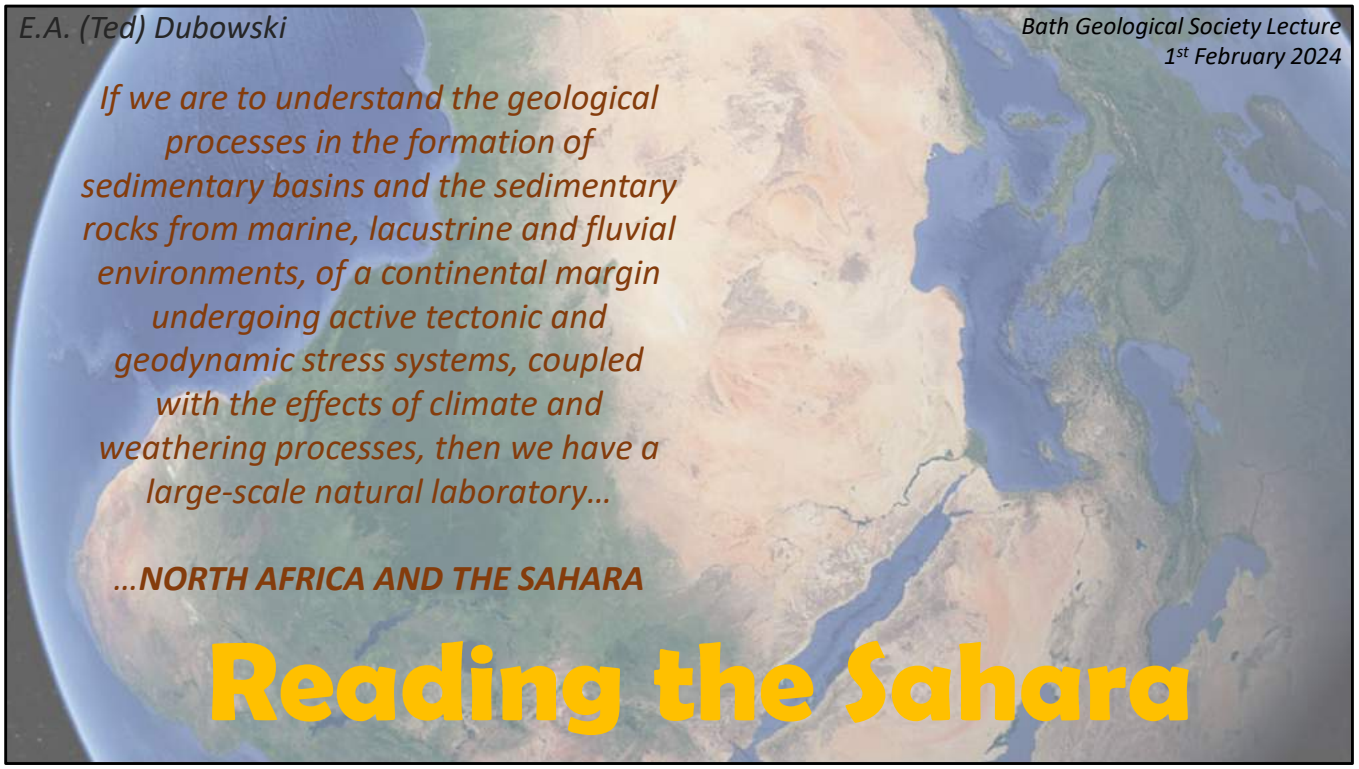


Good Evening

I thank Graham Hickman for the invitation to provide a talk on my project to the Bath Geological Society. By way of introduction, I'm Ted Dubowski, retired from active work as a Computer Science Teacher, my second career. I've come back to my geological roots, my first career, in my retirement, to return to my interest in the remote sensing of arid environments. I won't be commenting on how remote sensing works in this talk. Rather my intention is to focus on what the project is about, or not, and looking at a couple of areas to explain the project.

I'd started around 2018-2019 to do some personal research in remote sensing due to free availability of Landsat and Sentinel data. Initially, I was just going to focus on Egypt, out of my fascination for the place. My idea was to use Embabi's (2018) textbook, '*Landscapes and Landforms of Egypt*', to map the physiography and structural geology of Egypt using remote sensing data and GIS technology – the software being ArcGIS Pro and ESA Snap. Eventually, I also found out that the SRTM data was also freely available… and I really needed digital topographic data. The idea of digitising the old topographic maps didn't appeal to me.

