THE USE OF GAMING SOFTWARE AND HIVE TECHNOLOGY IN THE CONSTRUCTION OF VIRTUAL FIELD EDUCATION OF THE TANQUA KAROO

BY

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This thesis is submitted in fulfilment of the requirements for the degree of Master of Science in the Faculty of Natural Sciences at the University of the Western Cape

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DECLARATION

I declare that ***The use of gaming software and HIVE technology in the construction of virtual field education of the Tanqua Karoo*** is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full name.....**LUYANDA MAYEKISO**.................. Date.....01-Dec-2023.............................

Signed...

ABSTRACT

Geology is a field-based profession where it is mandatory for students to travel to distant locations for field-based training. However, in times such as the COVID-19 global pandemic, tight budget constraints, and large classes, make embarking on multiple field trips challenging. With digital technology moving to a position where “virtual” visits to geological sites could offer some of the information and interactions that are commonly acquired through field excursions, the creation of Virtual Field Trips (VFT) has become attainable. VFTs attempt to portray a real-world environment of a particular location through a compilation of data and photographs. Virtual trips also preserve geological sites for future generations and promote accessibility to people with mobility restrictions. It can also be used as a guide to rebuild and improve future virtual field trips in the field of geology. This study then aims to develop a VFT of the Tanqua Karoo study area to introduce 4th-year Geology students to the necessary information they need to understand before going on the physical field excursion. This study looks at the type of work that goes into creating a Virtual Field Trip (VFT) and its effect on improving student understanding of the area. The final reports of two different groups of students from 2021 and 2022 are studied to look at how the VFT has affected their performance.

The Tanqua Karoo VFT was created using a collection of software, one of which is Pano2VR, a software that can incorporate large amounts of data, producing a pathway for incorporating data in fine detail into a complex Virtual Field Trip. The final product is a composite tour visiting seven stations incorporating various types of data that include videos, high-resolution panoramas, Lidar models, 360° photographs, and drone videos and -images and a satellite image. It is web-based for easy accessibility and was introduced to the students in the Highly Immersive Visualization Environment (HIVE) for them to explore the VFT in preparing them for their field excursion.

The results of this study can be used to further study and analyse the impact of virtual trips on the learning gain of students as it has been shown that there has been an improvement in the marks of the 2022 group compared to the 2021 group, which could be attributed to the VFT. The web-based aspect of the Virtual Field Trip allows repeated ‘visits’ to the field area, therefore increasing the opportunities to learn. It is important to note that the small size of this group of students shows the effectiveness of virtual field trips only to a limited extent due to a small sample size and more research is needed to confirm the results.

ACKNOWLEDGMENTS

I would like to express my profound gratitude to God for His unwavering guidance and support throughout my academic journey. His divine strength and blessings have been my constant source of inspiration, helping me persevere in the face of challenges and not give up.

I am deeply indebted to my family, especially my sister and father, for their unwavering love, and encouragement that enabled me to pursue my education and achieve this milestone. Your support has been my cornerstone, and I am forever grateful.

The support of the Department of Science and Innovation through its funding agency, the National Research Foundation, and the Centre of Excellence for Integrated Mineral and Energy Resource Analysis (DSI-NRF CIMERA) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author(s) and are not necessarily to be attributed to the CoE, DSI or NRF.

I would like to express my sincere appreciation to my dedicated supervisors, Prof. Jan van Bever Donker for his help with photography and Dr. Mathew Huber for his help with videography and drone-captured photographs, as well as Prof. Dirk Frei, and Dr. Omowunmi Isafiade. Your invaluable guidance, expertise, and mentorship have been pivotal in shaping my research and academic growth. Your constant encouragement kept me motivated to do my best.

I would also like to extend my thanks to Dr De Ville Wickens for providing me with crucial geological information and field guidance during the data collection. Your guidance was important in the success of this research and expanded my knowledge in the field.

Finally, I want to express my gratitude to all my friends who have stood by me and supported me throughout this challenging journey especially Zaki and Noxi for always agreeing to have lunch with me. Your encouragement and understanding have made this experience more manageable and memorable.

To all those mentioned and countless others who have played a role in my academic and personal growth, I offer my heartfelt appreciation. This thesis would not have been possible without your unwavering support, and for that, I am truly thankful.

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1. INTRODUCTION

Geology is a field-based profession where it is mandatory for students to travel to distant locations for field-based training. Field trips are scheduled excursions to geological regions for the demonstration of basic geological events and relationships. However, in times such as the COVID-19 global pandemic and tight budget constraints, embarking on multiple field trips is institutionally challenging to achieve. Currently, computer software and hardware are progressing to a position where "virtual" visits to geological sites could offer some of the information and interactions that are commonly acquired through field excursions (Hurst, 1998). Other inhibiting factors that lead to the development of Virtual Field Trips (VFTs) are the growing number of students, rising costs of transport, increase in health and safety demands, and the increasing urbanization that leads to the destruction of valuable outcrops.

Virtual field trips attempt to portray a particular location through a combination of data, photographs, cartography, and technologies such as Geographic Information System (GIS) without the requirement of physically being there (Carmichael & Tscholl, 2011). E-learning is described as "electronically mediated asynchronous and synchronous communication for the purpose of constructing and confirming knowledge" and has demonstrated an increase in learning through active participation rather than passive (Fletcher et al., 2007). This technique of learning is a crucial theory behind the pedagogic benefits of using virtual field trips in higher education teaching, it encourages taking part and engaging in the virtual environment with peers and tutors (Cliffe, 2017).

Recently, virtual reality (VR) technologies have been actively engaged in education, training, and teaching in several application domains (Radianti et al., 2020). Recent advances in immersive technologies about visualization and interactions have made VR progressively more appealing to scholars (Radianti et al., 2020). Low-budget VR head-mounted displays (HMDs) allow everyone to experience immersive virtual environments. Freina & Ott (2015) define immersion as "a perception of being physically present in a non-physical world by surrounding the user of the VR system created with images, sound or other stimuli" therefore giving the participant a sense of being in the actual environment. A study by Krokos, Plaisant, & Varshney, (2019) proposes that students comprehend more information and can better apply what they have studied after taking part in VR exercises.

Fieldwork in geology has evolved and developed owing to the increase in technology and the necessity of keeping up with the fast-growing pace of modern-day life (Fuller, 2011). Although important, fieldwork alone does not constitute an effective teaching or learning strategy. Therefore, preparation by briefing students before and debriefing them after a field trip should be stressed to constantly evaluate the effectiveness of students' understanding of the linkage between the course material and the field trip (Kent et al., 1997).

The virtual field trips are not meant to substitute for the conventional field trips but to introduce students to the basic skills essential to understanding their environment prior to going on the field excursion (Gilmour, 1997). When considering virtual field trips for geoscience disciplines, spatial scale is of crucial importance and must be taken into consideration (Jones et al., 2009). Whilst there is no definite spatial scale for virtual reality trips due to their varying objectives and nature as observed by Arrowsmith et al. (2005), linking multilayers of virtual field trips scales can offer the most excellent learning experience for students.

The Department of Earth Sciences at University of the Western cape (UWC) is operating the only non-commercial Highly Immersive Visualisation Environment (HIVE) on the African Continent, which can be described as a 7m x 3m back projection 3D movie screen with motion trackers. The Department has embarked on a pioneering program that aims to incorporate this unique facility for geological field education by creating virtual field excursions based on the integration of high-resolution photography and 3D field photography. Some of the inhibiting factors that lead the University of the Western Cape to embark on the production of VFTs are growing student numbers, limited budget, and the pandemic. Students cannot visit most geological sites due to time and logistical constraints.

The Tanqua Karoo region is of particular interest for this research because of its Tanqua Fan complex, which serves as a model for many deep-water systems around the world and remains the most sought-after "open air laboratory" for studying the nature of fine-grained deep-water sedimentation (Wickens, 2022). The Tanqua Karoo is a good test case as the student numbers for the field trip are small enough to allow flexibility in terms of the approach so that multiple aspects of the VFT development can be tested. Furthermore, it is relatively close to UWC and its geology is suitable to be used to develop the techniques necessary in building the VFT.

The aim of this study then is to develop a VFT of the Tanqua Karoo study area, that is used as a preparatory interactive virtual tour for the purpose of teaching the geology honours student’s (4th-year Geology students). This is to improve the understanding of the depositional processes and facies distribution within fine-grained deep-water fan systems and their association to a reservoir and non-reservoir distribution, heterogeneity, architecture, and quality. This study looks at the type of work that goes into creating a VFT. The creation of the VFT incorporated various types of data that include videos, high-resolution panoramas, Lidar models, 360° photographs, and drone videos and images. All the data collected was processed and compiled with several software packages to create individual sites of the study area via web links. The students are guided through the VFT in a presentation format at the HIVE to introduce them to the relevant geological information they need to know. This study evaluates the effectiveness of having a virtual field trip presented to students before they embark on a physical field trip.

The creation and use of the Tanqua VFT is done to build student confidence by helping them locate themselves in the fan system and to recognize sedimentary features in the field. The building of the VFT was achieved by capturing clear photographs and Lidar scans of outcrops and taking video recordings of an expert in the field explaining the geological features to be studied. The final version of the virtual field trip is intended to be easily accessible to students as a form of visual guide available online with descriptions and annotations available at each of the field's focus regions. The students’ field report marks were used to make a performance comparison between the 2021 and 2022 groups of students. The 2021 group of students did not have access to the VFT before they embarked on the field trip while the 2022 group was introduced to the area and its features by means of the VFT prior to going on the physical field trip. Both groups of students were asked to report on the same questions making the results suitable to compare and draw conclusions about the effectiveness of the VFT.

2. THE USE OF DIGITAL GEOLOGY

Digital geology has been explored using different methods. Immersive platforms have been used in the past to explore geological sites and continue to be used an example is Rhoscolyn virtual landscape (https://www.see.leeds.ac.uk/virtual-landscapes/rhoscolyn/index.html) from the University of Leeds (Houghton, 2020). Although most VFTs are not true "virtual reality" (VR), they do attempt to provide autonomy and promote learning by allowing interaction with the virtual environment through exploration, analysis, learning, and testing of skills (Stainfield et al., 2000). There continues to be an evolution of the different methods that can be used to create virtual tours from using gaming engines to Google Earth and other high resolution satellite images. High-resolution graphics, audio, video, 360° photos and video, and specialised data such as maps or the use of GIS have all been featured extensively in more recent products (Carmichael & Tscholl, 2013; Klippel et al., 2020).

2.1 Virtual reality in Earth science

Immersive Virtual Reality (iVR) specifies the use of external tracking sensors to allow motion tracking of 3D glasses (Zhao et al., 2019). In an attempt to address problems present in typical Earth science visualization and analyses, Earth scientists have introduced iVR technologies. iVR can render geospatial data as 3D models or stereoscopic imagery within the perspective of the physical world (Zhao et al., 2019). Some advantages of using immersive technologies are related to the attributes of an iVR system; for example, "strong computing power due to the high-end processing engine and graphics cards, high-resolution displays, and large field of view in conjunction with a 360-degree field of regard" (Zhao et al., 2019).

According to Wang et al., 2020, the most important part of an interactive virtual reality experience is having a comfortable and natural environment for the user. When a virtual environment reacts to the user's actions naturally, it becomes effortless to maintain the user's excitement and immersion. If the virtual environment responds slowly then the immersion will reduce because of the brain noticing this (Wang et al., 2020).

The study by Wang et al. (2020) entailed the building of a global topographic model in the spherical coordinate system. The model's global geographic information was comprised of 3D data which consisted of 2D coordinates (latitude and longitude) as well as depth, elevation, etc. Through mapping, the position of a user in Unity® can be converted to geographic coordinates for data enquiries and reads. The mapping used the Mercator projection method to describe the degree of Unity® units corresponding to longitude or latitude (Wang et al., 2020).

2.2 Stereoscopic projection

Stereoscopic projection displays 3D images by displaying a stereoscopic image pair on a projection screen. The image data relates to the right and left eye views where the difference between the views is interpreted by the brain to stimulate a sense of depth. These images can be created from monoscopic images, modified with software, or recorded with a set of cameras spread out at eye distance (Bogaert et al., 2010). Practical stereoscopic projection systems need the observer to wear a special type of eyeglasses that split the left and right eye images (Neuman, 2009 as cited in Bogaert et al., 2010). The HIVE is equipped with alternating glasses but can also work with anaglyphic photography. When the images are viewed without the glasses they overlap and show a confusing image to the viewer. Nonetheless, some systems do not require eyeglasses (Son, 2009 as cited in Bogaert et al., 2010), like the lenticular plate which directs the image data to predefined viewing zones. Stereoscopic displays have been used in a variety of applications including scientific visualization. This development was aided by the contemporary interest of the film industry in 3D digital cinema which has assisted in the public awareness of stereoscopic systems (Bogaert et al., 2010).

2.3 Geocognition

Geocognition is the study of how people comprehend Earth phenomena. Understanding cognition in geosciences requires an insight into the cognition of professional geoscientists. Working memory research is one way that cognitive scientists have used to understand expertise (Simon & Chase, 1973; Baddeley, 1992; Robbins et al., 1996 as cited in Turner & Libarkin, 2012). The geoscience community has long believed that highly developed spatial thinking is essential to be successful in this field (Kastens et al., 2009 as cited in Turner & Libarkin, 2012). The majority of geoscientists use some kind of map, figures, and spatial representation to produce and interpret data about the Earth (Gilhooly et al., 1998 as cited in Turner & Libarkin, 2012). Therefore, geoscience educators are interested in developing students' spatial abilities. In addition to maps, stereographic projections of orientation data and block diagrams are essential tools for exploring the roles of expertise and spatial ability in geology. The ability of block diagrams to display complicated relationships in a simple format makes them an effective way to simulate the classic working memory chess experiments (Simon & Chase, 1973).

Geologists must be able to draw maps, features, and symbols to successfully represent observations (Turner & Libarkin, 2012). The ability to draw these features allows individuals to represent observed phenomena according to their perceptions of the important details. The simplification of reality into sketches allows for the understanding of an otherwise complicated environment (Turner & Libarkin, 2012). Labelling sketches reduces the uncertainty that would otherwise occur when interpreting sketch meaning. Labelling also requires a linguistic understanding of the sketch being drawn (Turner & Libarkin, 2012). The VFT must therefore take cognisance of these points and thus provide sketches and annotations to promote geocognition.

3. GEOLOGICAL SETTING

This study focuses on the Skoorsteenberg Formation of the Ecca Group within the Karoo Supergroup. From the late Carboniferous to the Early Jurassic, the Karoo Supergroup was deposited in sedimentary basins spanning Gondwana (Catuneanu, 2005). This Supergroup was deposited within the Karoo Basin, which is an enormous and complex sedimentary basin that covers nearly two-thirds of South Africa (Soeder and Borglum 2019). The Tanqua Karoo is situated in the southwestern corner of the Karoo Basin and is approximately 200 km away from Cape Town (Fig.1) in the Western Cape Province (Scott, 1997). The Tanqua area of South Africa's Karoo Basin has five Permian deepwater turbidite fan systems that are almost entirely exposed over 640 km^2. The Cape Fold Belt (CFB) consists of two branches with a central syntaxis; the development of the CFB was responsible for the formation of the Tanqua and Laingsburg subbasins. The study area is bound by the western and southern branches of the Cape Fold Belt (Fig. 1B) (Wickens, 1992).

3.1 The Karoo Basin

The Karoo Basin is a retro-arc foreland basin that developed north of the Cape Fold Belt related to the paleo-Pacific plate subducting beneath the Gondwana plate during the late Palaeozoic and early Mesozoic (Catuneanu, 2004 as cited in Coetzee et al., 2019). Compression and tectonic loading during the Cape orogeny (290-215 Ma) formed a foredeep that marked the start of sedimentation within the Karoo Basin (Hälbich et al., 1983; Hälbich and Cornell, 1983; Gresse et al., 1992; Hansma et al., 2015 as cited by (Coetzee et al., 2019). In the southern (Swartberg branch) and western branches (Cederberg branch) of the Cape Fold Belt (Fig. 1(B)), differential compression resulted in the development of a major anticlinorium where the two branches converge (De Beer, 1990; Wickens, 1992). The anticlinorium was a basin-floor high that led to the development of the Tanqua and Laingsburg sub basins (Fig. 1(B)) in the south-western parts of the Karoo Basin (De Beer, 1990; Wickens, 1992). The Tanqua subbasin developed into a wide, -open- style basin as a result of mild compression on the western branch of the Cape Fold Belt. In contrast, the Laingsburg subbasin developed into a deeper, narrower basin of a foredeep configuration due to increased compression on the Southern Branch of the Cape Fold Belt (Scott, 1997).

Early contraction and tectonic loading throughout the Cape orogeny at 290-215 Ma (Hälbich et al., 1983 as cited by Coetzee et al., 2019) created a foredeep that marked the beginning of sedimentation within the Karoo Basin (Coetzee et al., 2019). The basin is loaded with Carboniferous to Early Jurassic sedimentary strata of the Karoo Supergroup with a thickness of over 5 km (Soeder & Borglum, 2019).

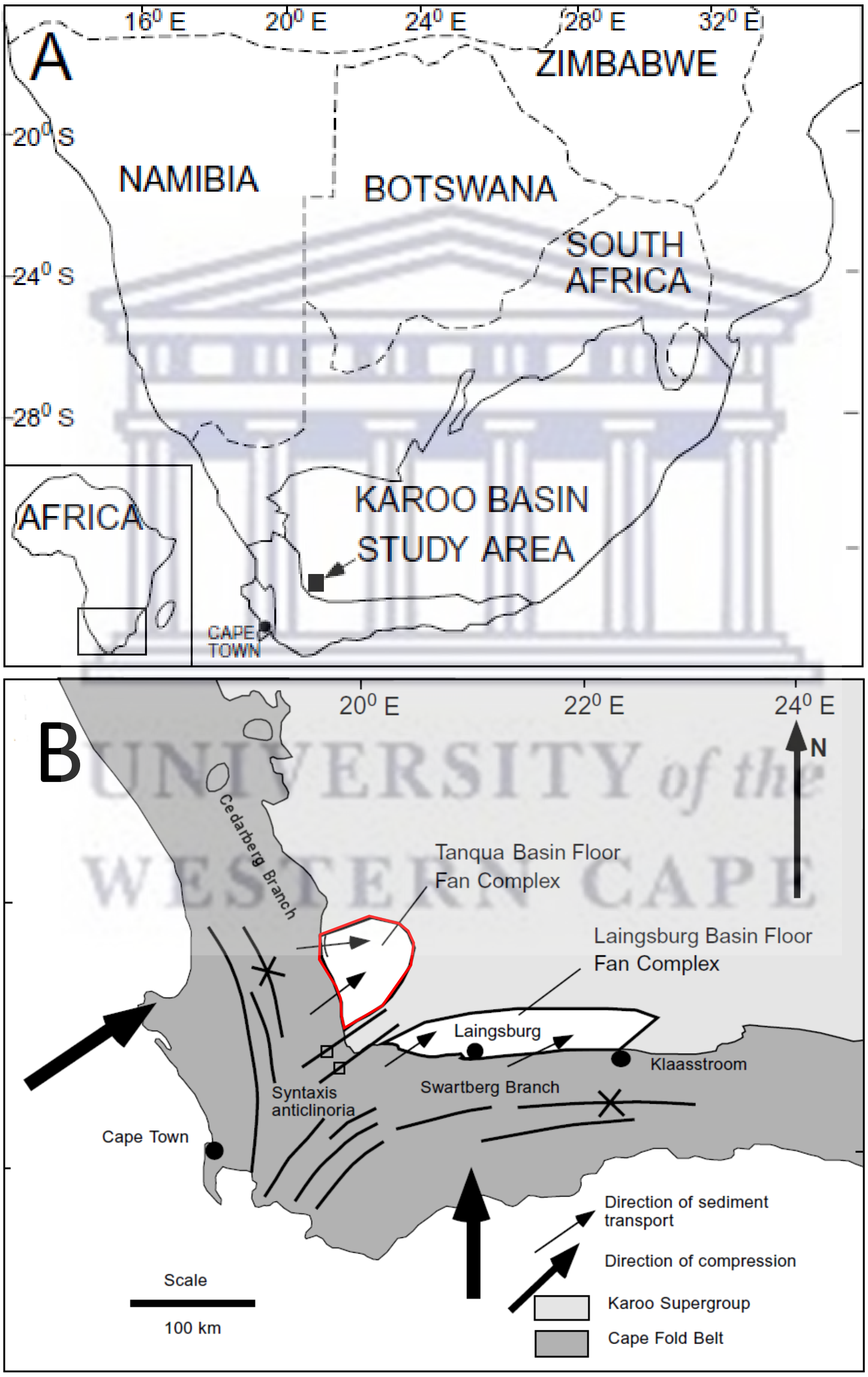

Figure 1. (A) Location of the Tanqua Karoo in South Africa. (B) The tectonic setting of the southwestern Karoo basin with the Tanqua karoo subbasin floor fan complex (study area) circled in red (modified after Wickens, 1994).

