</tr>
<tr>
<td>old formats*</td>
<td>Amiga, Atari, C64, ZX Spectrum etc. formats</td>
<td>X</td>
</tr>
<tr>
<td>Video/Audio:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AIF</td>
<td>Sound file, Audio Interchange Format</td>
<td>X</td>
</tr>
<tr>
<td>AU, SND</td>
<td>Audio format used by Sun and NeXT machines</td>
<td>X</td>
</tr>
<tr>
<td>MED*</td>
<td>MED/OctaMED sound format</td>
<td>X</td>
</tr>
<tr>
<td>MID</td>
<td>Musical Instrument Digital Interface (MIDI)</td>
<td>X</td>
</tr>
<tr>
<td>MP3*</td>
<td>MPEG audio layer 3 format</td>
<td>X</td>
</tr>
<tr>
<td>OGG*</td>
<td>OGG Vorbis sound format</td>
<td>X</td>
</tr>
<tr>
<td>RA*</td>
<td>Real Audio sound format (Real Player required)</td>
<td>X</td>
</tr>
<tr>
<td>WAV</td>
<td>Windows audio file</td>
<td>X</td>
</tr>
<tr>
<td>Format</td>
<td>Description</td>
<td>Include</td>
</tr>
<tr>
<td>-----------------</td>
<td>--------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>ASF</td>
<td>Advanced Systems Format</td>
<td>X</td>
</tr>
<tr>
<td>AVI</td>
<td>Audio Video Interleaved</td>
<td>X</td>
</tr>
<tr>
<td>MKV*, M4V*,</td>
<td>Movie formats</td>
<td>X</td>
</tr>
<tr>
<td>M2T/MTS/TS/M2TS/M2V*, MOV*, MP4*, WEBM*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOV*, MP4*</td>
<td>QuickTime Movie format <em>(Apple Quicktime required if Quicktime option activated)</em></td>
<td>X</td>
</tr>
<tr>
<td>MPG, MPEG</td>
<td>Moving Pictures Experts Group format</td>
<td>X</td>
</tr>
<tr>
<td>WMA, WMV</td>
<td>Windows Media Audio/Video format</td>
<td>X</td>
</tr>
</tbody>
</table>
Appendix B – PhotoScan System Specifications

Agisoft PhotoScan

Building geometry (Dense cloud and Mesh generation) step usually has the largest memory footprint, especially if the model is constructed in the Medium or High quality, and should be carefully taken into account. For aerial photography processing PhotoScan implements a special Height-field processing mode, which is highly optimized for this kind of data. It allows to process much more photos (several hundreds or thousands), than it is possible using Arbitrary mode.

Memory consumption during photo alignment is typically lower, but can be comparable or even exceed the amount of memory required for model building in Point Cloud mode, or in Low quality.

• Aligning Photos
Memory consumption during photo alignment depends mainly on the number of photos being aligned, and practically does not depend on the resolution of individual photos.

<table>
<thead>
<tr>
<th>Photos</th>
<th>100</th>
<th>200</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>5000</th>
<th>10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory consumption</td>
<td>500 MB</td>
<td>1 GB</td>
<td>2.5 GB</td>
<td>5 GB</td>
<td>10 GB</td>
<td>25 GB</td>
<td>50 GB</td>
</tr>
</tbody>
</table>

• Building Model (Height-field mode)
Memory consumption in Height-field mode depends on the number of photos, their resolution, selected quality and overlap. Dependency on the number of photos and their resolution is approximately linear.

In the following table approximate memory consumption for 12 MPix photo resolution is listed.

<table>
<thead>
<tr>
<th>Photos</th>
<th>100</th>
<th>200</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>5000</th>
<th>10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest quality</td>
<td>25 MB</td>
<td>50 MB</td>
<td>125 MB</td>
<td>250 MB</td>
<td>500 MB</td>
<td>1.25 GB</td>
<td>2.5 GB</td>
</tr>
<tr>
<td>Low quality</td>
<td>100 MB</td>
<td>200 MB</td>
<td>500 MB</td>
<td>1 GB</td>
<td>2 GB</td>
<td>5 GB</td>
<td>10 GB</td>
</tr>
<tr>
<td>Medium quality</td>
<td>400 MB</td>
<td>800 MB</td>
<td>2 GB</td>
<td>4 GB</td>
<td>8 GB</td>
<td>20 GB</td>
<td>40 GB</td>
</tr>
<tr>
<td>High quality</td>
<td>1.6 GB</td>
<td>3.2 GB</td>
<td>8 GB</td>
<td>16 GB</td>
<td>32 GB</td>
<td>80 GB</td>
<td>160 GB</td>
</tr>
<tr>
<td>Ultra high quality</td>
<td>5.4 GB</td>
<td>12.8 GB</td>
<td>32 GB</td>
<td>64 GB</td>
<td>128 GB</td>
<td>320 GB</td>
<td>640 GB</td>
</tr>
</tbody>
</table>