I found that the methods I used for Landsat 5 datasets, in the arid landscapes of South Australia, during my remote sensing formative years of 1989-1992, didn't seem to work

well in Egypt. So, looking at other methodologies, I came across Independent Component Analysis (ICA) and Decorrelation which sounded interesting, except ArcGIS does not have these tools nor does QGIS or ESA Snap. I thought about writing my own program in Python or learning to do things using R, as both languages having strong geospatial toolsets. The maths I'd need would be about 2 years of learning – I'd prefer to use my time working with data than learning maths. ERDAS Imagine had these tools, but the cost was out of my price range. Not surprisingly, my wife wouldn't let me re-mortgage the house to get a loan! Fortunately, a Hexagon salesman rang me up to see why I wanted to use the software, and to cut a long story short, Hexagon have supplied me a personal licence for both Imagine and the ATCOR plugin (used for atmospheric correction).

WHAT THIS PROJECT IS NOT…

- Not a standard scientific method
- No focused investigation
- No field work
- No laboratory analytical processes and procedures on samples
- No conclusion based on results

To be clear…

This project is not about a proper, formalised scientific investigative study to determine some specified hypothesis or theory. For starters, it would not be easy to just go out and do field investigations, or to GPS ground truth all the areas of interest, to collect background data and samples, to undertake spectral and geochemical analysis. Where in North Africa would you begin? Logistical planning and location access aren't something that could be easily achieved, especially where conflicting ideals promotes an infestation of lead flies and unknown zones of extensive localised explosive seismic shocks. Besides, being an open-ended study, where methodologies need to be thought out and modified and tweaked for differences of landscape, you don't really know what you might see. All that can be done is to collate as much research with identifiable locations to help support the long-term investigation this project will have. Unfortunately, the bulk of the really needed data is held by petroleum companies.

WHAT THIS PROJECT IS…

EXPLORATION

Looking down on this beautiful planet…

What can I see and what might it mean?

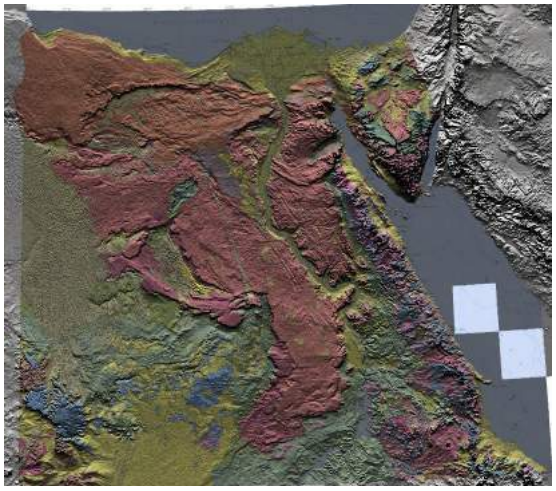
Rather, this project is about the use of 21st century technologies to explore the arid Earth's surface through the use of BIG DATA - satellite remote sensing technologies at a continental scale.

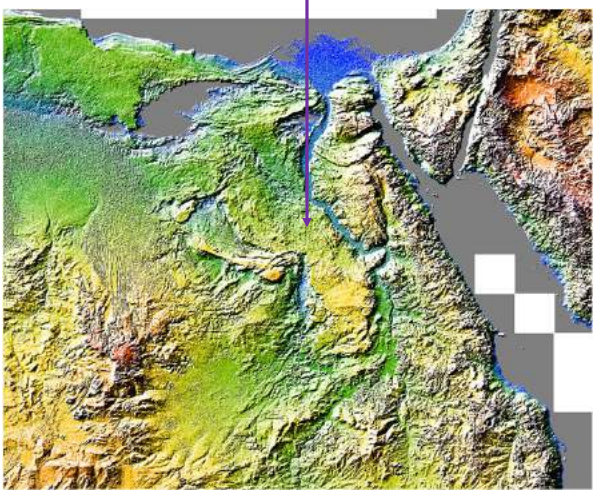
My rationale is to look at the surface of the Earth from the continental perspective, to creatively think about the integrated geological and geomorphological processes that make up the arid landforms North Africa. To ask questions of what we can see, as well as to question what we think we know. It is not about creating controversy. It's about getting to think differently. Why?