3.2 The Karoo Supergroup

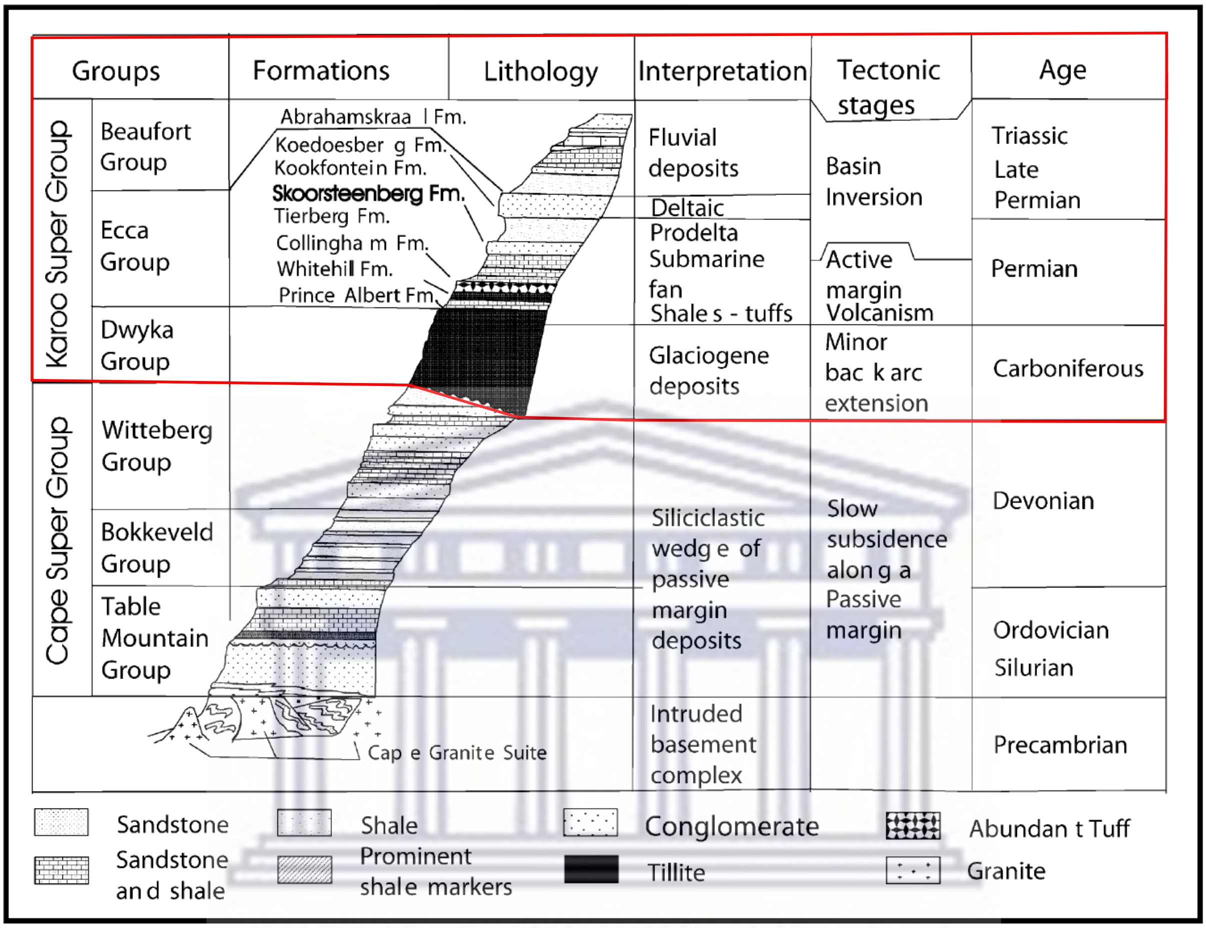

Figure 2. Stratigraphic division of the Karoo Supergroup highlighted in red (Wickens, 1994). The Skoorsteenberg formation in bold is the focus of the VFT.

3.2.1 General introduction

The Karoo Supergroup, which begins with a thick stretch of tillites with black shales, unconformably and paraconformably overlies the Cape Supergroup (Linol et al., 2020). The late Carboniferous–Triassic Karoo Supergroup is characterized by siliciclastic deposits of the basal glaciogenic Dwyka Group followed by the marine Ecca Group and ending with the fluvial Beaufort group (Fig.2) (Visser, 1991). The marine Ecca Group is the subject of this investigation into the use of VFT in preparing the students for the field excursion which visits two subbasins of the Karoo Supergroup namely: Tanqua subbasin and the Laingsburg subbasin. The Tanqua Karoo subbasin is composed of four formations one of which is the Skoorsteenberg formation (highlighted in red in Fig.2) which is the target of the excursion (Wickens, 1984).

3.2.2 Dwyka group

In the southern part of the Karoo Basin, the Dwyka Group (Fig. 3) is between 100 to 800 m thick (Linol et al., 2020) and is characterized by glacial deposits (Visser, 1991 cited in Johnson et al., 2001). Along the Cape Fold Belt, the Dwyka Group contains various units of massive to stratified diamictites and black shales that show a possibility of glacial outwash and rain-out deposits during the development and cessation of a large icecap covering the paleo-South pole (Bangert et al., 1999). The time and the extent to which the different phases of glaciation occurred is not well constrained, but the thin volcanic tuffs in the uppermost Dwyka date back to 296-302 Ma (Griffis et al., 2019) which implies regional deglaciation of the southern Gondwana near the Carboniferous-Permian boundary (Linol et al., 2020).

3.2.2 Ecca Group

The Ecca Group is between 1000 and 3000 m in thickness. Succeeding the deglaciation of the Dwyka Group and associated marine transgression, the mudstones of the Prince Albert and Whitehill formations of the Ecca Group (Fig.3) were deposited in a large shallow sea that was originally marine but later became brackish (Visser, 1991 as cited by Andersson et al., 2004). The overlying Collingham Formation has distal turbidites and volcanic ashes that indicate evidence of active arc volcanism to the south. The Collingham Formation is overlain by the mudstones of the Tierberg Formation that is succeeded by the Skoorsteenberg Formation which comprises sand-rich turbidites interbedded with mudstones (Wickens, 1984).

3.2.3 Beaufort Group

The deposition of the fluvial-lacustrine Triassic Beaufort Group (Fig.3) marked the end of Karoo Supergroup in the southwestern Karoo Basin. The name Beaufort Group is limited to fluvial deposits of Permo-Triassic rocks that were deposited within the main Karoo Basin of South Africa (Johnson et al., 1997). The Beaufort Group stratum predominantly comprises of mudstones and siltstones with minor lenticular and tabular sandstones deposited by a variation of fluvial systems. The transitional and diachronous boundary with the underlying Ecca Group records a gradual change from deltaic to fluvial depositional systems (Rubidge et al., 2000).

Sedimentation of the Beaufort Group in the south-western Karoo Basin began in the middle Permian by uplift in the Gondwana mountainlands (Hälbich, 1983). This caused a deposition of a 3500 m thick succession of sandstones and purple mudstones that contain a number of thin chert bands and rich tetrapod faunas in the foredeep. The deposition of this succession was mainly by overbank flooding of large meandering rivers of different sinuosity, that drained a large alluvial plain sloping gently towards the northeast in the direction of the receding Ecca shoreline (Turner, 1978). Deposition took place under semi-arid climatic conditions as verified by the occurrence of desiccation cracks, palustrine carbonated beds, pedogenic carbonate horizons and gypsum desert-rose evaporites (Keyser, 1966).

The presence of irregular accretion topography and the preservation of upper flow regime plane beds and lower flow regime ripple cross-lamination found in the channel sandstones show the seasonally changing discharge regime of the main rivers (Cole & Wipplinger, 2001). There are sandstone rich intervals that are 50 to 350 m thick that characterize a basal coarse member of five major fining upward megacycles within the lower Beaufort succession. The general tendency of the fining upward lower Beaufort succession is explained in terms of decreasing foredeep slope, channel gradients and sediment supply (Catuneanu & Elango, 2001; Catuneanu & Bowker, 2001). The occurrence of calc-alkaline volcaniclastic detritus and cherts of tuffaceous origin (Ho-Tun, 1979) implies that the provenance rocks in the southwest may have consisted of an active andesite volcanic chain situated on the eastern side of the Andean Cordillera in South America and West Antarctica (Veevers et al., 1994).

3.2.4 Stratigraphy of the Tanqua Subbasin

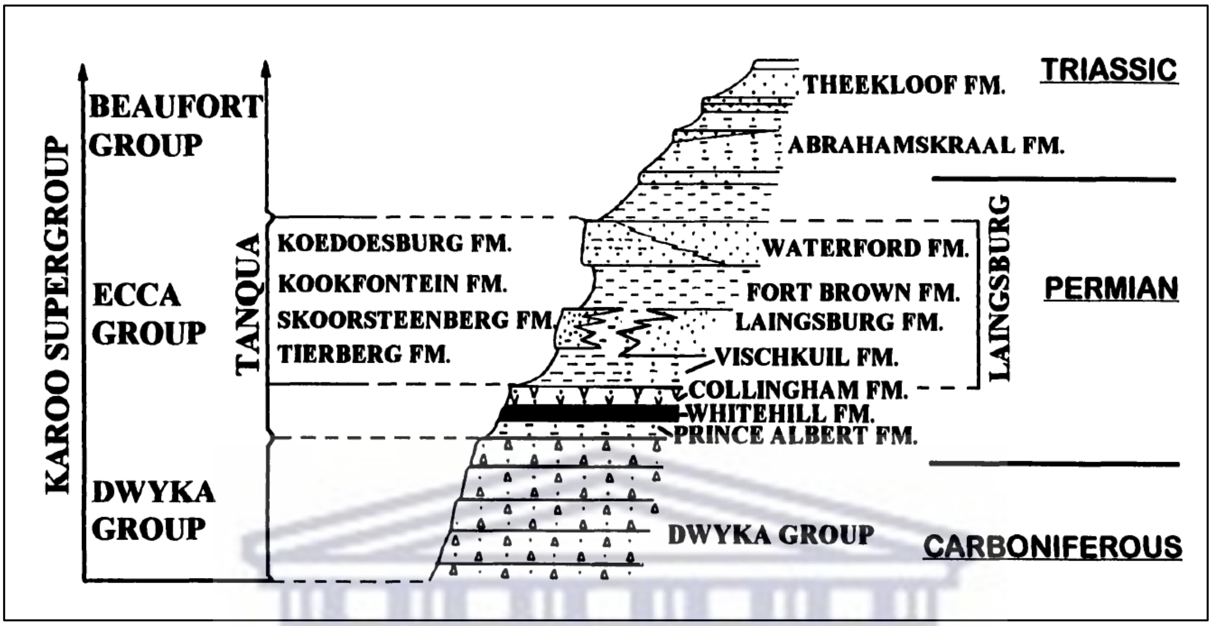

Figure 3. Stratigraphic section of the southwest Karoo Basin illustrating the split of the Tanqua and Laingsburg subbasins (modified after Wickens 1994). Refer to Figure 5 for more details of the Laingsburg and Tanqua subbasins.

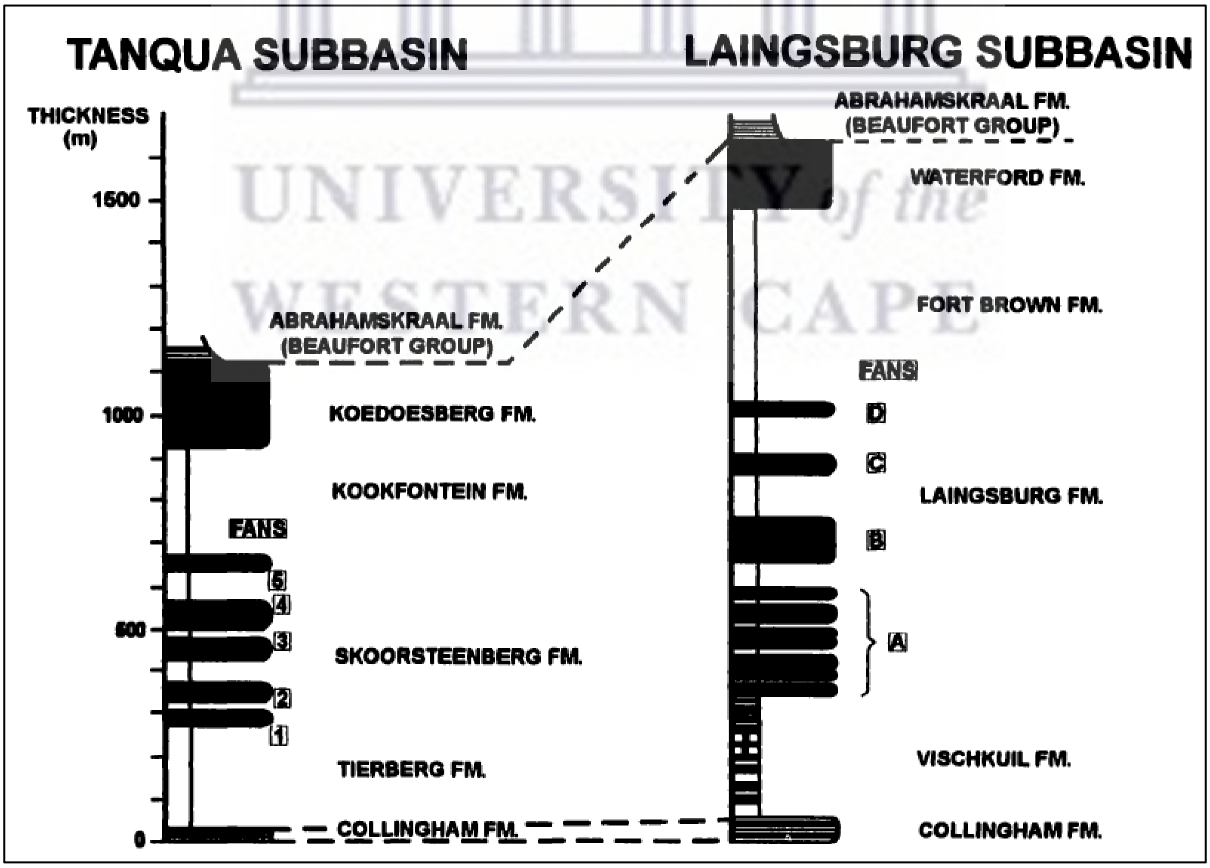

Figure 4. Shows that the formations are of the same age but with different composition (Wickens, 1994)

Based on former sedimentological outcrop studies, the Skoorsteenberg Formation has five widespread basin-floor fans (Fig. 4) known as the Tanqua Fan Complex in the Tanqua Subbasin that are informally called Fan 1 to Fan 5 from the oldest to the youngest (Wickens, 1984, 1992). Later studies reinterpreted Fan 5 as a slope fan (Johnson et al., 2001). The sandstone-rich basin-floor fans are separated by laterally extensive mudstones which represent times of maximum sediment starvation (Johnson et al., 2001). The outcrop area of the Tanqua Fan Complex is approximately 650 km^2 and thins out in an easterly and northerly direction. The outcrops of the fan systems are tectonically undisturbed and spread out for roughly 34 km in a north-south direction (Wickens, 1994). Fans 1, 2, 3 and 5 have paleocurrent directions that range from the south-southwest (SSW) to south (S) and from West (W) to West-Northwest (WNW) for Fan 4 (Fig. 5) (Wickens, 1992, 1994).

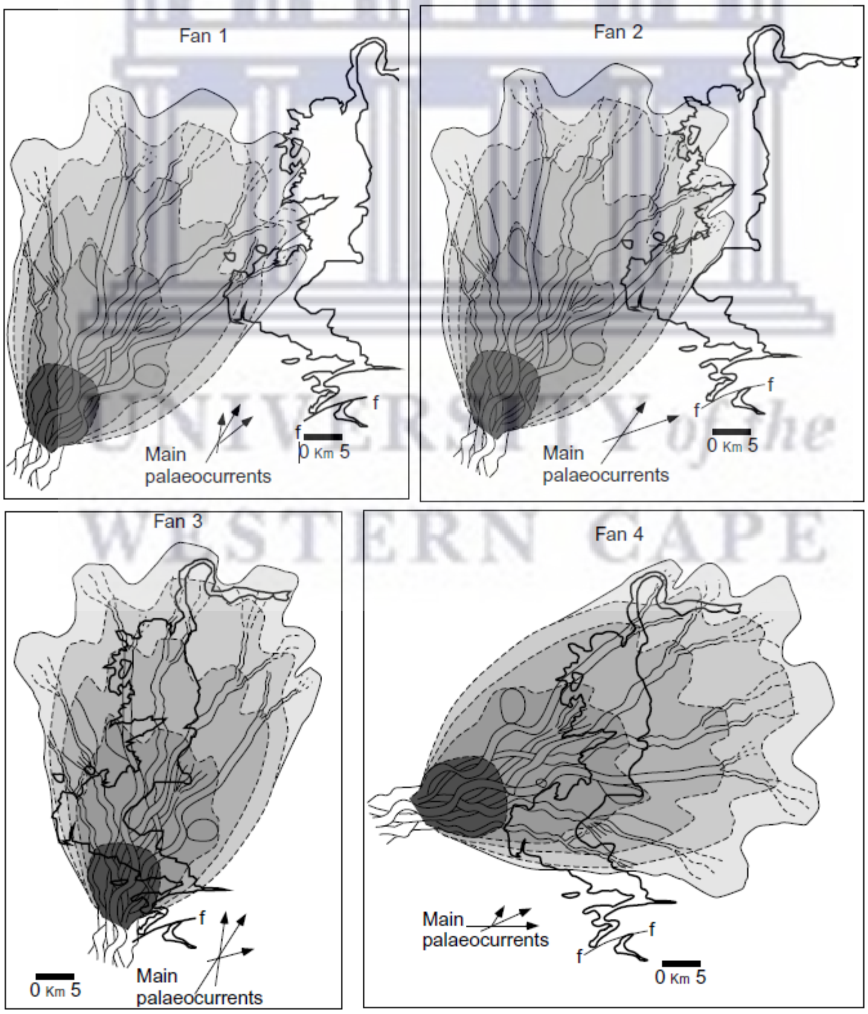

Figure 5. Paleocurrent directions of the outcrop Fans 1–4 during deposition (After Wickens, 1994). The polygon shown in different shades of grey represents the structure of fans from an aerial view and the polygon with a black outline represents the outcrop of the fans in the modern day. The darkest grey represents the most proximal parts of the fans and the lightest parts represents the fans margins. The top of the image is north.

The outcrops of Fan 1 and 2 cover a relatively small region and consist of predominantly sheet-like lobe deposits (Bouma et al., 1995). Fan 3 outcrops from a base-of-slope nested channel complex to channel-levee-overbank deposits and lastly it outcrops to the extreme distal portion of sheet-like outer-fan lobe deposits (Wickens, 1994; Bouma et al., 1995). Fan 4 outcrops over a large area and comprises laterally extensive, sheet-like deposits. Fan 5 displays mid-fan channel-levee-overbank complexes and expands to sheet-like outer-fan lobe deposits (Bouma et al., 1995).

The sandstone facies dominate throughout the fan units and can be identified by sharp bases and tops, frequent sole marks, rip-up shale clasts, and amalgamation associated with channel-fill or stacked sheet-like deposits. Thin bedded turbidites are frequently associated with ripple cross-laminated sandstone and siltstone facies. Overbank and interchannel subenvironments are characterised by medium to thick sandstone strata with climbing ripple lamination. Micaceous plant fragment facies, typically associated with clay clasts, are common on top of sandstone layers, particularly in the fans' distal pinch-out areas (Wickens, 2022).

3.2.5 Turbidite deposits

Turbidity currents are sediment flows with Newtonian rheology and a turbulent state in which sediment is sustained by turbulence and deposition occurs through suspension settling (Dott, 1963; Nardin et al., 1979; Lowe, 1982; Shanmugam & Moiola, 1995). These currents can evolve from debris flows and other slope failure mechanisms, serving as a key process for transporting sand-sized material to deep ocean basins (Shanmugam, 2016). These sediment-waning flows begin in deep marine environments, initially eroding and later depositing, eventually dissipating. In deeper waters, these currents may encounter obstacles or changes in the sea-floor gradient, affecting their velocity (Shanmugam and Moiola, 1985). Turbidity currents gradually lose energy and deposit their sediment on the sea floor, indicating their diminishing strength (Hsü, 1989). The deposits left by these currents are known as turbidites, characterized by the separate settling of coarse, and fine-grained particles and showing normal grading (Kuenen & Migliorini, 1950).

The most comprehensive explanation of turbidite deposition is attributed to A. H. Bouma and is referred to as the "Bouma Sequence”. The Bouma Sequence (Fig. 6) is the most used term for describing turbidity current deposits in the field. Bouma devised a typical sedimentary structure for turbidity currents with its five divisions Ta, Tb, Tc, Td, and Te (Bouma, 1962). Division Ta pertains to the settling of particles from a suspended state, whereas divisions Tb, Tc, and Td encompass the formation of parallel and ripple-laminated layers through the action of either traction or a blend of traction and suspension (Bouma, 1962)

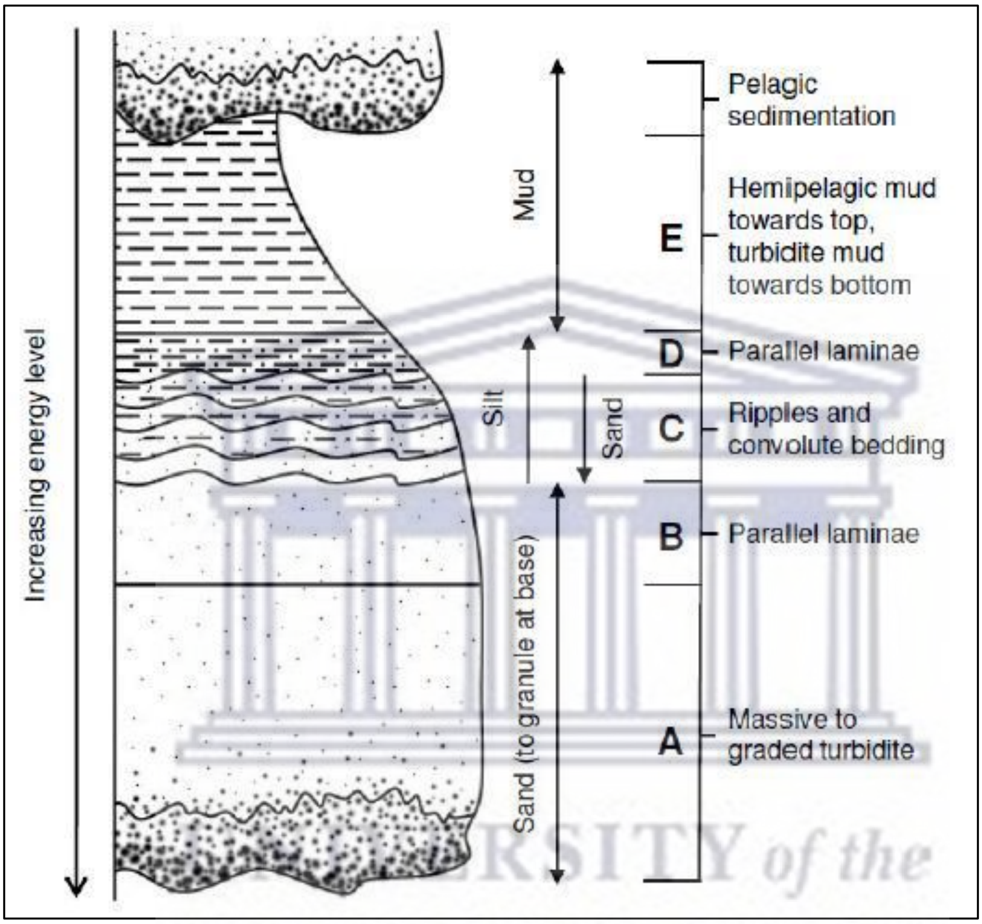

Figure 6. Ta, Tb, Tc, Td, and Te divisions are representative of the Bouma sequence. A represents massive sandstone beds, B represents parallel laminated sandstones, C represents ripple lamination and convolute bedding, D represents parallel lamination in siltstones and E is for hemipelagic shales or mud (Bouma 1962).