• Building Model (Arbitrary mode)
Arbitrary processing mode is designed for processing of compact objects, mainly captured from the ground level. It can be used to process data sets containing up to several hundreds of photos, but typically much less. Memory consumption in arbitrary mode depends on the number of photos, their resolution and overlap, selected quality level and also on the shape of the object. Dependency on the photo resolution is approximately linear.

In the following table approximate memory consumption for 12 MPix photo resolution is listed. Please note that memory consumption depends significantly on the kind of object being processed.

<table>
<thead>
<tr>
<th>Photos</th>
<th>20 - 50</th>
<th>100</th>
<th>200</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest quality</td>
<td>100 MB - 300 MB</td>
<td>150 MB - 450 MB</td>
<td>300 MB - 1 GB</td>
<td>1 GB - 3 GB</td>
</tr>
<tr>
<td>Low quality</td>
<td>500 MB - 1.5 GB</td>
<td>750 MB - 2.2 GB</td>
<td>1.5 GB - 4.5 GB</td>
<td>4 GB - 12 GB</td>
</tr>
<tr>
<td>Medium quality</td>
<td>2 GB - 6 GB</td>
<td>3 GB - 9 GB</td>
<td>6 GB - 18 GB</td>
<td>15 GB - 45 GB</td>
</tr>
<tr>
<td>High quality</td>
<td>8 GB - 24 GB</td>
<td>12 GB - 36 GB</td>
<td>24 GB - 72 GB</td>
<td>60 GB - 180 GB</td>
</tr>
<tr>
<td>Ultra high quality</td>
<td>32 GB - 96 GB</td>
<td>48 GB - 144 GB</td>
<td>96 GB - 288 GB</td>
<td>240 GB - 720 GB</td>
</tr>
</tbody>
</table>

• Decimating Model

Amount of memory required for model decimation depends on the initial polygon count only. It does not depend on the target face count, and thus breaking decimation in small steps will not help to reduce memory consumption.

<table>
<thead>
<tr>
<th>Faces (millions)</th>
<th>1</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory consumption</td>
<td>128 MB</td>
<td>640 MB</td>
<td>1.3 GB</td>
<td>2.5 GB</td>
<td>6.2 GB</td>
<td>12.5 GB</td>
<td>25 GB</td>
<td>63 GB</td>
</tr>
</tbody>
</table>
### Appendix C – Table of Methods

<table>
<thead>
<tr>
<th>Location</th>
<th>Setting</th>
<th>Photo set</th>
<th>Methodology</th>
<th>Photographs</th>
<th>Post-Processing</th>
<th>Processing Time</th>
<th>RAM Used</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broughton Creek</td>
<td>iPhone Set 1</td>
<td>Low light</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>2/06/2015</td>
<td></td>
<td>Low light</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>12/06/2015</td>
<td></td>
<td>Midday</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>14/06/2015</td>
<td></td>
<td>Midday and 4pm</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>12/06/2015</td>
<td></td>
<td>Midday and 4pm</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>14/06/2015</td>
<td></td>
<td>Midday and 4pm</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>27/11/2015</td>
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<td>Low light</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>12/06/2015</td>
<td></td>
<td>Low light</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>14/06/2015</td>
<td></td>
<td>Midday</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>12/06/2015</td>
<td></td>
<td>Midday and 4pm</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>14/06/2015</td>
<td></td>
<td>Midday and 4pm</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>27/11/2015</td>
<td></td>
<td>Low light</td>
<td>Raw Therapee</td>
<td>Yes</td>
<td>No</td>
<td>3.5GB</td>
<td>1GB</td>
<td></td>
</tr>
<tr>
<td>12/06/2015</td>
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<td>Low light</td>
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<td>14/06/2015</td>
<td></td>
<td>Midday</td>
<td>Raw Therapee</td>
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Appendix D (1-12) – see folder provided in USB

Appendix E (1-24) – see folder provided in USB

Appendix F – see file provided in USB
Appendix G – Blender Short Cuts

(Solidworks 2015)