When dealing with continental scale arid landscapes, this project is to develop a system of using a small suite of digital data that utilises a combination of topography, satellite lithological identification techniques, structural geology, geomorphology, physiography and palaeo-drainage to be able to map out as much detail as possible, in a uniform manner for regions of large areal similarities, across the continent: that is, getting maximum detail as possible with as few complex methodologies to produce a contextualised continental scale interpretative map. The outcome, therefore, is to provide as detailed a geological/geomorphological/physiographic basemap as possible that can then be used for different types of targeted investigation as well as to have detail where access to areas is restricted or untenable.

AI, classification and hydrological methods you think? No way José. These methodologies try to pick out features based on similarities, or approximated height, of pixels covering 900 sq meters of surface area. Complex, contextual geological/geomorphic information in which the feature resides and is affected by, isn't taken into account. This can only be determined by the human brain-eyeball interactions and the use of multilevel layering of various integrated data. These computerised methodologies are aimed to do rapid work, to get a project or article completed to a time frame – getting the detail is too time-consuming. This exploration project is about collecting as much contextualised detail and interpretative analysis, in order to maximise information that can be obtained from all the digital datasets. Yes, it's time consuming and I'm only one retired person willing to do something not considered economically feasible; kind of mapping one raindrop's ripple on the wide expanse of a sea. I'm sort of hoping that the ripple effect might be picked up by like-minded folk.

EGYPT…then beyond





Onto the project…

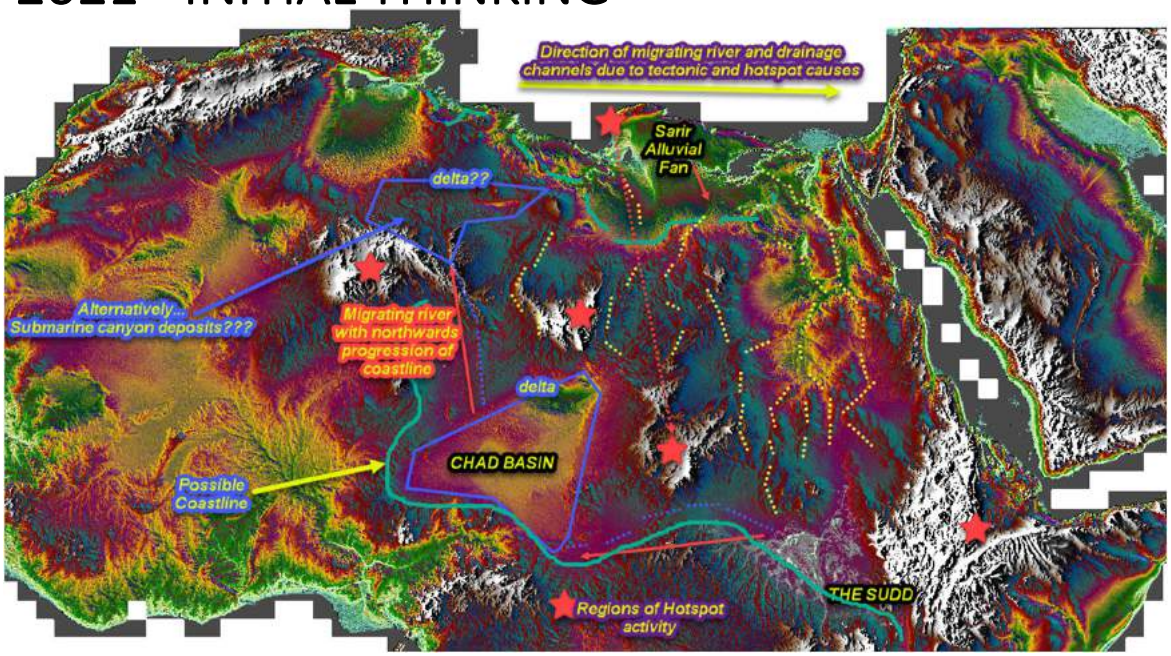
Having a digital base map is key, particularly a radar-based digital elevation model (DEM), as radar can penetrate slightly below the subsurface which helps provide a texture to the surface which aids in understanding and interpreting surface and geomorphological features when used either on its own or with other datasets. I managed to create an SRTM topographic image at 30 m resolution of Egypt, as well as geo-reference the 1982 Geological Map of Egypt (left image). Just covering Egypt for mapping physiography and structures wasn't sufficient, hence needing to extend the boundaries to cover the Sarir fan in Libya and down into Northern Sudan (right image). Working with the topography of Egypt required a bigger picture.