3.2.6 Architectural elements of the Tanqua Karoo's subbasin

For the purpose of this research, the turbidite fan sedimentary model (Fig. 7) has been used to demonstrate the locations of the different reservoir characteristics / architectural elements on the different parts of the continental slope to submarine plain. Based on the language used on the field excursion, upper and middle continental slopes on the model (Fig. 7) are referred to as the 'slope' in the field guide, while the lower continental slope on the model is referred to as the 'base of slope' in the field guide, whereas the submarine plain on the model is referred to as the 'basin floor' in the field guide. The architectural elements of the Tanqua Karoo are therefore referred to as 'reservoir structure types' on the model. The different elements of a sedimentary turbidite fan are levee deposits, channel-fills, transitional depositional styles and lobes.

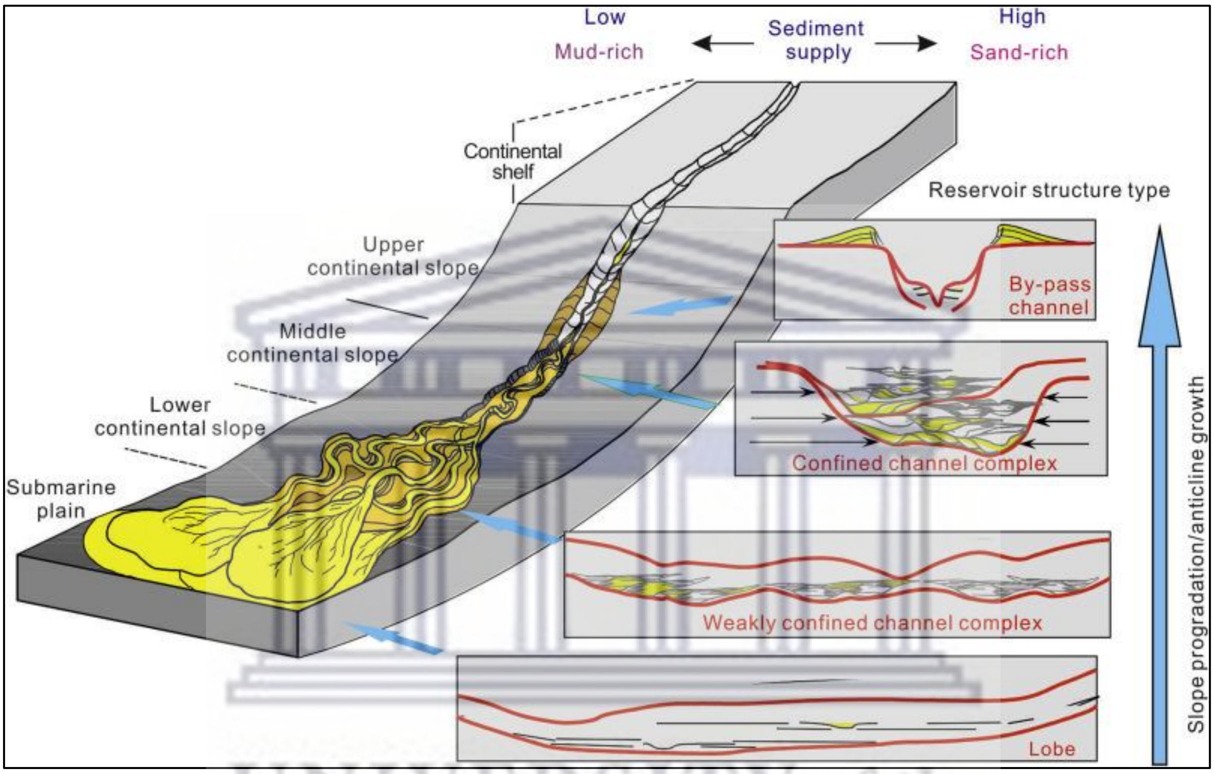

Figure 7. A sedimentary model showing the evolution of the fan system structures from the slope to the basin floor (slightly modified after ENI from Yanqing, 2018).

3.2.6.1 Levee/ overbank deposits

These sediments are usually very fine grained, thin bedded and normally ripple laminated deposits that are developed from lateral spreading from a main body of confined turbidity flows (Wickens, 2022). Levee deposits are characterized by lateral thinning and fining, away from channel fills. The terms "inner" and "outer" levees describe how a system is positioned in relation to a channelized environment, particularly in deeply entrenched broad channel systems, where inner is closer to the channel and outer is further away from the channel (Wickens, 2022).

3.2.6.2 Channel-fills

Channel-fills represent negative reliefs produced by a turbidite current flow and are characteristic of long-term passages for sediment transport. Sequences of channel-fills show a complex internal stratigraphy that accounts for the evolution of the channel through time. When channel-fills are laterally stacked they form channel complexes that are common in slope to base of slope settings (Wickens, 2022)

3.2.6.3 Transitional depositional styles

These deposits are found in regions where well-defined channels and channel-fill deposits are separated from well-defined lobe/sheet sand facies. This region shows some of the characteristics of both channels and lobes. These channel-lobe transition deposits are characterized by wide channels filled with a small number of beds and by multiple shallow, but relatively narrow cut and fill features (Wickens, 2022).

3.2.6.4 Lobes / sheets

Sandstone lobes are known as non-channelized bodies that range from 3 to 90 m in thickness and are composed of thick-bedded sandstones that alternate with thinner-bedded and finer grained interlobe facies. The tabular geometry and the lateral extent of sandstone lobes and the lack of channelized deposits represent inner and middle fan environments (Wickens, 2022).

4. METHODOLOGY

To create the VFT, several steps had to be taken in order to create a functioning product without infringing on the participants' rights or the use of unethical methods to collect data. The steps taken to conduct this research are summarized in the flow chart (Fig. 8).

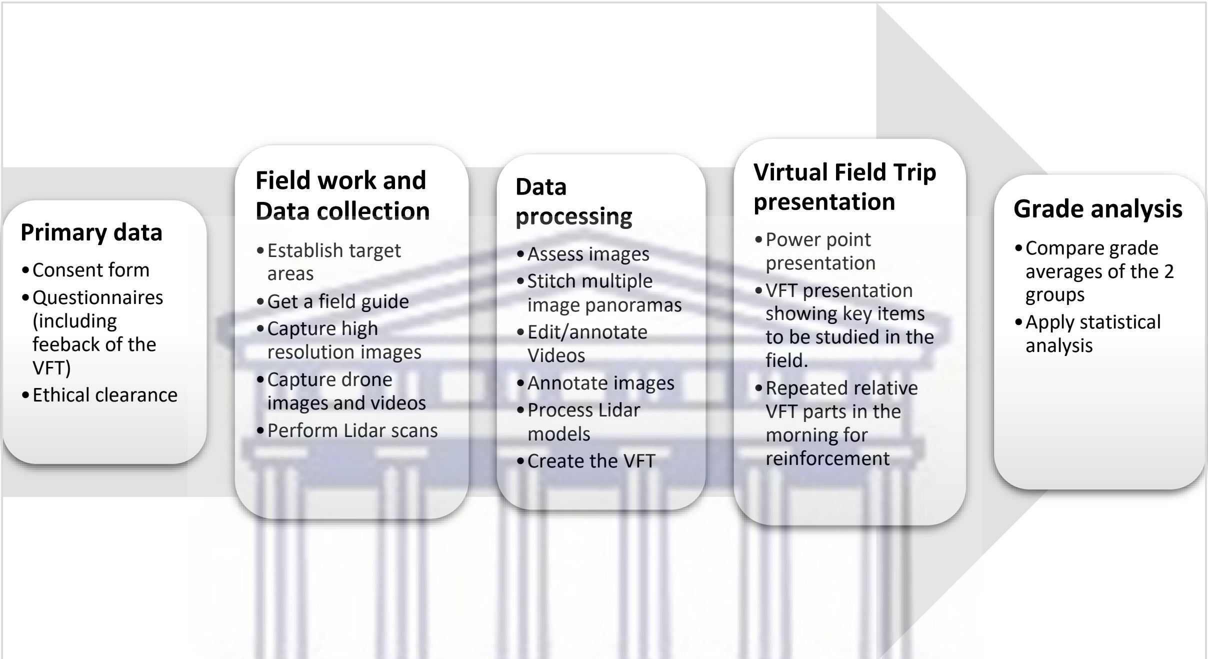

Figure 8. Building process of the Virtual Field Trip

4.1 Ethical clearance

To carry out this research, application to the Humanities and Social Sciences Research Ethics committee (HSSREC) of the University of the Western Cape had to be done to conduct a study that involves personal information of the participants. This application requires a proposal submission that clearly states the objectives of this research. Upon approval from the committee, further approval from the Registrar had to be obtained before the students could be approached. Explanation was given to the students as to what the aim for the study was and that participation would be voluntary and would not affect their marks, after which an informed consent form was signed by those who selected to participate. The consent form also stated that their names would be detached from their results, guaranteeing anonymity.

4.2 Fieldwork and data collection

The Tanqua Karoo was visited four different times. The first trip was in 2021, from the 19th to the 23rd of October. The purpose of this trip was to take videos of the field instructor (Dr. De Ville Wickens) introducing the sites to the students. The second trip was also in October 2021 to take multi-image panoramas and Lidar models without the presence of the students as the high-resolution photography is time consuming and would have unnecessarily delayed the excursion. The absence of the expert presented a problem as explained in section 6.5 of the discussion. The third trip was from the 6th to the 10th of June 2022. The goal of this trip was to take multi-image panoramas, Lidar scans, drone images and drone videos. This trip was taken without the presence of the honours class, but under the expert direction of Dr. De Ville Wickens. The fourth trip was from the 11th to the 15th of October 2022. The goal of this trip was to observe how the students interact with the field instructor after being exposed to the Virtual Field Trip. At the end of this trip the students had to sign an informed consent form to give permission on whether they wanted their field report marks to be used for research purposes. They also had to write informal feedback about their overall experience of the virtual field trip and whether it assisted them in the field trip.

4.3 Data types

4.3.1 Multi-image panoramas, 360 images, and detailed images

To create multi-image panoramas, the following equipment is available.

- Canon EOS R5 Mirrorless camera body, which has a 45MP full-frame high resolution sensor.
- Camera lenses for various situations are available to be attached to the Canon EOS R5 camera body:
  - CANON EF 14MM F/2.8 L II Ultra Sonic Motor (USM) (fisheye)
  - CANON RF 50MM F/1.2 L USM (standard lens)
  - CANON EF 100-400 F4.5-5.6 L IS USM II (distance zoom lens)
  - CANON RF 100MM F/2.8 L IS USM MACRO (Macro lens)
  - Canon RF-EF adaptor. This adaptor is needed because the Canon EF mount is a bayonet-style interface used to connect lenses to camera bodies. The EF mount's key advantages are its large diameter (54mm) and short flange distance (44mm), which allow for wide lenses with

rapid Auto-Focus rates (Nickelson, 2022). Flange distance is the distance between the lens mount and the sensor, and it is significant since it dictates how big or compact a camera can be, as well as how fast lenses it can utilize. The RF mount has the same inner diameter as the EF mount (54mm), but a shorter flange distance (20mm) than the EF system, allowing for wider lenses and faster autofocus rates**.** The letter "R" in RF stands for "radio frequency," referring to the fact that these lenses use a different type of autofocus motor than EF lenses. This provides some substantial benefits in terms of focus speed and accuracy (Nickelson, 2022).

- SYRP005 - Syrp genie ii, which is a motorized, remotely controlled panoramic camera head. This head (Syrp) is wirelessly connected to the iPhone X via Bluetooth to control the camera movement by an application called the Syrp app. The App enables the camera to pan to a starting point and endpoint of a panoramic image. To do this, the Syrp requires input of the focal length of the lens and the amount of overlap required to calculate the number of images to be taken and place them in a grid of columns and rows. The different type of lens used depends on the type of detail to be captured.
- iPhone X for the remote control of the Syrp and the Insta360-X-ONE
- E.IMAGE EK61O TRIPOD KIT
- Insta360-ONE-X a camera with two back-to-back 180^0 lenses to capture a 360^0 panorama in one shot.
- Canon XA40 4K is a 4k camcorder with remote microphones and sensor with 21.14MP.
- Mavic 3 Cine drone with a 20MP sensor and an ISO range from 100-6400. It can take still images and videos. The drone comes with a remote controller that controls both the camera drone movements. The two sticks on the remote controller can change the altitude, orientation, speed, and direction of the drone. The remote controller has a touch display screen for settings and preview of what the camera captures. The drone also has buttons that control the record, shutter, zoom and tilt of the camera.

The DJI RC Pro remote controller for the DJI Mavic 3 Cine drone includes a built-in 5.5-inch, 1000cd/m2 high brightness screen with a resolution of 1920x1080 pixels. The DJI

RC Pro has a maximum working time of three hours and offers a variety of aircraft and gimbal controls in addition to customisable buttons. The RC-N1 remote controller that is included with the DJI Mavic shows the video transmission from the aircraft.

To take photographs, the camera is mounted on the Syrp and connected by means of a cable. This combination is subsequently mounted on the E.image EK610 tripod. To take an overview panorama of a site at distance, the Canon EF 100-400 F4.5-5.6 L IS USM II lens is attached to the camera with the Canon RF-EF Adaptor and is set to its required starting and end-points via the Syrp application on the phone.

To take a correct photograph, the following techniques are used; ISO setting, diaphragm setting and shutter speed together to correct the exposure. To ensure that each image has the correct exposure both in shady and light areas , you use HDR.High Dynamic Range (HDR) is a method used by photographers to capture a wide variety of tones in a single image. HDR ensures that detail in the shady areas will be visible and that very bright areas are toned down (Ginn, 2019). The goal is to take numerous images at varying exposures (normal exposed, over exposed and under exposed images) and then combine them using software (e.g. Photoshop and PTgui) to generate an image with the best contrast and clarity possible (Ginn, 2019). Focus stacking is done using the macro lens which has a low depth of focus or when using the telephoto when there are subjects in the foreground of the scene, and multiple images must be taken to have the whole image in focus. To get the right exposure you set the diaphragm to the get preferred setting for the lens used and adjust exposure by manipulating the ISO and shutter speed (Fig. 9), because the higher diaphragm setting increases the depth of focus of the image. It is self-evident that the tripod must be steady during this process. The camera has a focus stacking function and a HDR function, but they cannot be used together. In case they have to be used together you can connect the camera to a Promote Systems Control unit which overwrites the cameras own settings.

To influence the field of depth of an image, an appropriate aperture must be set, and to avoid motion blur shutter speed must be set, and the ISO (International Standards Organisation) configured for graininess (Fig 9). The ISO number affects how responsive the camera sensor is to light, thus regulating the shutter time required for the chosen aperture. The next step is to use manual focus to focus and photograph in various places. Manual focusing ensures that the subject of interest is captured at optimal sharpness and not the shrub in front of it. The number of images per outcrop will depend on the focal length of the lens and whether Focus stacking or HDR are used where several images are taken to get all the different areas of an image in focus or exposed correctly respectively.

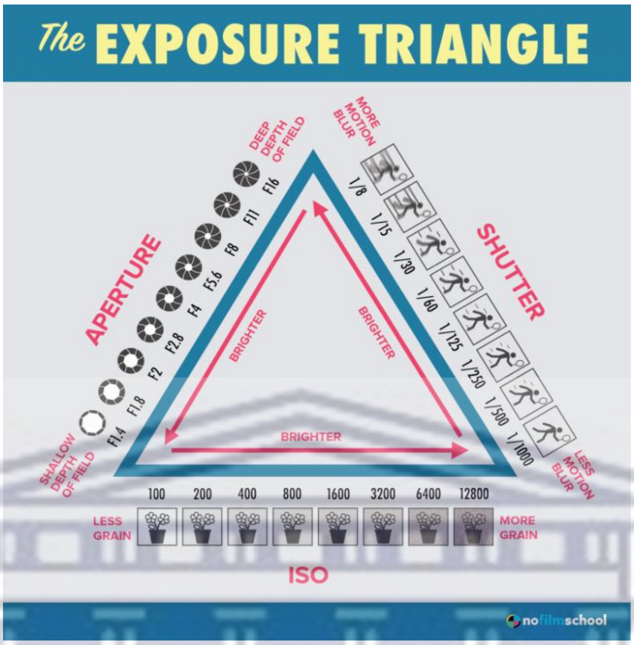

Figure 9. Exposure triangle that summarises the aperture, shutter, and ISO settings.

To take 360^0 images, the Canon camera is attached to the Canon Ef 14 mm F/2.8 L II USM lens or the Insta360-one-X and the camera must be attached to the tripod. The Insta360-one-X camera is connected to the iPhone X via Bluetooth and is controlled by the insta360 application on the phone, whereas the camera is connected to the Syrp with a cable and is set up wirelessly in the phone via Bluetooth to take single images in a $360^o/180^o$ rotation. To take close-up images the Canon camera is attached to the Canon RF 100 mm F/2.8 L IS USM Macro lens. The Canon Rf 50 mm F/1.2 L USM lens is used to take general overview images at low to medium distance.

4.3.2 Videos

The videos were taken using the Canon R5 camera and/or the Canon XA40 4K video recorder (camcorder). The Canon camera was attached to the Canon RF 50MM F/1.2 L USM lens and was handheld. The Canon XA40 4k video was also handheld while videoing and was wirelessly connected to the speaker's lapel microphone. In some situations the camcorder was set up on a tripod for stability.

4.3.3 Drone images and videos

The Mavic 3 Cine drone was used to take all the aerial videos and panoramas. This was done by capturing images at regular intervals while flying past important outcrops in a grid pattern. The photographs were captured in automatic mode by choosing the starting and end points of the areas of interest. These photographs were then imported and combined for panoramas or photogrammetric models using Agisoft Metashape.

4.4 Software

The functionality of the Tanqua virtual field trip was created using a collection of software summarized in the table below. These software packages were run using a windows PC with a 32 GB RAM, with a 64 bit operating system and an Intel(R) Core i7-9750H CPU @ 2.60GHz.

Table 1. Software used to create the final Virtual Field Trip

SOFTWARE	FUNCTION
Paint 3D® (Version: 6.2203.1037.0)	This software package was used to design hotspot buttons and arrows and to annotate pictures with text, lines and colour.
Adobe Photoshop (Version: 24.3.0)	This software package was used to straighten warped panoramas, crop large images and edit images.
DaVinci Resolve 18 (Version 18.0.3)	This software package was used to edit videos.
Pano2VR® (Version: 6.1.13 pro 64bit)	This tool was used to compile all the collected data (images, Lidar models, and videos) to build the virtual Field Trip.
Audacity® (Version 3.1.0)	The platform was used to edit video sounds by removing background noise (wind)
Panorama Tools Graphical User Interface (PTGui) Pro 12.21	The platform was used to stitch individual images to panoramas.
3D Scanner (LiDAR) iPhone 13 pro	The software package was used to render all the Lidar models of the virtual field trip.
Agisoft Metashape (Version 2.0.1)	The software package was used to stitch images from the drone to create panoramas and 3D outcrops

4.4.1 Paint 3D®

This software package was mainly used to create and customize buttons to be imported into the final VFT product that was compiled using Pano2VR®. It was also used to crop and annotate images with appropriate geological information for the final build of the VFT. These annotations include lines, text and colour shadings to clearly mark areas of interest.

4.4.2 Photoshop®

Adobe Photoshop® was used to straighten warped panoramas and fill in white spaces with blue in the skies of the images and to crop images into circles and create transparent backgrounds for certain images.

4.4.3 Audacity

This software package was used to cancel background noises such as wind disturbances from video audios. This was done to have clear audio from the field instructor.

4.4.4 Sketchfab

This is an online platform that was used to render, edit, and host all the "Light Detection and Ranging" (Lidar) products that were produced for the virtual field trip. The 3D models can be rotated and zoomed in by a user. This platform was used to annotate the Lidar models accordingly using information panels and hotspots. This site significantly reduces the resolution of the image.

4.4.5 DaVinci Resolve

When using this platform, media files are imported under File> Import file> Import media or by dragging and dropping media files from 'File explorer'. When the media have been imported, it can be dragged and dropped into the timeline to edit. The videos can be organized and edited in the timeline window. Editing includes trimming, cutting, adding audio, removing audio, adding text, and adding images to the videos.

4.4.6 Pano2VR®

The last step in generating the VFT is to input all of the collected data into Pano2VR. Each site's home page is a 360-degree image that has been marked with hotspots that link to YouTube URLs, website URLs, pictures, and information panels. The hotspots contain geological information or are used as a form of teleportation to a different focus area within a specific site. The geological information is presented in the form of video explanations and/or text form. Each hotspot's properties can be changed to include titles and related details. The YouTube videos are incorporated within the 360^0 environments, while all other links lead to external websites.

The 'Generate Output' button is used to create the VFT final product. The virtual environment's final output is exported as an HTML5 output type with a 'silhouette skin' which is a type of interface and an output folder containing all the data for each site. The silhouette skin enables the output to include buttons at the bottom centre of the screen. These buttons function to zoom in, zoom out, do an automatic 360^0 rotation, view panoramas/pages in the tour, enable fisheye viewer, and to view full screen. The output type is compatible with any browser.

4.4.7 Agisoft Metashape

Agisoft Metasape was used to stitch and generate Lidar models taken by the iPhone and 3D models of outcrop images captured by the drone. The models were processed at the end of each field day. This software package was also used to stitch the captured images to create panoramas.

4.5 Presentations

4.5.1 PowerPoint and Virtual Field Trip presentation

The PowerPoint presentation (Appendix C) was prepared to focus on the key subjects of the study area and diagnostic elements of turbidite systems. The PowerPoint presentation also outlined the outcrops of interest and was presented to the honours class (4th year Geology class) at the HIVE room. The virtual field trip was presented using Google Chrome links. These links were accessed by generating output from the Pano2VR® software.

5. RESULTS

5.1 Collected data and products

The Tanqua Karoo study area serves as an example of an "open air laboratory" of a petroleum system demonstrated by turbidite fans. The nature of these turbidite fans is that they spread out for kilometres and thus the creation of this VFT to demonstrate their lateral extent using seven constructed VFTs. As part of the introductory slides, a Google Earth image (Fig. 10) was used to show the locations of each of the sites. This is to show the spatial relationship between the different sites of the virtual trip.

Figure 10. Google Earth™ image of the Tanqua Karoo area with location pins of all the VFT sites.