I spent months slowly drifting over the DEMs I created, following large- and small-scale features, zooming in and out, rotating perspectives from different angles and viewing in 3-D, frequently exaggerated to highlight the very low topographic features, just to get my eye in on what is being shown by digital topography. Embabi's reference was used to give me direction of the geomorphology I'm likely to see. Initial Landsat processing of the Western Limestone Plateau together with the digital topographic base focused my attention on long-low scarps that form the depressions common in Egypt. Palaeo-drainage was a significant issue in the physiography of the formation of smaller depressions, but also in large basin formation and in the nature of topographic

sculpturing. At least in Egypt, there is also a significant difference in drainage between the eastern side of the Nile versus the western side caused by the interaction between lithological formation, palaeo-drainage and tectonics. My very first questioning thought was if the initial sculpting of the surfaces was actually below sea level.

Purely based on reconnaissance of the topography, and together with some processing of Landsat 8 and Sentinel 2 satellite data, I decided to expand the study to cover all North Africa from the 0 UTM line, northwards, amounting to 2,363 tiles to mosaic. This was due to realising that what I was reading in the textbook, as well as in journal articles, didn't really gel with what I was seeing, particularly over the large expanse of the Western Limestone Plateau, which has a paucity of geological mapping. Furthermore, the geomorphic and physiographic features appeared to be inter-connected across the continent – similar features are found across the length and breadth of the Sahara.

2021 - INITIAL THINKING



Processing a full North Africa SRTM mosaic took about 110 hrs on a 16-gigabit laptop without any graphics processor. I did this about 2-3 times over a year, latterly with a decent workstation, 32Gb with graphics processor, to try out different methods whilst learning the ArcGIS Pro software. The above image, gave me an opportunity to get some of my initial thoughts down based purely on interpreting what I believed I ***might*** be seeing on a continental scale . Whilst some of these initial ideas I have discounted, it did provide me with a hypothesis to follow…

HYPOTHESIS

The North African landscape has its basis in the geodynamic emergence of a Tethyan passive margin along an older, Gondwanan, continental landmass

The thinking I developed about North Africa was: given the nature of the surficial geological units, significantly marine deposits, tending towards lacustrine and fluviatile sediments as they get progressively younger, then where did all the surficial sand deposits come from? Looking at the accumulations of the sand deposits on the SRTM base map, the nature of the dune formations, often chaotic with interference patterns, the scarp formations and the variable nature of palaeo-drainage at all scales, and the strong structural geological fabric, I've come to believe there's more to the sand dune deposits than pure aeolian formation. More likely aeolian reworking of what was already laid down and then exposed.

At this point in time, all I can offer are a lot of questions and thoughts based on the following statement: *what we think we know now, a lot of creative re-thinking needs to be used when you consider the surficial, continental perspective, from different azimuthal viewpoints, and in the different light of the electro-magnetic spectrum.* Hence, this talk being given at the end of the reconnaissance and method design investigation stages of the project – The Prelude.

Personally, I am no expert in remote sensing, nor do I have a background in North African geology. All I'm doing is trying to establish methodologies of studying continental scale Earth Science through the remote sensing technologies and then creatively think about what I see, using established knowledge, because I'll never get to ground truth

North Africa. What I do know, is that my experiences gained in South Australia allowed me to successfully develop and prove my ideas using the technology. Hopefully, I can achieve the same for North Africa.

SOME QUESTIONS…

Where did all the sand come from?

Is the Nile the longest (***continuous***) river in the world?

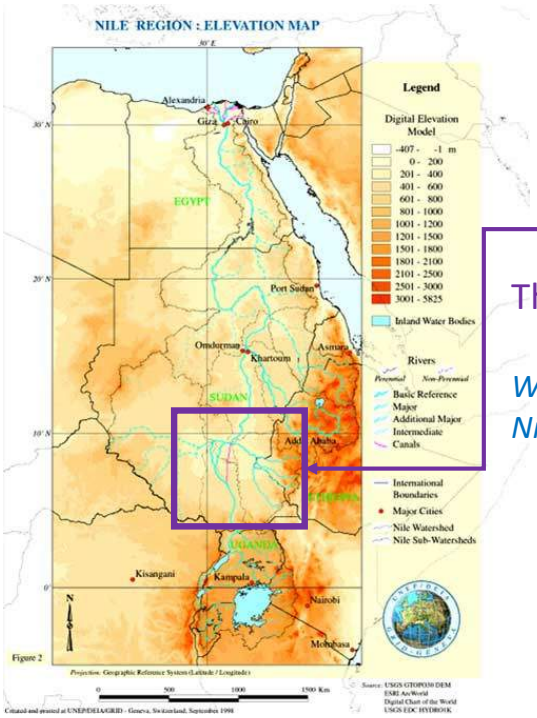
Was there ever a Nile River canyon?

Could the recent landscape have formed by a mega-flood?

Some questions, above, I will touch on to help explain what I'm trying to achieve using remote sensing. I'll start off with the one big drawcard when people think of the Sahara…

THE NILE RIVER

Is it really the longest river in the world?



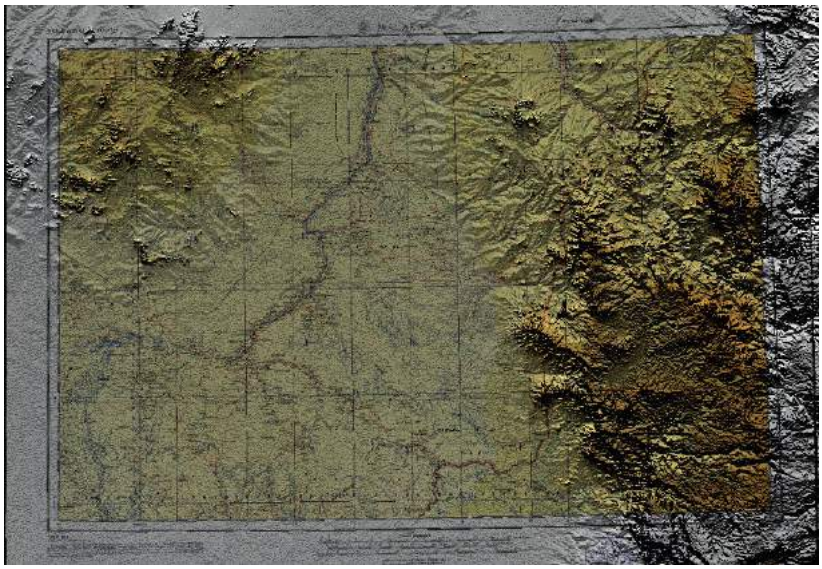
The Sudd

What happens to the Nile River here?

After I'd extended my zone of interest from Egypt to all of North Africa, the Nile River in the marshy regions of the Sudd attracted my attention on the DEM. That's the issue to consider…the Sudd Basin is a marshland and viewing the digital topography, one can question whether there is a well-developed channel for the Nile River.

THE SUDD…(1)