5.1.1 360^0 images as landing page

The 360^0 images (Fig.11) were used as introductory landing pages to pan around an area to look at the general overview. These 360^0 images have hotpots (buttons) where you can navigate to the next panorama or information panel. At the bottom middle of each 360^0 images, there is a panel used to navigate between images in each tour, such as multi-image panoramas, 3D models, drone images and videos. Information panels are available to provide geological information where a user can scroll up and down depending on the information available about a specific place of interest.

Figure 11. A screenshot of a 360-degree view of an area with hotspots identified as circled numbers and in this case an arrow also acts as a hotspot leading a user in the direction it is pointed.

5.1.2 Multi image panoramas

The multi-image panoramas are annotated with line drawings and polygons to highlight the important features of an image. Arrows pointing out of the label were used to point at important features in an image and double-headed arrows are used to highlight the extent of individual units or important sedimentological features. These images were annotated with back buttons at the bottom left corner to navigate back to a previous image. At the bottom right corner of a panorama, a next button is carefully placed to navigate to the next image of the trip.

Numbers on the panoramas represent buttons that can be used as a way of navigating the panorama in a sequential form for contextual reasons. For example, the numbers suggest that 1.1 be viewed before 1.2, and 2.1 be viewed before moving to 2.4 to get the context of the tour in the correct sequence. All the panoramas of the trip have a back button to the far left of the screen and a next button on the far right (Fig.12). The multi-image panoramas can be zoomed into using the mouse scroll wheel and/or the + and – in the navigation bar at the bottom of the image, to get a closer look at the details. These navigation buttons at the bottom middle of the screen (Fig. 13) are used to navigate and interact with the VFT. The navigation bar; from left to right are used to zoom in, zoom out, switch on the 360° rotation until stopped, view panoramas in the trip, enable fisheye view, and to view full screen.

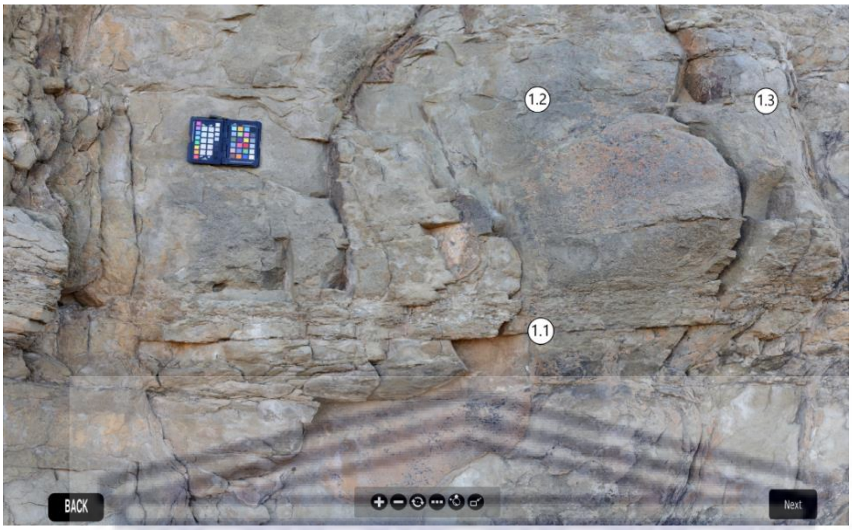

Figure 12. A screenshot from the VFT showing a high-resolution panoramic image of the massive sandstone bed, that is roughly 10 m high, displaying amalgamation surfaces that are clearly described in a video and information panels available when the circled numbers on the screen are clicked. A back and next button are located at the corners of each screen.

Figure 13. The buttons to navigate the VFT are situated at the bottom center of the screen (marked with red rectangle) and are used to (from left to right) zoom in, zoom out, do an automatic 360° rotation until stopped, view panoramas in the tour, enable fisheye view, and view full screen. When the fourth button of the navigation bar is selected (as shown in this figure), it is crossed out and a set of image panels appears above the navigation bar. The image panels with a tick at the top right corner indicate that they have been visited.

5.1.3 3D models

A “3D button” redirects a user to a 3D viewing website (Sketchfab). Sketchfab allows for the Lidar models to be rotated and zoomed for an interactive viewing experience. Information buttons on the 3D Lidar models are placed to view information about the features in question. The Lidar models (Fig. 14) have information buttons where details about a specific model can be viewed.

Figure 14. An example of a Lidar model displaying rip-up clasts on top of a sandstone bed. The number one represents a hotspot that displays a black information panel with white text containing information about a specific feature. These models are hosted in Sketchfab via a button linked to this platform. To exit this platform the user simply needs to close the window.

5.1.4 Drone images and videos

Drone videos show an aerial view of a site and introductory information about each of the sites is available in the videos (Fig. 15). The information shows up as small information panels that pop up at the bottom left corner of the screen for a few seconds. These panels demonstrate the name of the location, rate of deposition, main sedimentary features, and the fans visible at that specific site. The videos can be paused, played, rewound, and fast-forwarded.

Figure 15. A screenshot from the VFT showing an embedded video that introduces the area by highlighting the key sedimentary features of the area as well as depositional environments associated.

5.2 The Virtual Field Trip products

5.2.1 The Unity® game engine product

The original intention of the project was to create a virtual trip using the Unity® game engine, with the concept including a landing site illustrating the relative positions of the various trips, the 360 images, and hotspots of information of interest. However, due to the time required to build scripts for each action, that plan had to be abandoned as there would not be sufficient available time to complete the tour on schedule.

Ultimately, the conceptual framework for the usage of the Unity® game engine was realized through other software packages such as Pano2VR© to complete the virtual trip. Pano2VR© is a 2D platform and does not present the user to an immersive experience like Unity® would have done. Therefore, the final trip does not include an element of the Unity® game engine.

5.2.2 Virtual Field Trip sites

5.2.2.1 Site 1: Ongeluks river

Ongeluks River (https://ikamva.uwc.ac.za/content/VR28Nov2023/Ongeluks2/), located at 32°50'39.58"S 19°58'34.90"E is the first stop of the virtual trip and is the southernmost site of the field tour. This site is used to demonstrate the most proximal part of the turbidite fan (Fig. 16A). The reservoir characteristics in this area demonstrates that turbidite channels are favourable targets for oil and gas exploration because their geometry is easily recognizable on 3D seismic images thus ensuring a high success rate. The channel fills in this area are in hydraulic communication as a result of multiple points, where scour and fill are evident. The preserved thin-bedded inter-channel turbidites and rip-up clast facies create flow disturbances in the channel complex. This outcrop is found at about 400 m away from where the cars are parked. The outcrop is exposed as a 110m high cliff section that trends in an east-west direction and is approximately 8 km wide.

The sediments of this area are of the Skoorsteenberg Formation of the Ecca Group. This part of the study area shows a channel-fill complex (Fig. 16B) and its characteristic geometry and sedimentary features that are typical of a base of slope setting of a turbidite system. The channel-fills are composed of massive, amalgamated fine-to-very fine-grained sandstone bodies that are separated by siltstone or thinner sandstone units that illustrate Bouma divisions. The channel-fills fine upwards and the main sedimentary features found in this area are bypass facies, ripple lamination, massive sandstone beds, parallel laminations (Fig. 17B), scour surfaces, amalgamation, sand stringers and convolute beds (Wickens, 2022).

The channel-fill at the bottom of the complex is composed of a massive, amalgamated sandstone unit that is associated with rip up clasts along the amalgamation surfaces (https://youtu.be/yLxSz9JO4CM) There are thinner bedded sandstone units that show parallel lamination, and ripple lamination found at the base of one of the channel-fills that are overlain by a massive sandstone bed (Fig. 17B). At the base of one of the channel-fills there is a bypass facies (Fig. 17A) that is comprised of claystone rip-up clasts, convoluted bedding, and sandstone stringers. This unit is overlain by a massive sandstone unit.

Figure 16. (A) This outcrop of Fan 3 is found at the upper and middle continental slope of the turbidite sedimentary model (B) An example of a channel complex from the Tanqua Karoo where the red line indicates two channel-fills.

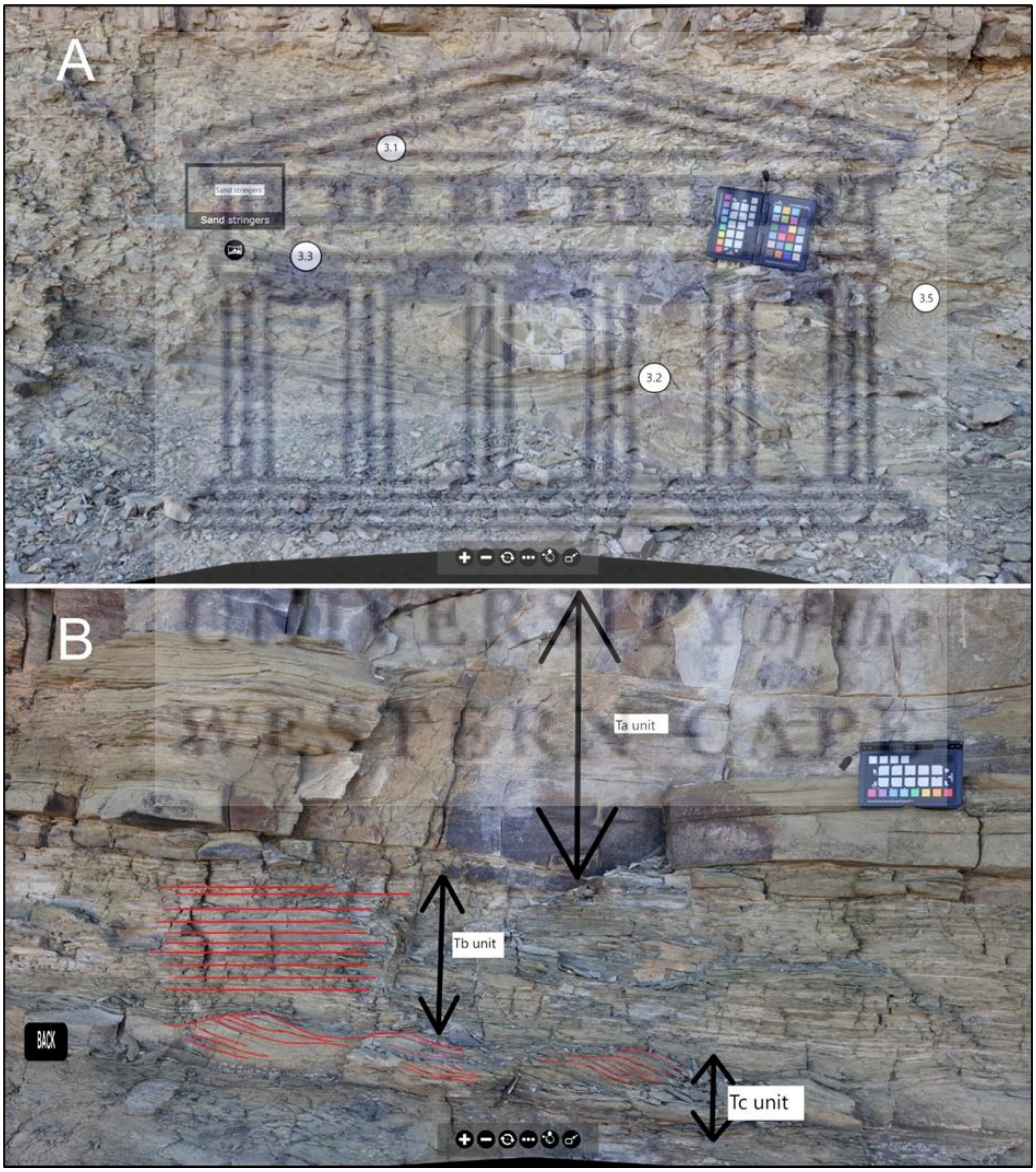

Figure 17. (A) A screenshot from the VFT of a multi-image panorama showing an example of bypass facies as the bottommost layer of one of the channel-fills. (B) A screenshot from the VFT An example of the Bouma sequence at the bottom of one of the channel fills. This is an example of an annotated screen from the VFT to clearly highlight the layers seen and their respective names.

5.2.2.1.1 Digital products

The final digital products at this site include ten multi-image panels, one 360^0 image panel, and two embedded YouTube videos. One video is an explanation of the amalgamation surface that contributes to the massive sandstone bed nature of the channel fill and the other is a drone video highlighting the important characteristics of the area. The 1^{st} image panel is a 360^0 view of the area. The 2^{nd} panel shows a massive sandstone with amalgamation surfaces and one information panel that explain reservoir characteristics of this area. The 3^{rd} panel shows the Bouma divisions, and an extra image shows the annotated image where the 4^{th} panel is an annotated image of the Bouma divisions. The 5^{th} panel shows bypass facies at the bottom of a channel fill and two (6^{th} and 7^{th}) more panels that open up as hotspots from this image. The 8^{th} panel shows an image with a scouring surface and one other image that shows up from a hotspot annotated to highlight the scouring surfaces.

5.2.2.2 Site 2: Kraal

The Kraal (https://ikamva.uwc.ac.za/content/VR28Nov2023/kraal2/) is a stop that is not visited by the students but is made available as a stop in the virtual trip and is not visited because it is not included in the field guidebook, but it is included because it shows good examples of overbank deposits which will be of benefit to the students at other outcrops. It is found northeast of the previous site, 2 km away at 32° 49' 50.7" S, 019° 59' 48.5" E. This outcrop is approximately 100 m away from where the cars park and is exposed as a 10 m outcrop that trends in a northeast-southwest direction. The sediments deposited in this area are that of the Skoorsteenberg Formation of the Ecca Group. This area represents sedimentary features of overbank deposits at the base of slope of a turbidite system (Fig. 18A). This area is characterized by laterally continuous beds of fine to very fine-grained sandstone units with ripple lamination (Fig. 18B).

5.2.2.2.1 Digital products

The final products of this site includes two image panels and information panels with the relevant geological information. One panel is a 360^0 landing page and the other panel shows a multi-image panorama of overbank deposits. There is one information panel that describes the geometry of overbank deposits and the reservoir characteristics of the area.

Figure 18. (A) This outcrop at the Kraal is represented by ripple lamination beds in the turbidite sedimentary model's upper continental plain. (B) A screenshot from the VFT showing ripple laminated sandstone strata that is characteristic of overbank deposits.

5.2.2.3 Site 3: Kleine Riet Fontein

Kleine Riet Fontein is a stop that is not visited by the students because the road that leads to the outcrop is narrow and dangerous for inexperienced drivers. This site is made available in the VFT because it shows good examples of a channel complex, overbank deposits and calcareous concretions. It is situated 10.5 km northwest of the previous location at 32^{o} 46' 48.8" S 019^{o} 53' 45.7" E It is a slope area with relatively flat mountain tops. All the outcrops of interest can only be observed from a distance. (https://ikamva.uwc.ac.za/content/VR28Nov2023/Kleinreitfontein2/).

The sediments of this area represent the Skoorsteenberg Formation of the Ecca Group. This site has four different fans exposed to show the various features that represent different parts of the turbidite system. The observed architectural features in this site are sheet-like deposits and crevasse splay deposits. Fan 1 represents the margins of a fan at a basin floor setting (Fig. 19A) of the turbidite system and shows laterally extensive massive sandstone beds with calcareous concretions. Fan 1 in this area is underlain by hemipelagic shales. The calcareous concretions (Fig.19B) are seen as large, brown ball-shaped features that spread across the sandstone layer Fan 1 is overlain by a hemipelagic shale unit followed by Fan 2 (Fig. 19B)

Fan 2 has an approximate thickness of 40 m and shows sheetlike, amalgamated sandstone beds that are separated by thin shale units and is representative of the proximal parts of a fan at a basin floor setting (Fig. 19B).

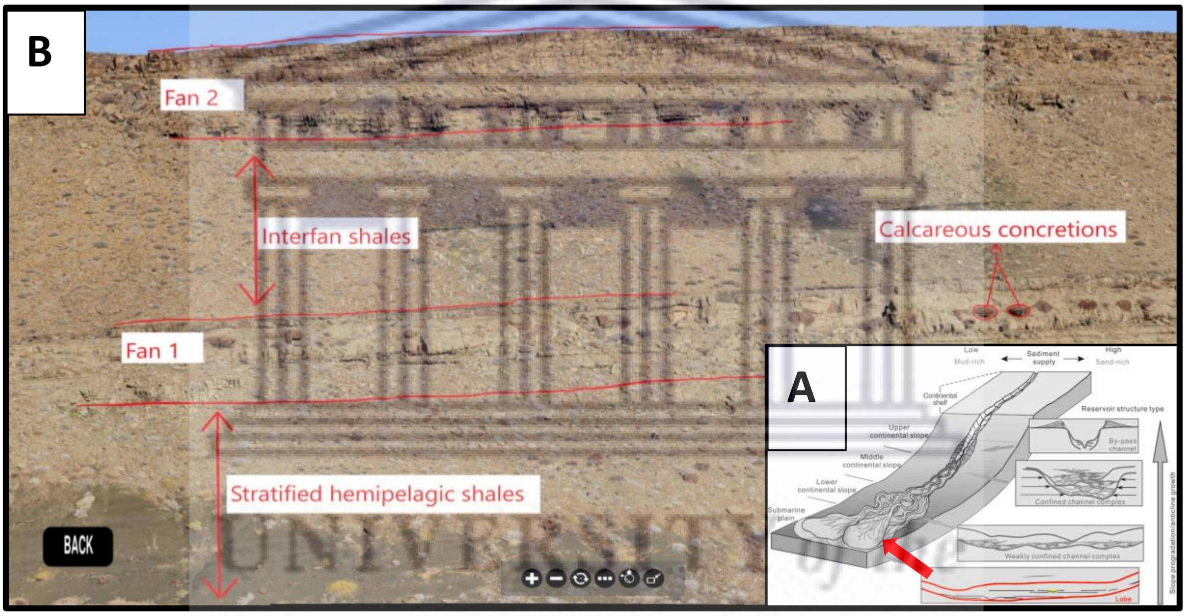

Figure 19. (A) This outcrop shows Fans 1 and 2 that are characterized as lobes located on the turbidite sedimentary model's submarine plain. (B) A screenshot from the VFT shows Fans 1 and 2 as tabular sandstone units, which are characteristic of lobe deposits seen on the sedimentary model's submarine plain. Fan 1 features calcareous concretions along the sandstone unit, indicating fan margins.

Fan 3 (Fig. 20B) is approximately 45 m thick and shows overbank deposits that are represented by tabular sandstone bodies that are dominated by ripple-laminated sandstone beds. The bases and the tops of the units in this area are well defined. This fan is divided into three depositional units, where the lower unit shows thin-to-medium bedded sandstone associated with massive sandstone and the middle layer shows alternating silty sandstone and shale while the upper unit has an upward fining trend.

Fan 4 (Fig. 20B) shows weakly developed sheet sandstones that are characteristic of a heterolithic package of alternating thin to medium bedded turbidites and shows channel-fills. The channel-fills are stacked to form a channel complex. These channel-fills show several erosive scours claystone rip-up clasts, and thick bedded amalgamated Ta beds (Wickens, 2022).

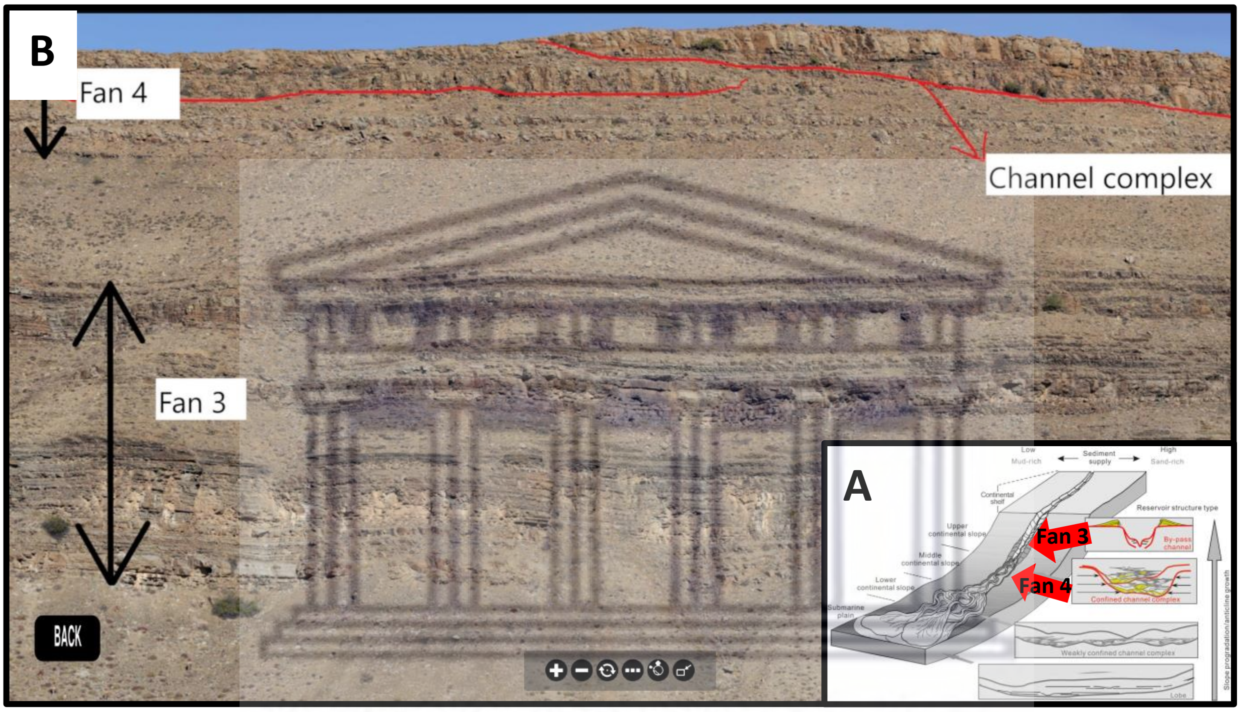

Figure 20. (A) This outcrop shows Fans 3 and 4, found on the turbidite sedimentary model's upper and middle continental slopes (also refer to Fig. 7). (B) Fan 3 is represented by ripple-laminated sandstones, which are typical of levee deposits found on the sedimentary model's upper continental slope, and massive sandstone strata, typical of channel complexes on the middle continental slope, characterize Fan 4.

5.2.2.3.1 Digital products

This site has six image panels and several information panels highlighting the main geological features in this site. The 1st image panel is a 360° view landing page with another panel linked to it via hotspot to show an image with two information panels and an additional image panel that shows an annotated image of the fans that are visible in this area. The 3rd panel is a 360° landing page that shows a different part of the site to show with two additional panels where one shows the different fans at this point and the other is an annotated image.