Malakal
Georeferenced Topographic Map

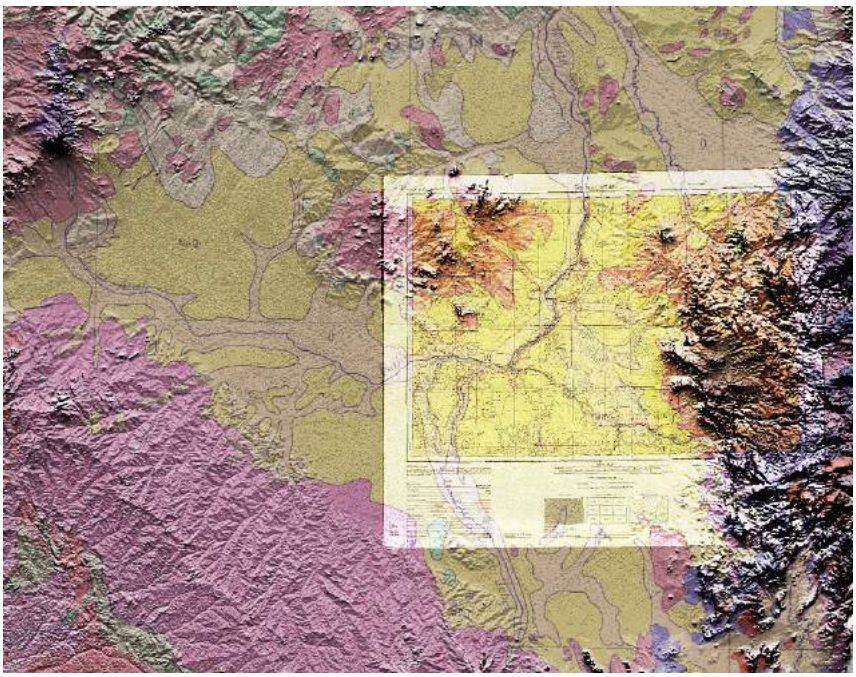


Africa Maps - Perry-Castañeda Map Collection - UT Library Online (utexas.edu)

Africa does have coverage of topographic maps. The only ones I have access to are the British and US Army maps from the 1940's-1960's available from the University of Texas collection. The Sudd Basin has coverage, but like in most locations, air photo mapping and interpretation is of variable quality.

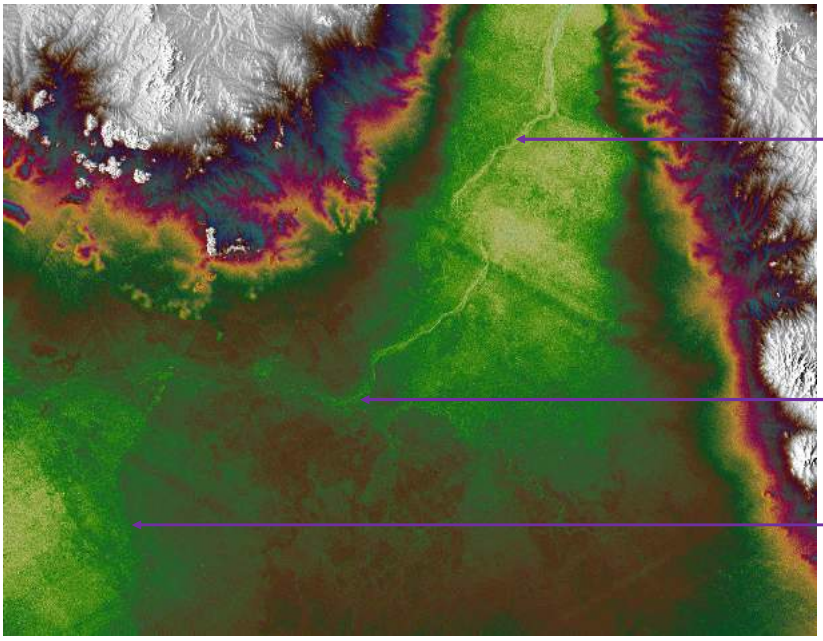
THE SUDD…(2)