5.2.2.4 Site 4: Loskop

Loskop (https://ikamva.uwc.ac.za/content/VR28Nov2023/Loskop2/) is 10.9 km northeast of Kleine Riet Fontein at 32°43'21.02"S 19°58'5.10"E. This outcrop is exposed as a 295 m high mountain with a relatively flat top. The 4x4 vehicles park 400m away from the outcrop.

The sediments of this area form part of the Skoorsteenberg Formation of the Ecca Group. This site represents an area of transition from Channel-fills to bedded successions which represent mid-fan transition to outer-fan elements. The main features observed at this site are Channel-fills and Sheet elements (Wickens, 2022).

The bottom layer of this outcrop is composed of a hemipelagic shale unit that is overlain by a narrow sandstone channel-fill of Fan 2, shown in Figure 21B by the number 1.1 as a sandstone layer that extends laterally. This fan is overlain by a shale unit which in turn is overlain by massive, amalgamated sandstone beds of Fan 3 at the axis, which laterally change into more bedded successions towards the margins (Fig. 21B and 22A), hence it represents an area of transition from channelized to non-channelized deposits. These bedded sandstone units are separated by silt and shale units (Fig. 22B).

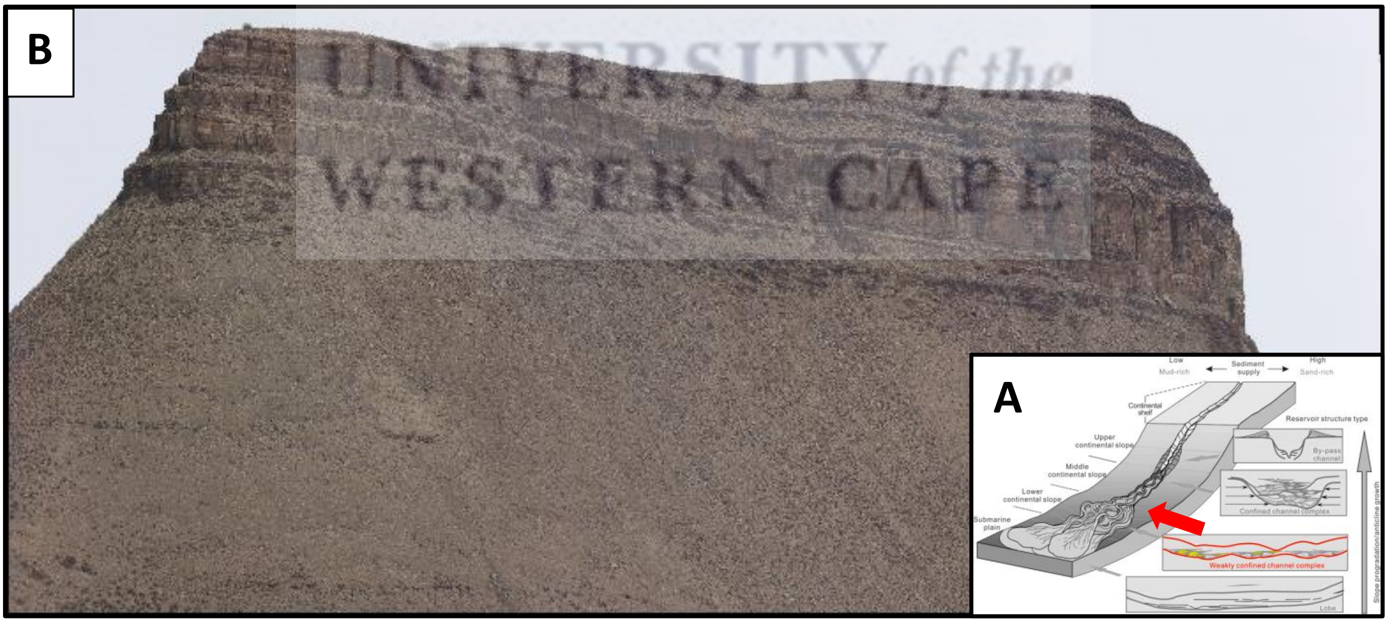

Figure 21. (A) This outcrop shows Fan 3 at Loskop and is represented by a weakly confined channel fill that changes into tabular sandstone units at the off-axis and are located at the lower continental plain of the turbidite sedimentary model (also refer to Fig.7). (B) This area is characterized by a channel fill that transitions into a more tabular bedded sandstone as one proceeds away from the axis, as is typical of a transition zone between channelized and non-channelized deposits.

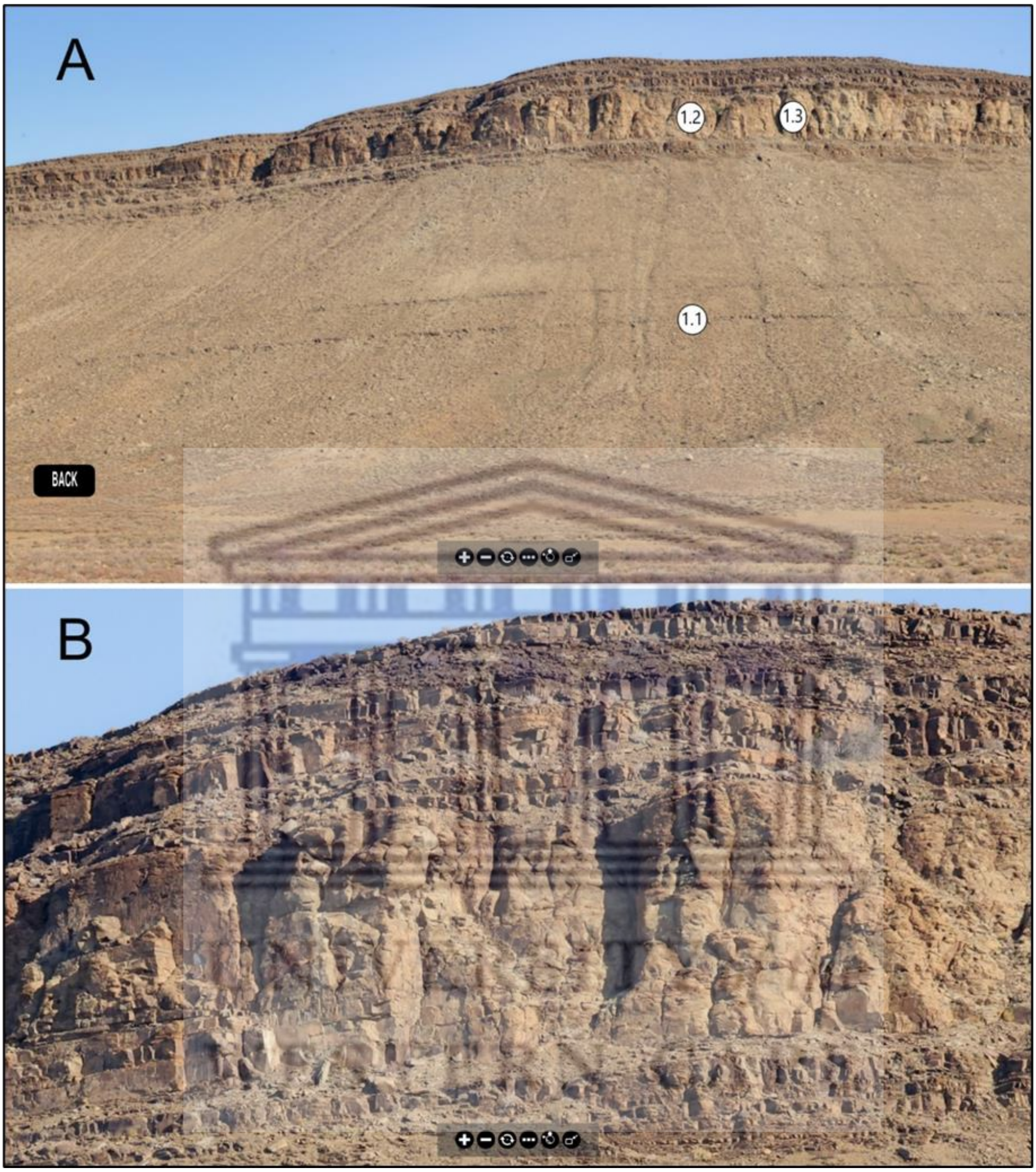

Figure 22. (A) A screenshot of Loskop from the VFT showing an annotated high resolution multi-image panorama. This is a transition zone, with a channel-fill of massive, amalgamated sandstones changing into more tabular sandstones farther from the axis. (B) The image illustrates the VFT's zooming capabilities for examining the geometry of the units in greater detail.

5.2.2.4.1. Digital products

The product in this area includes 3 image panels. The first of the panels is a 360^{o} landing page, and the other two image panels show an outcrop of a transitional zone and an annotated version of the outcrop. There is an information panel that describes the architecture of the area.

The one panel contains two information panels that describe the architecture of the different fans shown in this area (accessed through 1.1 and 1.2 in the VFT here shown in Fig 21A). The 3rd panel shows an annotated version of the outcrop.

5.2.2.5 Site 5: Rondavel

This site (https://ikamva.uwc.ac.za/content/VR28Nov2023/Rondavel2/) is located 11 Km away from the previous site in a northeast direction at (32°39'47.53"S 20° 3'46.11"E). It is an area located at a dry riverbed where the outcrops are stacked at one side of the riverbank. This area is dominated by lobe deposits of Fan 3.

The sediments of this area represent the Skoorsteenberg Formation of the Ecca Group. This outcrop represents lobe deposits that are found at the most distal part of a submarine fan system. The observed geometry at this locality is the sheetlike nature of lobe deposits. The main sedimentary features are scouring, flute marks (Fig. 23D) amalgamation, loading (Fig. 23C) and rip-up clasts.

The eastern outcrop is characterized by a shale layer that is overlain by sheet-like/ tubular non-channelised sandstone bodies known as a lobe (Fig. 23B). The bottommost sandstone layer (lobe element) that is in contact with the underlying shale, consists of loading structures and flute marks (Fig. 23D) visible at the base of the unit (Wickens, 2022). The overlying sandstone lobe deposits are separated from the underlying sandstone bodies by a thin shale unit. Some of the sandstone units show rip-up clasts.

The bottom layer of the western outcrop shows a sandstone layer that is overlain by a shale unit. This shale unit is overlain by tabular sandstone bodies (lobes) where the uppermost sandstone layer shows amalgamation**.** An outcrop that represents lobes of Fan 4 shows a succession of hemipelagic shales at the bottom of the succession overlain by a sandstone unit of Fan 4. This area represents the most distal parts of a fan at a base of slope setting.

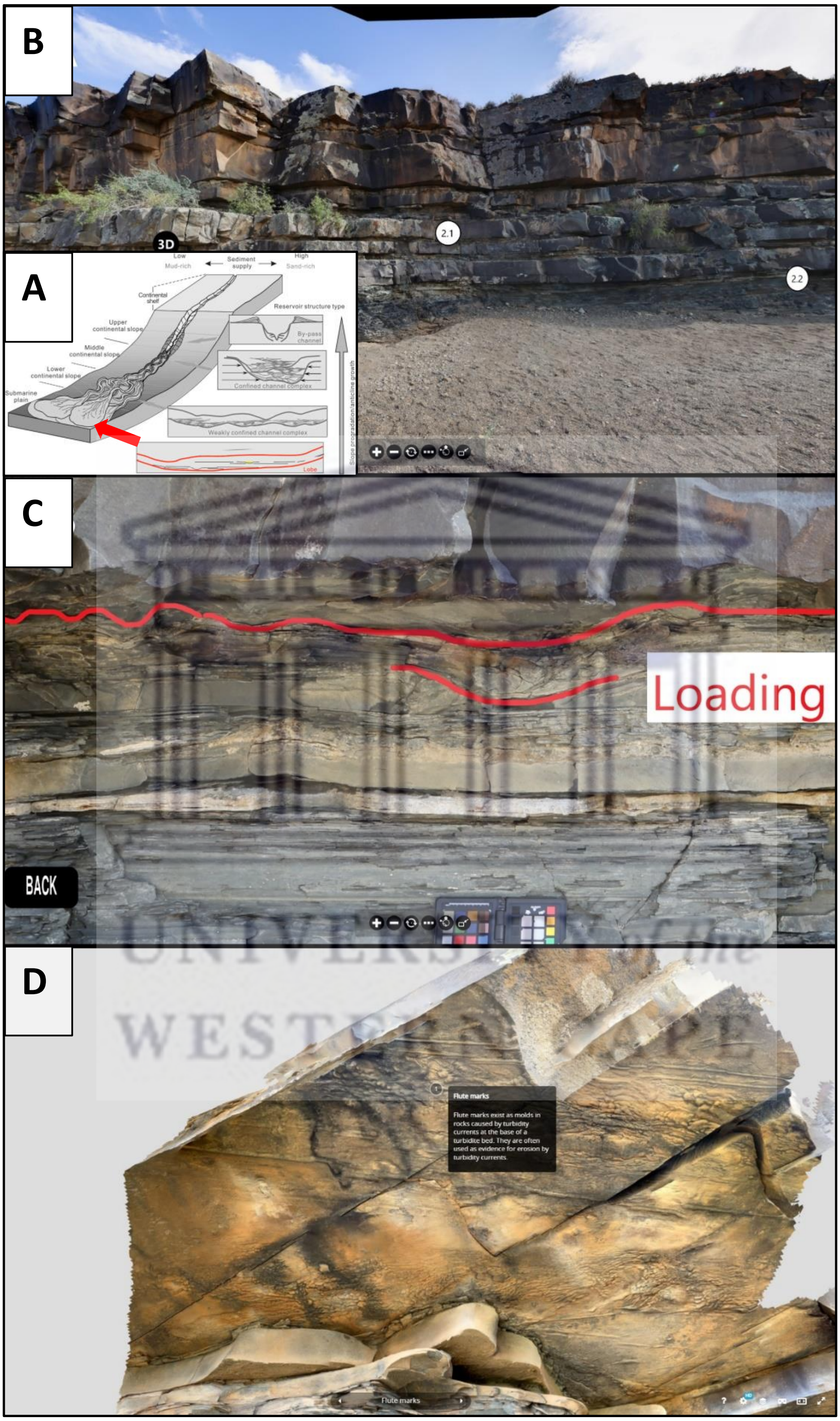

Figure 23. (A) The outcrop at Rondavel is represented by lobe deposits on the submarine plain of the turbidite sedimentary model. (B) A screenshot from the VFT showing a multi-image panorama of the Rondavel area demonstrating the geometry of lobe deposits. (C) Loading structure is illustrated as an example of a sedimentary feature generated when dense units overlie less dense units in this part of the fan system. (D) A lidar model showing flute marks found at the bottom of the sandstone unit is highlighted by the 3D button in the image. The lidar model is labelled with a number that, when clicked, opens an information panel as shown in this figure.

5.2.2.5.1 Digital products

The digital products in this area include ten image panels, one drone video highlighting the geological characteristics of the area, one Lidar model and several information panels. The Lidar images were processed in the field and all the other data was processed at the university. The 1st of the panels is a 360° view landing page of the area, with one youtube video embedded to highlight the architecture of the lobe deposits and one other image panel available via a hotspot showing the Visgat area with its lobe deposits and an additional annotated image panel of this particular site. The next set of panoramas shows the rondavel area lobe deposits. The 4th image panel shows lobe deposits and two annotated additional panels connected via a hotspot showing the architecture of lobes and another image that shows the sedimentary model. The 8th panel shows another side of the area with lobe deposits with two other annotated panels connected via hotspots and an information panel that explains the characteristics of the fan.

5.2.2.6 Site 6: Skoorsteenberg

Skoorsteenberg (https://ikamva.uwc.ac.za/content/VR28Nov2023/skoorsteenberg2/) is found at 32°34'28.92"S 19°58'48.22"E and is located 12.6 km away from Rondavel. In this area, cars park in front of the mountain and this parking spot is a good position to look at the general overview of the outcrops of interest. This outcrop is a well exposed 250 m high mountain.

This area illustrates three different sections of a turbidite fan system, namely: the pinch-out area, mid-outer fan sheets and transitional elements as well as base of slope setting. At Skoorsteenberg, Fans 3, 4 and 5 are observed (Wickens, 2022).

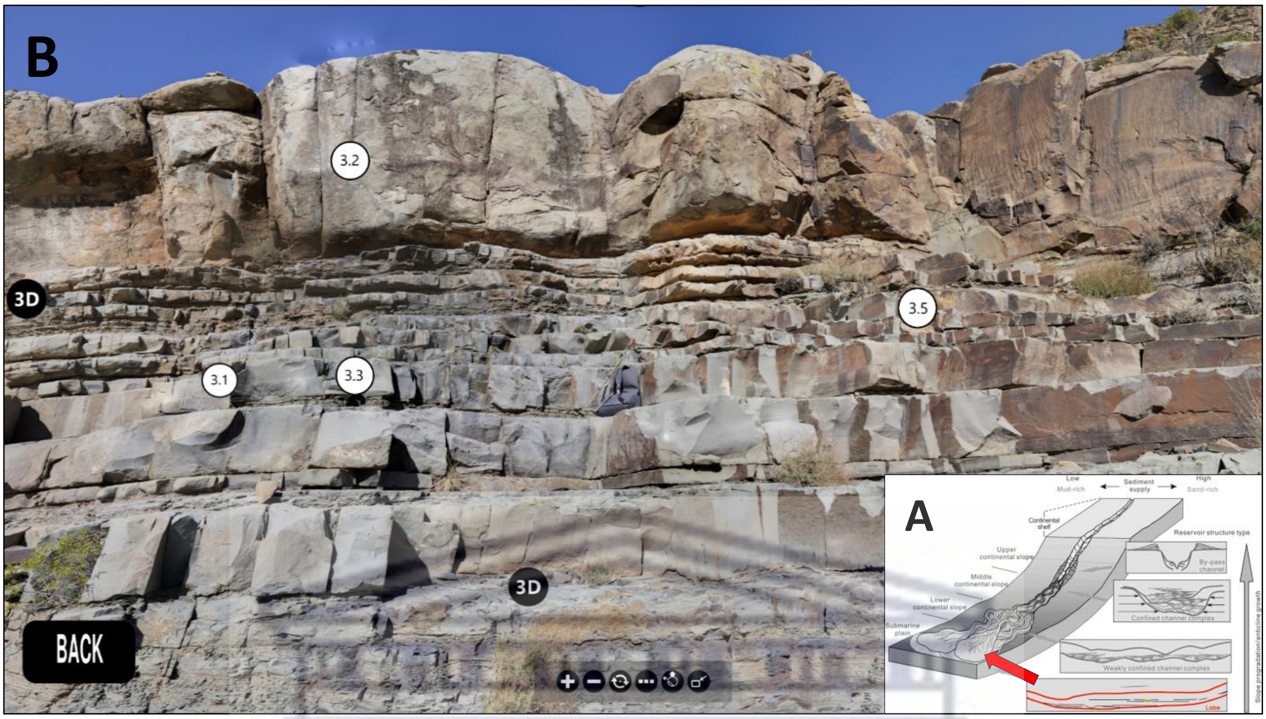

Figure 24. (A) The outcrop of Fan 3 at Skoorsteenberg is represented by lobe deposits on the submarine plain of the turbidite sedimentary model (also refer to Fig. 7). (B) A screenshot from the VFT showing an example of lobe deposits in an area of low confinement.

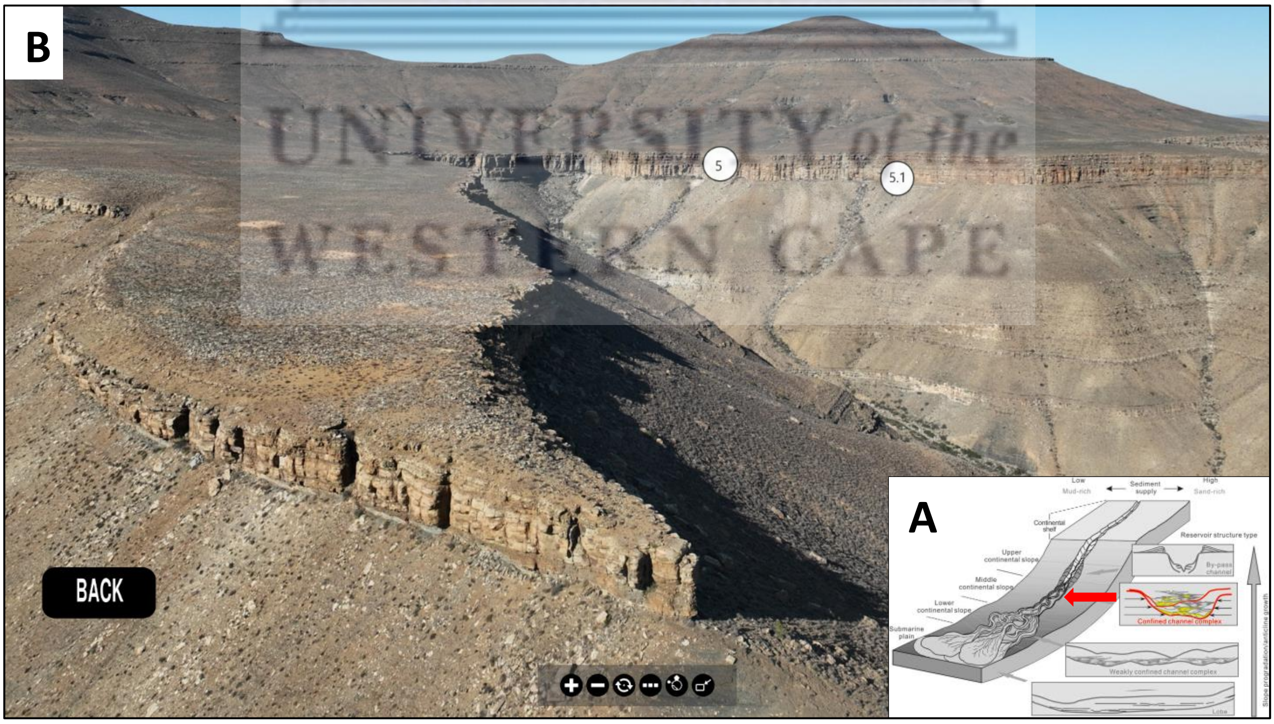

Figure 25. (A)The outcrop at Fan 5 of Skoorsteenberg is represented by a channel-fill located at the upper and middle continental plains of the turbidite sedimentary model. (B) A VFT screenshot showing a channel-fill, indicated by the circled numbers in the image.

At this outcrop, there are hemipelagic shales that consist of interbedded laminated-to-massive mudstones and thin siltstone beds that are overlain by turbidite sandstones of Fan 3. The hemipelagic shales below Fan 3 contain calcareous concretions (Fig. 26A) and weathered tuff beds. Fan 3 is composed of hybrid beds (Fig. 26B), massive, amalgamated sandstone beds and tabular sandstone beds that are separated by siltstone and shale units. Some of the sandstone beds of Fan 3 contain rip up clasts (Fig. 26C) and debrites (deposits formed by debris flows (Fig. 26B). Fan 3 in this area has a net to gross ratio of 83% (estimate of the storage capacity of the formation) (Wickens, 2022). This is overlain by mudstone lithofacies that are overlain by turbidite deposits of Fan 4. Fan 4 is characterized by sheetlike sandstone beds that represent mid-to-outer fan sheet elements. Fan 4 is separated from Fan 5 above by a rhythmic succession of thin bedded sandstones and siltstone lithofacies. Fan 5 is characterized by channel fills which represent a base of slope setting. This fan shows two channelling styles that include channel scours with massive sandstone beds and channel fills with thin-to-medium bedded heterolithic bedding (Wickens, 2022).

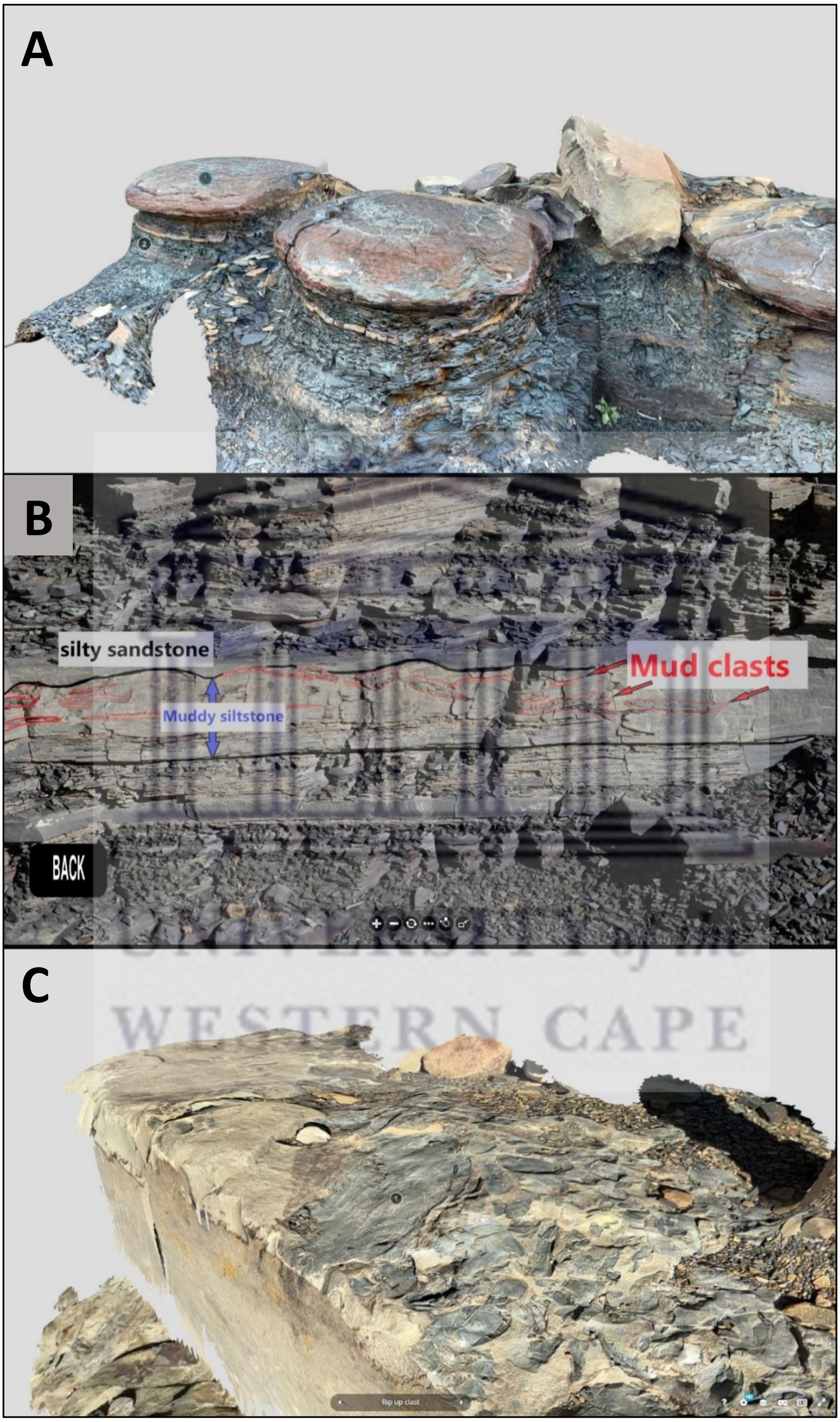

Figure 26. Screenshots taken from the VFT. (A) an external link to a lidar model of concretions as one of the sedimentary features identified in the area. (B) A hybrid bed containing key identifying elements highlighted by lines and word labels. (C) A lidar model of rip-up clasts on the surface of a sandstone bed.

5.2.2.6.1 Digital products

This area has 15 image panels including drone images and a 360° landing page, one drone video highlighting the key geological characteristics of this area, four Lidar models, and several information panels. The 1st image is a 360° view of the area with two hotspot that lead to an embedded youtube drone video that shows the general characteristics of the area and the other hotspot leads to an image that highlights the fans in the area, an information panel that describes the characteristics of this area and an image that shows the sedimentary model. The 3rd and 4th image panels show calcareous concretions with an information panel and a button leading to an external link that shows a Lidar model. The 5th image panel shows lobe deposits with three links that lead to Lidar models that show dewatering structures, rip up clast and a 3D outcrop of the area. This image panel also has two information panels describing the architecture and reservoir characteristics of the area. One more panel linked to the previous panel shows a close image of the outcrop with an additional panel that shows a linked debrite. This close-up image has one information panel and two image panels that highlight the linked debrite in the outcrop and the other shows an illustration of a linked debrite from a model. The 11th image panel has two information panels describing the fans in the area and three image panels that highlight the different fans by annotated images and a sedimentary model.

5.2.2.7 Site 7: Kanaalkop

This site (https://ikamva.uwc.ac.za/content/VR28Nov2023/kanaalkop2/) is found at 32°46'2.00"S 19°55'34.62"E, 22 km away from Skoorsteenberg. The outcrop at this area is exposed as an amphitheater showing where the beds are deposited in a laterally continuous manner.

The general architecture of this area represents lobe deposits of a deep-water sedimentary system. In this region, sandstone lobes predominate and are alternated by thin layers of shale units. Amalgamation, scouring and thinning out of beds are some of the sedimentary features found in this area. Although this location shows Fans 1, 2 and 3 this stop is included because Fan 2 shows amalgamated sandstone bodies (Fig. 27B) and shale units while Fan 3 shows a channel-fill and overbank deposits (Fig. 27B).

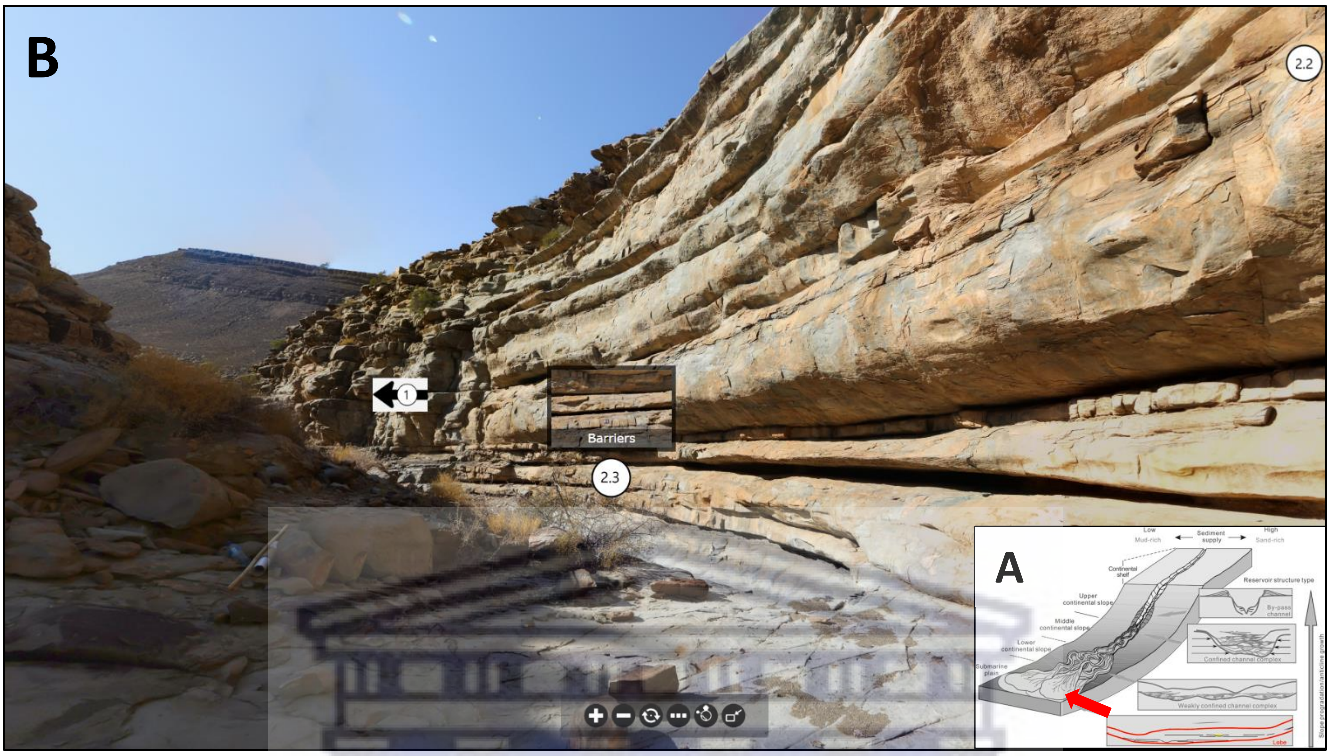

Figure 27. (A) The outcrop shows fan 2 of Kanaalkop, represented by lobe deposits on the submarine plain of the turbidite sedimentary model. (B) A screenshot from the VFT showing an example of lobe deposits in an area of low confinement. The image showing above the circled number (2.3) is a preview window that shows when the cursor hovers over the hotspot.

Fan 2 (Fig. 28B) in this area is approximately 30 m thick and is represented by a hemipelagic shale unit that is overlain by non-channelized massive, amalgamated sandstone beds. The sandstone in this area possesses a light brown to yellowish colour. Some of the sandstone beds show scour surfaces and thinning out of beds. The amalgamation surfaces are found between the sandstone units. These amalgamated sandstone beds change into bedded tabular sandstones that are separated by thin shale units. This fan is overlain by a shale unit that separates it from the overlying Fan 3 (Wickens, 2022).

Fan 3 (Fig. 28B) is approximately 50 m thick and begins with truncated and eroded ripple laminated strata that is overlain by a channel-fill. Towards the margins, the channel-fill gradually changes into thinner bedded parallel laminated sandstone beds that alternate with shale beds. The upper part of Fan 3 consists of alternating thin-to-medium bedded sandstone beds, siltstone, and shale with climbing-ripple lamination.

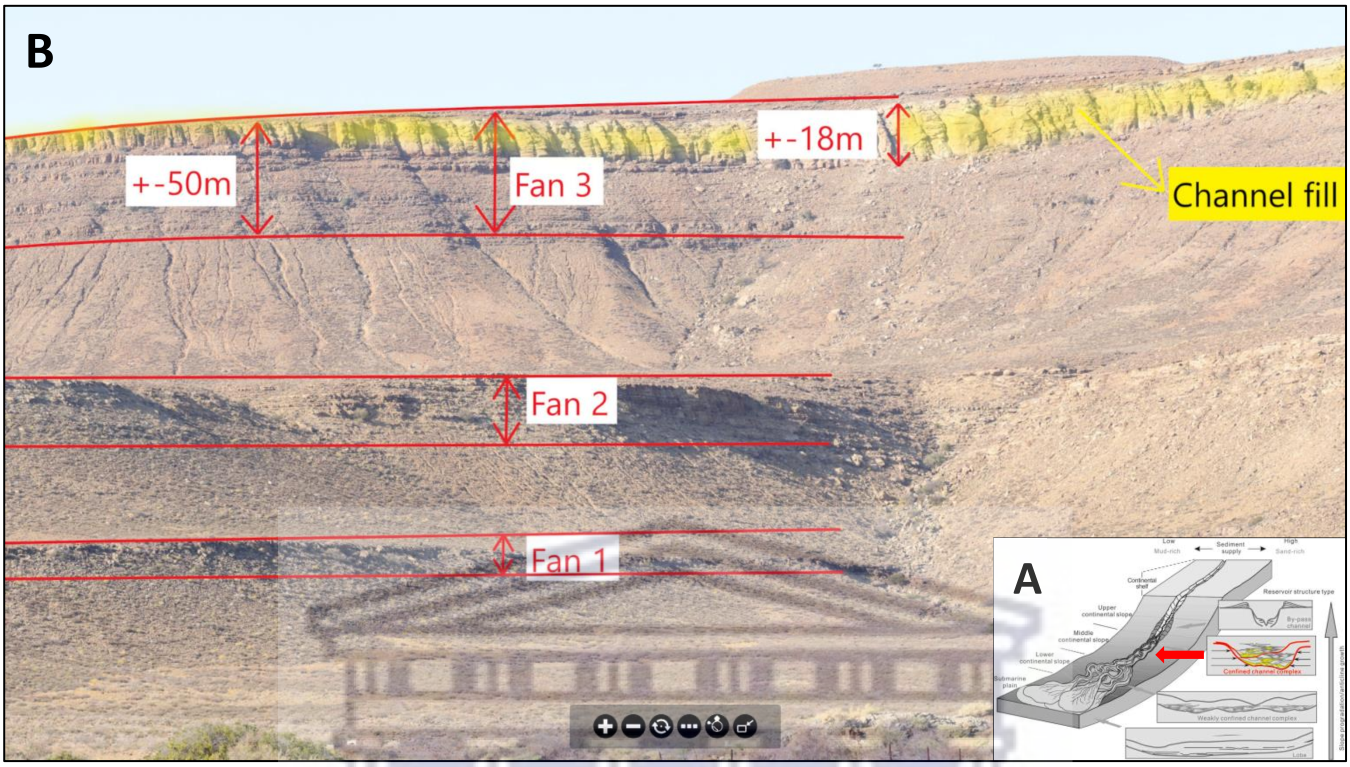

Figure 28. (A) The outcrop shows Fan 3 of Kanaalkop, represented by a channel fill located at the upper and middle continental plains of the turbidite sedimentary model. (B) A screenshot from the VFT shows Fans 1,2 and 3, where the channel-fill highlighted in yellow forms part of Fan 3.

5.2.2.7.1 Digital products

There are seven image panels, one drone video highlighting the main geological characteristics of the area, one video where the field instructor explains the sedimentary features of the area and several information panels relevant to the images. The first is a 360° landing page of the area with one information panel describing the geometry of the units and two video hotspots where one video is a drone video showing the characteristics of the area and another is a video that explains the specific sedimentary features seen in the area. The next image panel is 360° view of an amphitheatre with three hotspots that show an information panel describing amalgamation, and annotated image showing the feature; and a third image that shows hemipelagic shales.

5.3 Presentation of the VFT to students

The PowerPoint presentation and Tanqua Karoo VFT were given on the 10th of October 2022 to a group of 18 people at the HIVE (Highly Immersive Visualization Environment) venue at the University of the Western Cape (UWC). The audience consisted of 10 UWC honours students, three University of Fort Hare guests, three UWC lecturers and two petroleum industry professionals. This presentation was given during the afternoon around 1 pm after two presentations that were given by the industry professionals. The virtual field trip was presented via a html link from a laptop.

The presentation was done on a Monday after a weeklong course that focused on deep water deposits to familiarise the students to the topic of turbidites. The field trip commenced on the 11th of October 2022, which means that the VFT was presented one day before the field trip. The virtual trip presentation was originally scheduled to take place a week before the physical field tour, but it was moved to Monday to the day before the physical tour because of the lecture series over running its time. As a result, the VFT was presented the day before the start of the excursion. The change in plans was prompted by the coordinator's decision to include external speakers who were not originally planned for, which meant that they would have to appear on the same day as the virtual field trip presentation. This meant that the students would not have access to the virtual trip to familiarise themselves with the various elements they would be shown in the field. The total presentation of the PowerPoint and Virtual Field Trips lasted for approximately two hours.

This presentation was given to introduce the facies and the geometries of turbidites that are most suitable for reservoirs. This presentation reinforced the content presented by the guest lecturers. The PowerPoint presentation demonstrated the key architectural styles of the study area in correlation to a sedimentary model of a turbidite. The sedimentary model of a turbidite system was used to demonstrate where the different sedimentary features of the turbidites are found. The slides included a Google Earth map of the sites that were to be visited to give an indication of the scale and locations of the sites. A slide showing seismic images of buried fan systems was presented to demonstrate what turbidites look like in seismic images**.**

At the end of the of the presentation, the audience was given a review form to anonymously comment on their overall experience of the PowerPoint and virtual trip presentation and 11 attendees filled in the forms. The questions are summarized in Appendix D. They were asked about the adequacy of the representation, image resolution, assistance in preparing for a real excursion, and suggestions for improvement. The responses are as follows:

- Participants 1 to 11 generally found the VR trip to adequately represent the field area, with good image resolution and helpful assistance in preparing for the real excursion.

- Participant 4 suggested improving the tour by making it more correlated, comprehensive, and preferably in a single video showing different areas of interest.
- Participant 5 suggested improving the resolution to show sedimentary structures.
- Participant 6 recommended creating more videos explaining the fans and adding slides for formations.
- Participant 9 suggested giving a talk two days before the trip to help students prepare better.
- Participant 11 proposed showing a map first to indicate the locations of different VR outcrops.

Overall, most participants had a positive experience with the VR trip, with some offering constructive suggestions for improvement.

5.4 Field school

At the beginning of the field school, the students were introduced to the regional geology of the area by the field instructor (Dr De Ville Wickens of Georoutes). There were nine stops made at the important sites to introduce all the sedimentary features to observe. The students were given tasks to complete at some of the stops. The tasks included outlining the different architectural styles in panoramas as well as predicting gamma ray logs at certain sites. These tasks were led by the field instructor with the assistance of the petroleum industry professionals and UWC lecturers as well as senior students present.

The virtual field trip was rerun in the mornings of each day spent at the Tanqua Karoo to jog the students' memory and re-enforce what they had seen the previous day. At the end of the field trip, the students were given informed consent forms that needed signatures and permission to whether they allowed their field report marks to be used as part of the research.

5.5 Student results from 2021 and 2022

The 2021 class had 15 participants (Appendix E) and their average pass mark for the field report was 65%, with a maximum of 94 %, a minimum of 46 % and a standard deviation of 12.6 summarized in Table 2 and Figure 28. The 2022 class had nine participants (Appendix E) and their average pass mark for the field report was 78%, with a maximum of 90 %, a minimum of 65 % and a standard deviation of 7.5. It is to be noted that the standard deviation decreased significantly between the two groups and that the minimum increased significantly from 46% to 64%. This information is summarised in Table 2 and Figure 29.

Table 2. Comparison of the 2021with VFT vs 2022 without VFT assessment marks.

Year	Average	Max	Min	St. Dev
2021	65	94	46	12.6
2022	78	90	64	7.5

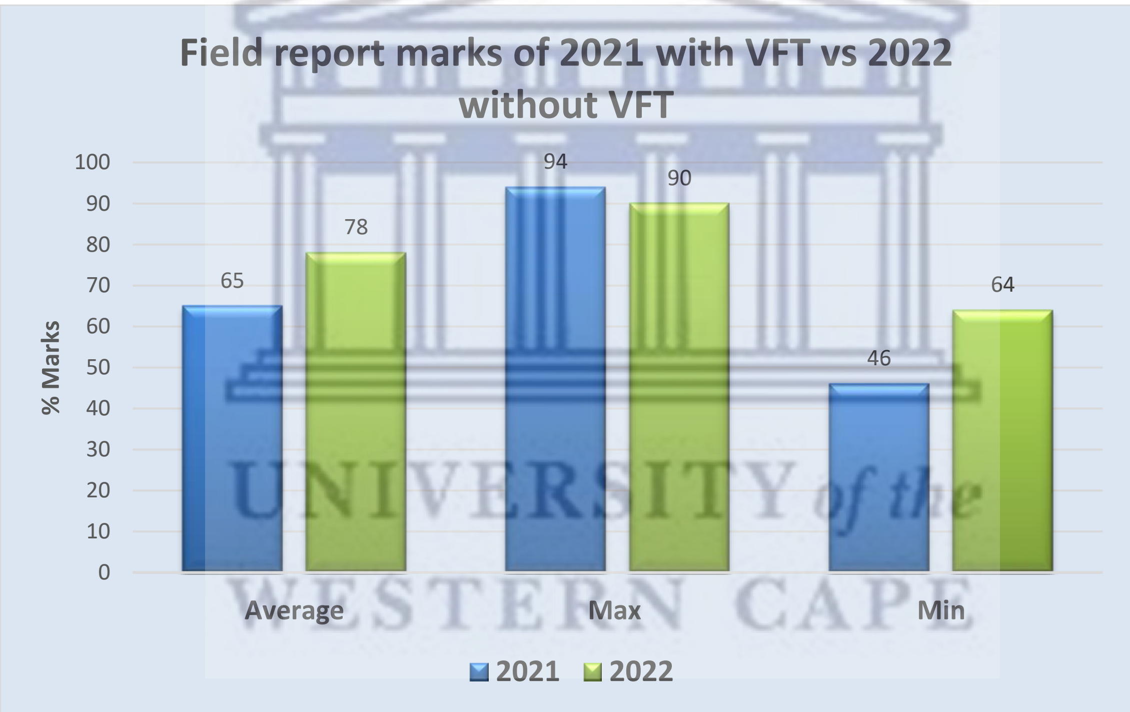

Figure 29. Assessment marks for the two groups of students.

5.6 Feedback from the 2022 students after the field trip

After the students had signed consent forms for their data to be used, they were asked to write reviews on the overall experience of the field school and how they felt the VFT helped. Their comments are summarized in the discussion under the “student reviews and response to the VFT” subheading and Appendix D.

6. DISCUSSION

This study looked at the type of work that goes into creating a Virtual Field Trip and evaluated the effectiveness of having it presented to the students before they embarked on a physical field trip. It was furthermore undertaken to establish whether software can be used to construct a successful VFT that is suitable for teaching purposes. The final VFT product was successfully produced and presented to the target audience (4th year geology students) and contained the necessary geological information at various sites of the study area.

This VFT helped in correlating theorical models such as the Bouma sequence model to outcrops in the area. The VFT was able to demonstrate the scale of the area and highlight the important features to note at each location. Students were able to ask questions during the presentation which encouraged engagement with the VFT.

The seven VFTs vary in size as a result of the amount of information and detail that is available at each site. Sites with multiple geometries and sedimentary features to display thus resulted in larger products with a lot more information offered by various sources of data, such as 3D Lidar models, panoramas, drone films, and explanatory videos. All of the information provided in the VFT was taken from the field guidebook (Wickens, 2022) that the field instructor provides for the students. It is important to have the VFT readily available via link for the shareability of information and cross education.

6.1 Data collection and final products

Before the commencement of data collection an ethical and university clearance had to be obtained to conduct surveys and questionnaires at the end of the VFT presentation. It took 14 field days over a period of three weeklong field trips to photograph over 1000 images. Five of those days were wasted on trying to find the sites because of the absence of the field guide. It was therefore noted that it is important to have a person who knows the study area to accurately find the areas of interest to save time trying to find all the sites and avoid getting lost. It also helps to record field notes of every single detail of the images taken in the field to avoid confusion when compiling all the data. Another important factor of data collection is being fully aware of the targeted areas to capture relevant geological information.

The time of day and weather conditions play an important role in the quality of the photographs taken, because of the quality of the light and the harshness of shadows as the latter will determine if one needs to use HDR which takes more time that direct photography. When the outcrop is fully exposed to the sun without the contrast of sharp shadows, photographing on a sunny day might be beneficial. A sunny day might also indicate that an image contains sections with shadows where features cannot be seen due to the high contrast. A gloomy day can also mean that an outcrop can be photographed without having harsh contrasts and therefore producing a good quality image. The scale of the area affects travelling time between outcrops which limits the number of outcrops per day for photography. This implies that it may not be possible to revisit a site if during the quality assurance of the images in the evening it is found that certain images need to be retaken. This therefore necessitates an additional field trip and explains why three trips were needed.

The final VFT is stored in the university teaching platform called Ikamva. All the VFT links are stored under the relevant module.

6.2 Student reviews and response to the VFT

There were mixed views on how the students felt and interacted with the VFT. The review comments made on the virtual field trip gave a positive response from the students where a majority of them found the VFT useful, while some felt like more could have been added. The comments showed that some students remembered aspects of the VFT when in the physical field tour as one student had commented " The use of the virtual trip before actually visiting Tanqua karoo has aided me in the identification and recognition of geological features" and another commented "I would have liked if a few more outcrops are taken, but I've learned a few things from the virtual trip such as I was able to recognize the concretions in the field area because she showed them to us on the virtual trip, such things like that". This was helpful in promoting the students' interest of the different sedimentary features seen in the field. This agrees with a study by Nix (1999) that suggests that VFTs are supposed to provide students with more opportunities to acquire scientific abilities such as observation, inference, prediction, comprehension, and problem solving.

Students highlighted the following benefits:

1. Enhanced Preparedness: Students mentioned that the virtual trips provided them with a comprehensive understanding of the Tanqua Karoo region, including its morphology, lithospheric units, sedimentary structures, and associated interpretations. This preparation

enabled them to have a clear "big picture" understanding of the area prior to the field trip (Students A, E, F).

2. Introduction to Geological Concepts: The virtual trips introduced students to important geological concepts, such as the identification of turbidites and concretions, which would have been difficult to grasp solely through field observations (Students B, D, F).

3. Visual Aid: The visual presentations, including images and videos, were highly appreciated as they allowed students to better understand and remember geological features. Students found it particularly helpful when unfavourable weather conditions hindered their ability to view outcrops in person (Students C, E).

4. Suggestions for Improvement: While the virtual trips received positive feedback, there were suggestions for improvement. These included enhancing the resolution and clearly outlining the limitations of the virtual tool (Student A). Additionally, students recommended providing them with readings and pictures to familiarize themselves with the structures before the field trip (Student C). Some students also expressed a desire for more outcrops to be represented using Lidar and more drone footage to enrich the virtual experience (Student H). Picture quality and aligning geological maps with pictures were also identified as areas for potential improvement (Student I).

Overall, the virtual field trips played an important role in enhancing students' preparedness and understanding of the Tanqua Karoo region, but there is room for improvement in terms of resolution, content alignment, and incorporating student narrations to further enhance the experience.

The students were guided through the VFT only once, limiting the time to carefully study each site, but the repetition of certain sedimentary features at the different sites made the students remember the key features when they got to the field. One natural synergy between VFTs and physical field tour is to assign an VFT prior to the physical field tour to familiarise students with the surroundings and content of the trip but in the case of this research there was limited time to repeat visitations to the field sites. To mitigate the limited time the students had with the virtual field trip, the tour was presented to them on each morning of the field school in order to reinforce the experience of seeing the various features in the field.

6.3 The influence of the VFT on the students' grades

Both the 2021 and 2022 groups had weeklong classes before going to the field trip. The 2021 group was introduced to reservoir engineering and drilling techniques. This group did not have access to the virtual field trip and hence their grades were not influenced by the VFT. The 2022 group had a lot more introductory classes that lasted for a week (including the VFT). The classes introduced the students to deep water sediments. The classes comprised of a research project that required the students to identify and define deep-water sediments (turbidites and contourites) to identify the suitable architectures for oil exploration. The introduction to turbidites gave the 2022 group of students an advantage in understanding the turbidite deposits better. This group also had a class where they had to identify suitable oil reserves from a booklet of seismic profiles. The last class entailed an even further introduction to the turbidite systems with examples other than the Tanqua karoo turbidite fan system. The virtual field trip then gave the students a visual depiction of what the turbidite deposits look like in outcrop and an introduction of the field area they would be visiting during the following week.

Based on the findings of this research it is concluded that there has been an increase in the marks of the 2022 group of students compared to the 2021 group. The increase in the marks cannot be attributed to the virtual trip alone as there were a lot of other factors that may have played a role in the increase of the marks including the pre-trip classes offered.

6.4 Implementation of the Virtual Field Trip

As stated above, the final product of the virtual field trip was used as a tool to introduce the Tanqua Karoo field area to the geology postgraduate students (4th year Geology students) as intended. But its web-based format enables the trip to be presented to external audiences. The virtual field trip was presented to audiences outside of the University of the Western Cape. It was first presented at an international level to a group called the Geology Reservoir Geology and Basin analysis group (GE-RGBA) from the University of Geneva. This was an easy way of showing the Tanqua Karoo as an example of deep-water sediments to an audience that specialises in Basin analysis. One of the attendees commented "*Target building 3D outcrop models same way you did with structures. I suspect large file size made the presentation difficult to follow at a time especially the videos. It will be nice to use platforms that make it easier to handle and share such large files*". Extracts from it were presented by Prof. van Bever Donker at the 2023 Geocongress in January 2023 conference, and in April 2023 at the EGU assembly in Vienna (virtually). The VFT was further presented on the 3rd of June to a group of Reservoir engineers, Petroleum geologists and Geophysicists from Nigeria before they traveled to Tanqua Karoo the next day.

6.5 Problems encountered during data collection

During data collection it was learned that an expert guide is needed to navigate the area to accurately capture all the important features needed in order to avoid wasting time trying to find outcrops. The Tanqua Karoo is a remote area, which means that is it easy to get lost without proper knowledge of the area. The outcrops in the area look similar and that can cause confusion when trying to identify specific areas. Going to the Tanqua Karoo proved to be very costly since vehicles had to be hired for each of the trip. because this is a remote area without cell phone coverage, we hired two vehicles for security reasons with all the cost arising from that. This also meant that money was lost on the unsuccessful trips where poor quality data was obtained.

Some of the data collected from 2021 was not used due to low quality images and videos having no sound because of incorrect connections to the mic. One of the other problems encountered during the data collection was hiking with camera gear up slope. This slowed down the time to get to the top because of balancing on the slopes with camera gear. There were several other conditions that led to standing on slopes to capture certain areas of interest and this proved to a bit tricky to set up a tripod. Another problem was forgetting to correctly setup the Syrp device, where we changed lens and forgot to feed the correct information into the Syrp which led to having a panorama impossible to stitch because of the gaps as overlap was wrongly calculated. One other problem encountered in the field was forgetting to charge the devices which led to a day in field going to waste as a result of having a low battery phone needs for the remote control of both the Syrp and the Insta360-One-X.

6.6 Limitations

The virtual field trip was limiting in its ability to be fully immersive due to the abandonment of using the Unity® game engine which also allows for a more immersive experience. Although most VFTs are not true "virtual reality" (VR), they do allow users to interact with the virtual environment through exploration, analysis, learning, and testing of skills (Stainfield et al., 2000). Some of the information not offered by VFTs are sensory aspects such as smell, feel, and taste, and therefore VFTs offer visual, spatial, and geological information only.

Another limiting factor encountered in this study is that the assessment marks were collected from a small sample which means the effectiveness of the VFT cannot be generalized to a broader audience. Another problem was that the students did not have time to access the VFT during their own spare time due to changes made in the days approaching the physical field excursion.

6.7 Omitting the use of Unity®

The use of Unity® was discontinued because it took a long time to compile a product due to the amount of coding required to have a fully functioning virtual trip. Each action made in the virtual field trip requires a code that allows for certain responses from the tour. The availability of Pano2VR© made it easier to move from Unity® as Pano2VR© has all the functions already available that would require code. The decision to not use the Unity® game engine does not affect the outcome of the results. This is because the result was reasonable in its features. The major difference between using Unity® and Pano2VR© is that Pano2VR© cannot embed 3D models within the 360° environments. This means that the 3D models are available via external links. An advantage of using Pano2VR© is that programming skills are not required.

7. CONCLUSIONS AND RECOMMENDATIONS

A set of virtual trips have been developed of the key outcrops of the Tanqua Karoo area and has been used as a preparatory interactive virtual trip. From the comparison of the final reports produced by students in 2021 and 2022 after attending the same tour, as well as from the comments made in response to the reflective questions, it has been concluded that there is a positive impact of the VFT on the students' understanding and ability to recognise key features in the field.

It can therefore be concluded that a virtual trip can help by preparing students for field experiences. The accessibility of virtual trips can allow people with restricted mobility to 'access' a field area. It can also be used for international audiences. These virtual field trips allow repeated 'visits' to the area and therefore increasing the opportunities to learn. This can be useful to individuals that need more time to understand certain concepts. Virtual trips also preserve geological sites for future generations.

7.1 Recommendations

This study can be used to further study and analyse the impact of virtual trips on the learning gain of students. It can also be used as a guide to recreate and improve future virtual field trips in the field of geology. The success of a virtual field trip lies in proper preparations for the data collection process, in terms of knowing the areas of interest and proper use of the equipment available. It is unavoidable that initial plans and ideas on how to create a virtual field trip may change during the creation of a VFT. These changes may be due to limited time or wanting to add additional material as time goes on.

Conclusive information about the impact of having the VFT as a tool of improving students' performance in the field would require it to be run for several years on larger groups of students in order to build up a numerically larger sample. Having a larger group of students can help with getting more accurate or conclusive results to limit the possibility of biased results. It is important to note that the sample number of this group of students shows the effectiveness of virtual field trip only to a limited extent. The creation of a VFT that does not need much guidance from the creator or instructor of the VFT would be an even greater advantage for independent learning.

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APPENDIX LIST

Appendix A: Ethical clearance documents

Appendix B: Data table

Appendix C: Power point presentation

Appendix D: Virtual Field Trip Questionnaire and Review form

Appendix E: Field report marks of the 2021 and 2022 groups

APPENDIX A

A collection of documents needed to conduct research with students.

INFORMATION SHEET

UNIVERSITY *of the* WESTERN CAPE

Faculty of Natural Sciences

Department of Earth Sciences

THE USE OF GAMING SOFTWARE AND HIVE TECHNOLOGY IN THE CONSTRUCTION OF VIRTUAL FIELD EDUCATION OF THE TANQUA KAROO

The Applied Geology Division (APG) of the Department of Earth Sciences in the Faculty of Natural Science at the University of the Western Cape, under the directorship of Prof D. Frei (dfrei@uwc.ac.za) would like to request your participation in a study conducted by Ms **Luyanda Mayekiso** (BSc, BSc Hons Applied Geology, PGDip immersive technologies 3623599@myuwc.ac.za) for the completion of her Master of Science degree in Applied Geology.
The project is supervised by Prof J. Van Bever Donker (APG, jvanbeverdonker@uwc.ac.za).

Purpose of the study
The goal of the study is to test the effectiveness and the use of Virtual Field Tours (VFT) to supplement field excursions in the Applied Geology Honours course. The VFT will be created by using High Definition (HD), panoramic, composite images of rock outcrops as well as 3D-photogrammatic composites of drone images of the outcrops visited in the Tanqua Karoo field school. Gaming software will be used to build aspects of the tour.
We aim to explore the development of students' understanding of geological concepts, interpretative techniques and recognition of the characteristics of a petroleum reservoir equivalent and how the use of the Virtual Field Tours technology prior to visiting the outcrops influences the level of competency in this regard.

Study procedures
During the excursion later this year and next year, the academics in charge of the excursion will assess the geology Honours students on selected outcrops in the field on their interpretative skills. These assessments form part of the normal class activities and will be conducted at various outcrops during the Tanqua Karoo excursion.
In 2022 this will be preceded by a virtual tour to the same area that has been constructed after the 2021 excursion, after which the assessment results of the two excursions will be compared.

Questionnaire: At the end of the 2022 excursion, all participants will be asked to complete a short questionnaire on their experiences of the VFT and whether it has helped in completing the excursion.

Benefits
There are no direct benefits or risks to you due to your participation in the study; however, we hope that the data from this study will give us insights into the enhancement of geology teaching through VFTs.

Page 1 of 3: Information

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HSSREC, Research Development, Tel: 021 959 4111 email: research-ethics@uwc.ac.za
Ethics approval registration number:

UNIVERSITY of the WESTERN CAPE

Faculty of Natural Sciences

Department of Earth Sciences

Confidentiality

Your confidentiality and anonymity are of utmost importance to us and we will endeavour to ensure that this will not be compromised in any way. Your information from the questionnaire will be confidential and all data will be anonymised for the purposes of this research.

Voluntary participation/withdrawal

All questionnaire tasks will form part of the regular Geology Honours course. However, should you opt out of the study, your questionnaire responses and assessment results will not be used in the data analysis. You will in no way be disadvantaged compared to other students who participate in the study.

If you decide to participate, you are free to withdraw from the study at any stage and for any reason.

Research results

For participants who are interested, the analysis of the development of students' geological understanding after engaging with the VFTs compared to those who did not participate in the VFT in 2021 will be reported back to the class at the end of the semester. The assessment results that we get from this research will be used for future research purposes in the year 2022.

All questionnaires and assessment results will be kept in a secure location for five years after the completion of the study and then disposed of through the University's Records and Archives department's policies and procedures.

Page 2 of 3: Information

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UNIVERSITY of the WESTERN CAPE

CONSENT FORM

Faculty of Natural Sciences
Department of Earth Sciences

THE USE OF GAMING SOFTWARE AND HIVE TECHNOLOGY IN THE CONSTRUCTION OF VIRTUAL FIELD EDUCATION OF THE TANQUA KAROO

DECLARATION

I, ………………………………………………………………………… (full names of participant) hereby confirm that I understand the contents of this document and the nature of the research project, and that **I DO/ DO NOT** (delete what is not applicable) consent to participating in the research project.

I understand that if I consent now, I am at liberty to withdraw from the project at any time should I so desire, by notifying the researcher.

SIGNATURE OF PARTICIPANT: ……………………………………… DATE: ………………………………

Contact information
Researcher: Ms Luyanda Mayekiso: 3623599@myuwc.ac.za
If you have any additional queries, please contact my supervisor Prof J. Van Bever Donker jvanbeverdonker@uwc.ac.za.

Page 3 of 3: Consent

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UNIVERSITY OF THE WESTERN CAPE
PERMISSION TO CONDUCT RESEARCH

DEAR **Luyanda Mayekiso**

This serves as acknowledgement that you have obtained and presented the necessary ethical clearance and your institutional permission required to proceed with the project referenced below:

RESEARCH TOPIC

The use of gaming software and hive technology in the construction of virtual field education for the Tanqua Karoo Field School.

Name of researcher	:	Luyanda Mayekiso
Permission valid till	:	22 June 2024
Institution	:	University of the Western Cape
Ethics reference	:	HS21/4/14
Permission reference	:	UWC 5007806868327641146

You are required to engage this office (researchperm@uwc.ac.za) in advance if there is a need to continue with research outside of the stipulated period. The manner in which you conduct your research must be guided by the conditions set out in the annexed agreement: Conditions to guide research conducted at the University of the Western Cape.

Please be at liberty to contact this office should you require any assistance to conduct your research or require access to either staff or student contact information.

Regards
Dr Ahmed Shaikjee
Deputy Registrar Academic Administration

Approval status: **APPROVED** 29 June 2021

To verify or confirm the authenticity of this document please contact the University at researchperm@uwc.ac.za.

UNIVERSITY OF THE WESTERN CAPE
Robert Sobukwe Road, Bellville, 7535, Republic of South Africa

UNIVERSITY *of the* WESTERN CAPE

60 YEARS *of hope, action & knowledge*

23 June 2021

Ms L Mayekiso
Earth Sciences
Faculty of Natural Sciences

HSSREC Reference Number:	HS21/4/14
Project Title:	The use of gaming software and hive technology in the construction of virtual field education for the Tanqua Karoo Field School.
Approval Period:	22 June 2021 – 22 June 2024

I hereby certify that the Humanities and Social Science Research Ethics Committee of the University of the Western Cape approved the methodology and ethics of the above mentioned research project.

Any amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

Please remember to submit a progress report by 30 November each year for the duration of the project.

The permission to conduct the study must be submitted to HSSREC for record keeping purposes.

The Committee must be informed of any serious adverse events and/or termination of the study.

Ms Patricia Josias
Research Ethics Committee Officer
University of the Western Cape

Director: Research Development
University of the Western Cape
Private Bag X 17
Bellville 7535
Republic of South Africa
Tel: +27 21 959 4111
Email: research-ethics@uwc.ac.za

NHREC Registration Number: HSSREC-130416-049

FROM HOPE TO ACTION THROUGH KNOWLEDGE.

The University of the Western Cape is a Public Higher Education institution established and regulated by the Higher Education Act, No. 101 of 1997 (Republic of South Africa), with the language of instruction being English. The University is duly accredited by the Council on Higher Education and its degrees and diplomas are registered on the National Qualifications Framework in terms of the South African Qualifications Authority Act, No. 58 of 1995.

RESPICE PROSPICE

CONDUCTING RESEARCH AT THE UNIVERSITY OF THE WESTERN CAPE

ANNEXURE AGREEMENT

Conditions to guide research conducted at the University of the Western Cape

ANNEXURE

CONDITIONS TO GUIDE RESEARCH CONDUCTED AT THE UNIVERSITY OF THE WESTERN CAPE

The onus rests on the researcher/investigator to observe and comply with the conditions set out below with the aim to conduct responsibly ethical research. Clarity must be sought from the authorising office should the interpretation of the conditions be unclear. University staff and offices may opt not to participate in any study should they feel it infringes on their own work or research.

1. ACCOUNTABILITY

1.1. The University reserves the right to audit the research practices of the researcher/ investigator to assess compliance to the conditions of this agreement.

1.2. Data collection processes must not be adapted, changed or altered by the researcher/ investigator without written notification issued to the authorising office.

1.3. The University reserves to right to cease research if any proposed change to the data collection process is found to be unethical or in contravention of this agreement.

1.4. Failure to comply with any one condition in this agreement may result in:

1.4.1. Disciplinary action instituted against a researcher/investigator employed or registered at the University;

1.4.2. The contravention reported to the organisation employing or registering the external researcher/ investigator.

2. GOVERNANCE

2.1. Approval to conduct research is governed by the Protection of Personal Information Act, No 4 of 2013, which regulates the entire information life cycle from collection, through use and storage and even the destruction of personal information and it is incumbent on the researcher/investigator to understand the implications of the legislation.

2.2. The researcher/investigator must employ the necessary measures to conduct research that is ethically and legally sound.

ANNEXURE AGREEMENT

Conditions to guide research conducted at the University of the Western Cape

3. ACQUIRING CONSENT & RIGHTS OF PARTICIPANTS
3.1. It is incumbent on the researcher / investigator to clarify any uncertainties to the participant about the research. 3.2. Written consent must be obtained from participants before their personal information is gathered and documented. 3.3. Participation in the research must be voluntary and participants must not be pressured or coerced. 3.4. Participants have the right to access their personal information, obtain confirmation of what information is in the possession of the researcher / investigator and who had access to the information. 3.5. Participants have the right to withdraw from the research and insist that their personal information not be used.
4. DATA AND INFORMATION MANAGEMENT
4.1. Due diligence must be afforded by the researcher/investigator to: 4.1.1. Mitigate any risks that could compromise the privacy of participants before 4.1.2. during and after the research is conducted; 4.1.3. Collect only information that is relevant to the aim of the research; 4.1.4. Verify all personal information collected about a participant if the information is supplied by a source other than the participant; 4.1.5. Refrain from sharing participant information with a third party; 4.1.6. Apply for an exemption if the identity of participants should be revealed in the interest of the research aims. 4.2. The researcher/investigator must employ appropriate, reasonable and technical measures to protect, prevent loss of and unlawful or unauthorised access of research information.

Should you have any questions relating to this agreement please contact:
ashaikjee@uwc.ac.za, or researchperm@uwc.ac.za

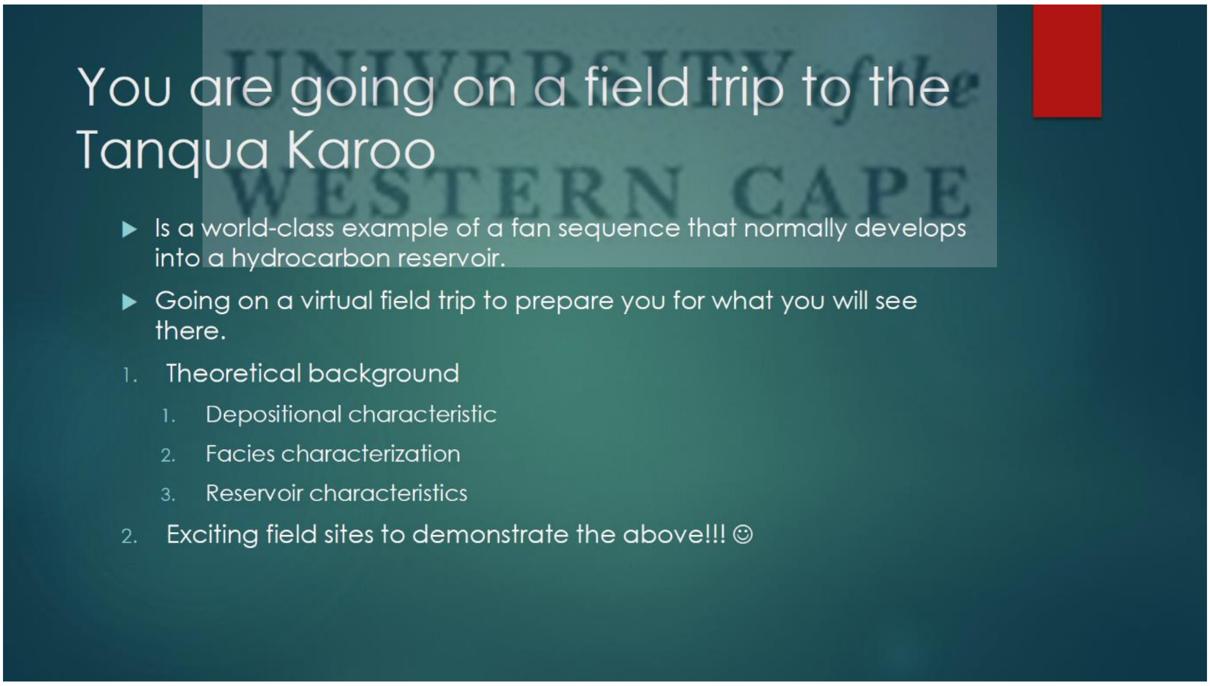
APPENDIX B

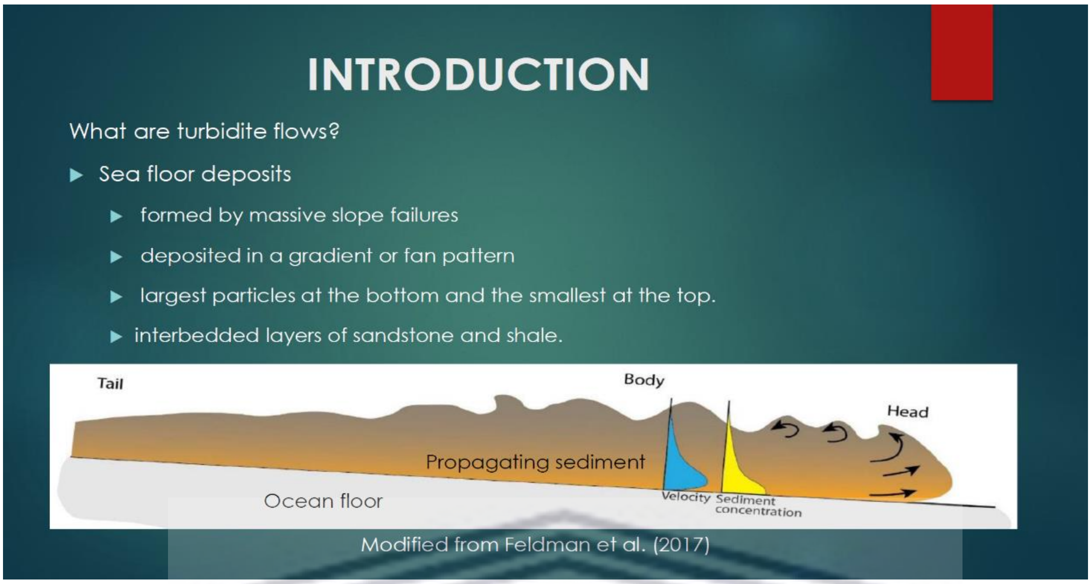
Table B1. Data table with the raw data collected for the creation of the VFT.

SITES	DATA TYPES					
	Lidar models	Images	Drone videos	Videos	3D outcops	360^0 image
Ongeluks	0	1195	1	3		1
Kraal	1	331	6	6		1
Loskop	0	888	0	7	1	1
Rondavel	1	1106	3	11		2
Skoorsteenberg	4	904	3	5		1
Kanaalkop	0	939	2	1	1	2
Klein Reit Fontein	0	257	0			2

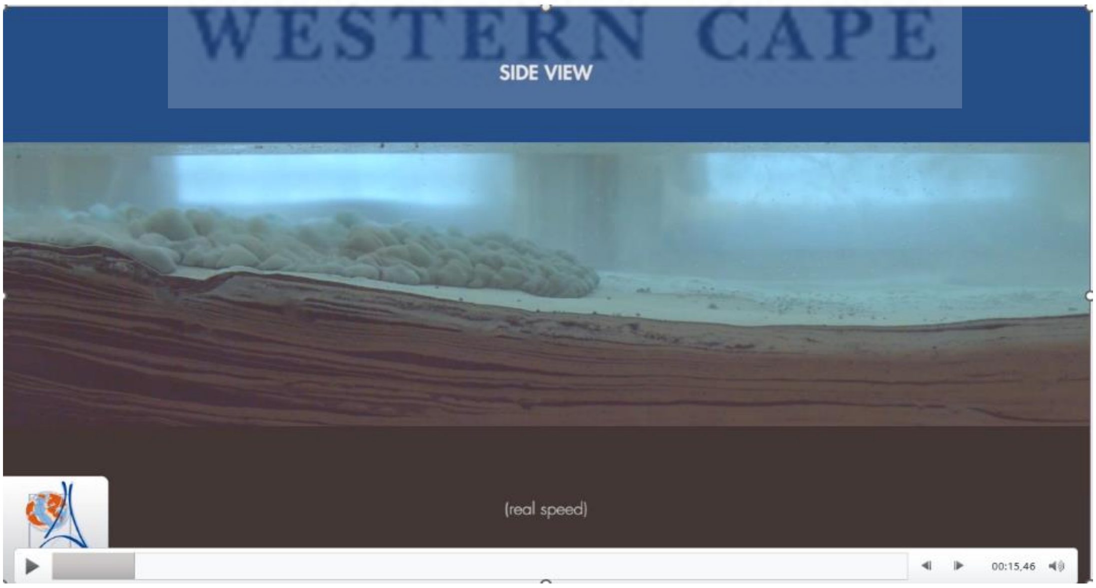
APPENDIX C

These are the presentation slides that were used to introduce Turbidite flows and the architectural styles of the different elements of the Tankwa (Tanqua) Karoo. These slides were used right before the Virtual Filed Trip was presented.



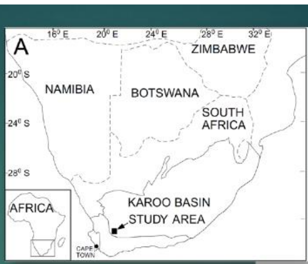

INTRODUCTION
What are turbidite flows?
Sea floor deposits
formed by massive slope failures
deposited in a gradient or fan pattern
largest particles at the bottom and the smallest at the top.
interbedded layers of sandstone and shale.
Tail
Body
Head
Propagating sediment
Ocean floor
Velocity
Sediment concentration
Modified from Feldman et al. (2017)

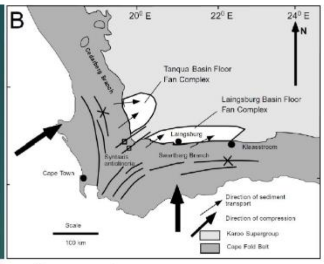

Why study turbidites?
Turbidites make good reservoirs
Good reservoirs make lots of money.

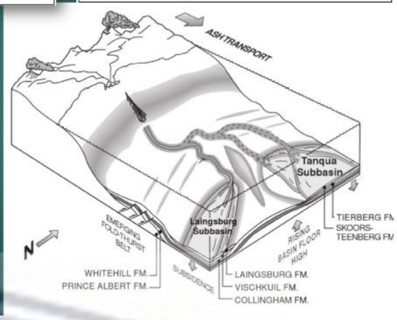

SIDE VIEW
(real speed)
00:15.46

Study area

- The Tanqua Karoo basin
- Permian age
- Five deep-water turbidite fan systems
- Exposed over some 640 km2.

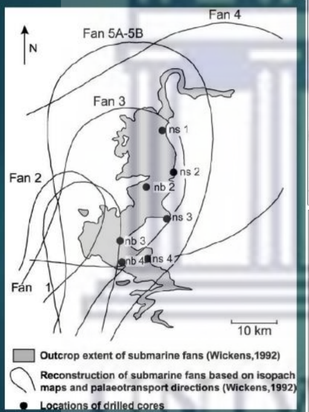


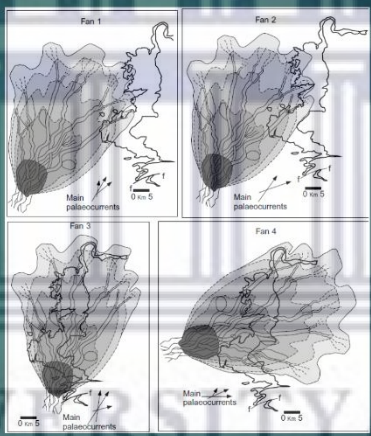




Images source: Wickens (1994)

Fan Paleocurrents





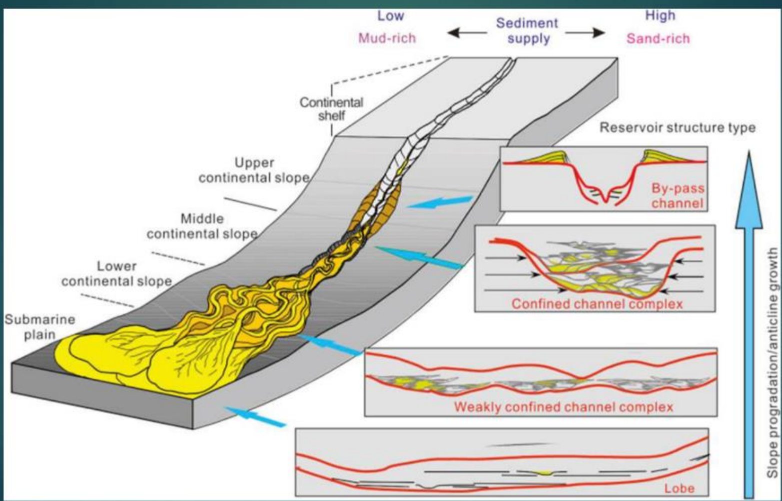
Source; eft image (Stephen et al.,2001)
Right image:(Wickens 1992(

Architectural elements of the Tanqua fan complex

Fan sequence and reservoir

- Two rock types
  - Sandstone
    - High porosity
    - High permeability
  - Shale
    - Low porosity
    - Low permeability
- Rules of the game
  - If sandstone, stuff can go in and move around
  - If its shale, stuff can't go in or move around

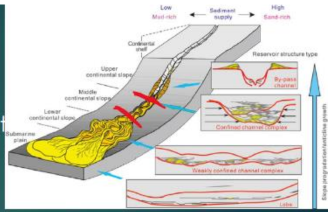
Sedimentary model of turbidite fan



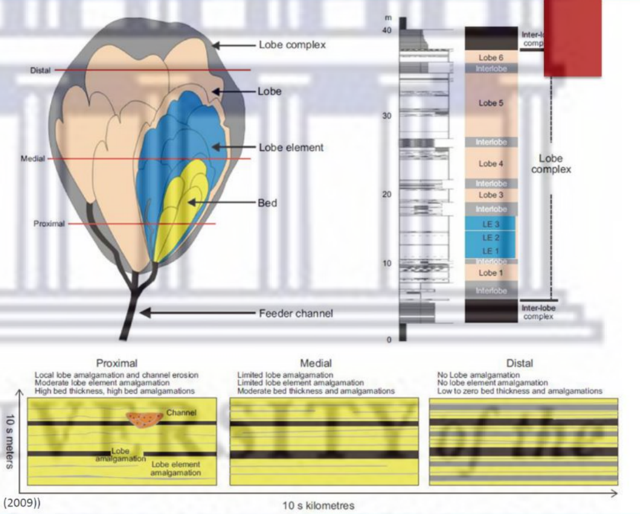
Source: Yanqing., 2018

Channel fills

- Channel: elongate depression, passage for flowing sediment
- Confined turbidite current flows
- Common in slope to base-of-slope successions.



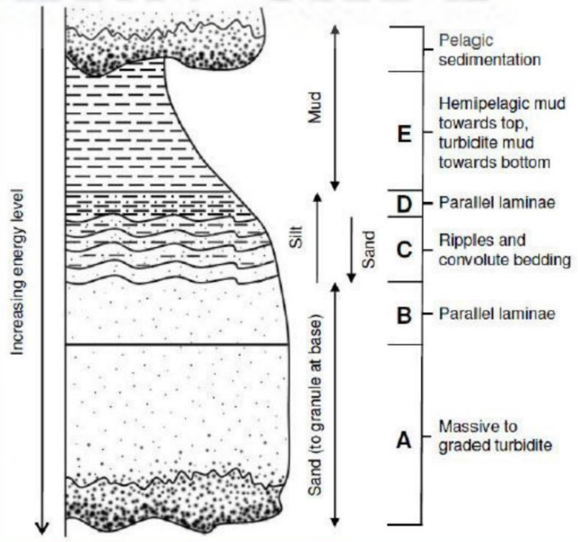
LOBE COMPLEX HIERARCHY



Source; (Prelat et al. (2009))

The Bouma sequence

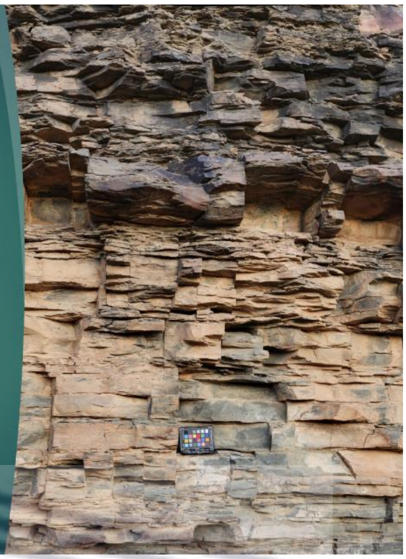
- Predictable order of sedimentary deposition resulting from a turbidity current.
- Fining upwards.
- Units are labelled A through E.
  - Usually described as Ta,Tb etc.

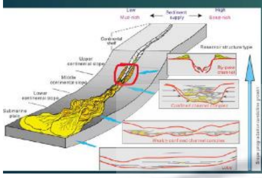


Bouma (1962)

Overbank/Levee deposits

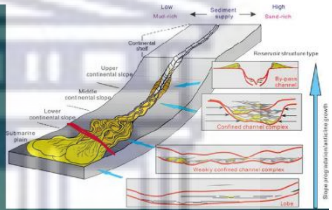
- Overbank deposits
  - fine-grained, thin-bedded, ripple laminated deposits
  - Forms when the sediment/turbidite flows over the levee
- Turbidite has lower energy when not in the channel
- Lower energy





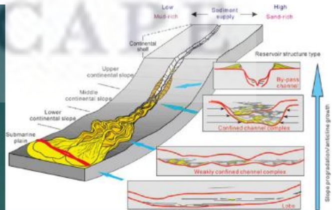
Transitional deposits

- Channel-lobe transitions are characteristic of both channels and lobes.
- Occur in unconfined areas dominated by sediment bypass.



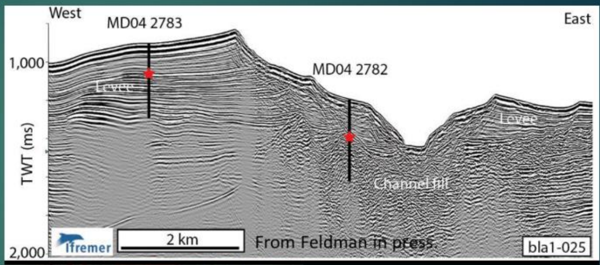
Lobes/sheets

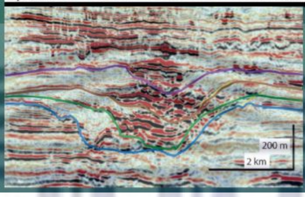
- Sheet-like deposits found at the end of a channel.
- Non-channelized bodies, thick-bedded sandstones that alternate with thinner fine-grained interlobe facies.
- Occur at inner and middle fan environments.



Buried fan systems and reservoirs

- Turbidite channels are favourable targets of oil and gas exploration as their geometry makes them easy to recognize on seismic images ensuring a high success rate.
- Turbidite levees make poor reservoirs and are rarely explored targets and are clearly visible in seismic sections





Top image: The seismic image shows a channel fill and its adjacent levees. Bottom image: The seismic interpretation shows a channel complex (each channel fill represented by the blue, green, brown and purple line) from Mayall et al. (2016)

Now we're going on a virtual tour !!!

APPENDIX D

Table D1. A questionnaire provided at the end of the VFT presentation with anonymous comments.

Participant	Did the VR tour adequately represent the field area?		Was the resolution of the images shown sufficient to recognize features such as grain size and sedimentary structures?		Has the VR tour assisted you in preparing for the real excursion?		How do you suggest we can improve the tour?
	YES	NO	YES	NO	YES	NO	
1	x		x		x		The tour is great, with clearly visible features that show the succession of rocks
2	x		x		x		
3	x		x		x		
4	x		x		x		To make the virtual tour more correlated, comprehensive and if possible be in one video just showing different areas of interest.
5	x		x		x		The resolution can be improved to show sedimentary structures
6	x		x		x		Do more videos explaining the fans. Create slides for formations
7	x		x		x		According to what has been presented, everything is fine and well prepared. Therefore nothing needs to be improved. I'm looking forward to the trip.
8	x		x		x		The virtual tour was sufficient and helped to get an idea of how the area looks like
9	x		x		x		I suggest that the talk is given two days before the trip so that after the talk the students can go through the notes and be ready on the day of the trip
10	x		x		x		Fantastic visualization. No comment for now

11	x		x		x		Maybe you could show the map first, where the different VR outcrops are located (they are separated by many

Table D2. Reviews made by the students on the overall experience of the the VFT and the accompanying physical tour

Student ID	**REVIEWS**	**RECOMMENDATIONS**
A	The tool acclimatized us to the morphology, lithospheric units, sedimentary structures, and associated interpretations of the Tanqua Karoo in advance. From this, the questions we had about the Tankwa karoo were answered prior to the trip. This provided us with a 'big picture' understanding of the Karoo well in advance to the trip	Resolution can be improved. Limitations of the tool should be made clear to the users or participants.
B	The virtual field tours were very helpful in introducing the study area. They provided guidance not only on what to expect on the field but also knowledge of what turbidites are and their distinct characteristics which could not have been seen by walking on the field	
C	For me the visual presentation of the study area was very helpful. This is because pictures stick more and when you get to see the features physically you then remember what they are. When traveling as a group sometimes when the lecturers point at things, you are not sure if what you are looking at is the correct thing but because the pictures show exactly what a feature is and how it looks it is easy to know. In areas where the weather doesn't allow students to view every outcrop the videos help a lot for students not to miss any important information.	I suggest that the students get the readings and pictures (just as we received the study guides) so that they are familiar with the structures, and it is easy to recall them when physically viewing them.
D	The virtual tour that was conducted by Luyanda helped me to get an idea or picture of the Tankwa area and what to expect. I appreciate how she conducted or presented it to us. I would have liked if a few more outcrops are taken, but I've learned a few things from the virtual tour such as I was able to recognize the concretions in the field area because she showed them to us on the virtual tour, such things like that. the video of the turbidite also helped. that was a really good video to depict how a turbidite works.	
E	The use of the virtual tour before actually visiting Tankwa karoo has aided me in the identification and recognition of geological features. It also helps with understanding concepts as well as visualizing them as opposed to only reading about them. It is a great tool to prepare for field school because we know what to expect on a large scale all the way to the fine details.	
F	The virtual tour helped a lot in preparation for the Tankwa karoo excursion. Having to see the virtual tour before coming to the field assisted in terms of identifying the different structures present, for example, the concretions. Also you get to see all the possible lithologies present in the Tankwa karoo before coming to the field. The scour surfaces, and amalgamation of sandstones were clearly shown in the virtual tour which is also an advantage when you are on the field.	
G	The virtual field tour was very well done and gave an introduction to what we had to expect from the field	a recommendation can be to indicate where on a map is the outcrop. If I compare it to the field trip, the virtual field trip mainly showed the

	actual field trip. The images were clearly showing features needed and important to see.	images of the features, while the location of the features was a bit unclear to me. It was only until I got to the actual field (or after DeVille explained where we were) when I knew where the outcrops are.
H	Thoroughly enjoyed the ability to view the rocks in outcome in 3D without physically being there. This gives the viewer a good understanding of what they will see in the outcrop. The ability to see a telephoto view of an outcrop and being able to zoom in without losing clarity. The lidar application is innovative in showing in 3D and allowing to move around.	What would be nice is more drone footage. The footage used is fantastic and that creates the longing to see more especially closer to the outcrop. If possible more outcrops be represented using lidar would be cool.
I	Presentation and was really really great.	Picture quality was very good but there is still room for improvement. Aligning geological maps with pictures to make the tour more cohesive. Covering a round-up Tankwa subbasin with pictures would really bring the tour to life i.e taking areal, structural and cross-section pictures. Pictures to have a background of the picture i.e taken picture should be followed by some sort of narration to contextualize and give orientation (geological history, setting and parts of the fan system the pictures are from). Incorporate DeVille narrations of the place with the tour If possible more students to be encouraged to take on this research to have a more wholesome tour

APPENDIX E

Table E1. Comparison of the 2021 and 2022 Field report marks.

	2021 group	2022 group
	94	84
	78	74
	71	78
	62	85
	73	74
	62	90
	56	65
	46	80
	64	74
	56	
	71	
	56	
	73	
	46	
	69	
Mean	65,1	78,22222
StDev	12,6	7,496295
Max	94	90
Min	46	65