Malakal Topographic Sheet
NE Africa Geological Map 1:10,000,000



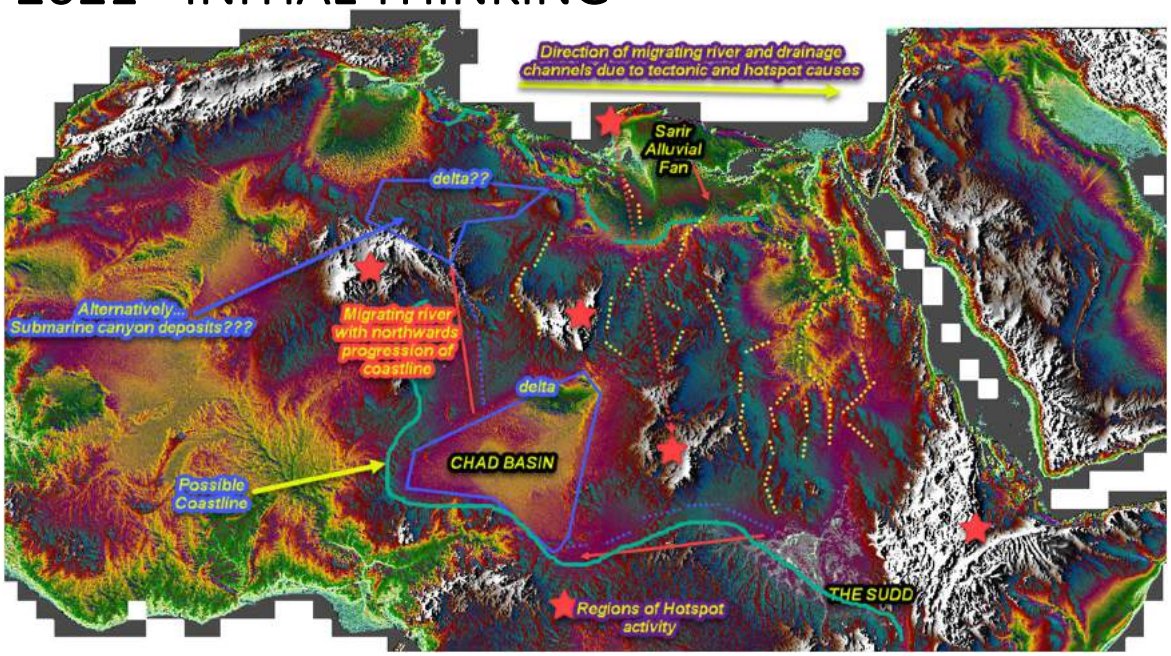
Adding the geological data from Map 8 of the Geological World Atlas suggests how digital topography can enhance the interpretation of the regional area.

THE SUDD…(3)



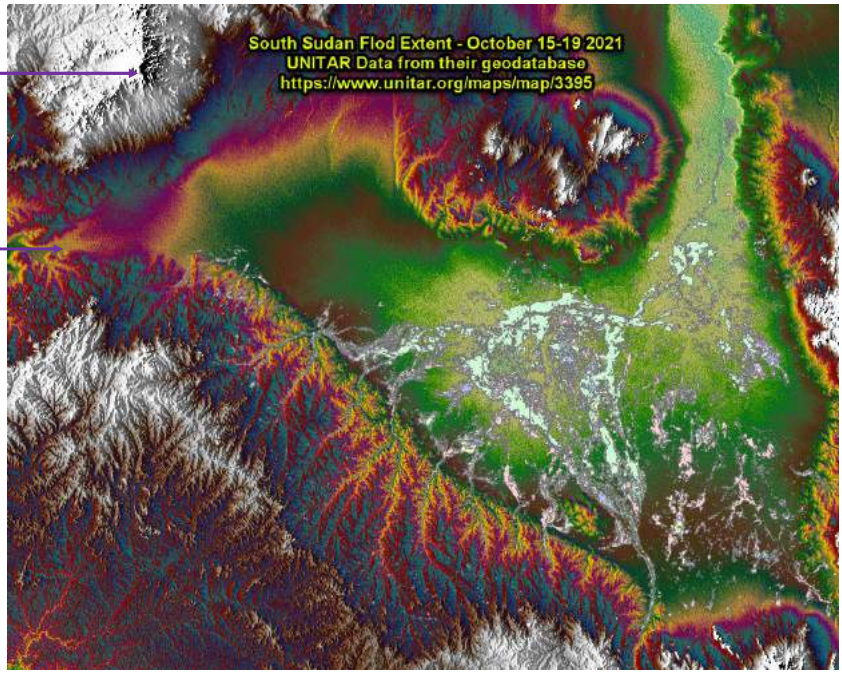
Looking solely at the digital topography, we can see the Nile River entering the Sudd from the north but becoming more weakly defined in the Sudd wetlands the farther south you go. Let me just return to the North African DEM I showed earlier.

2021 - INITIAL THINKING



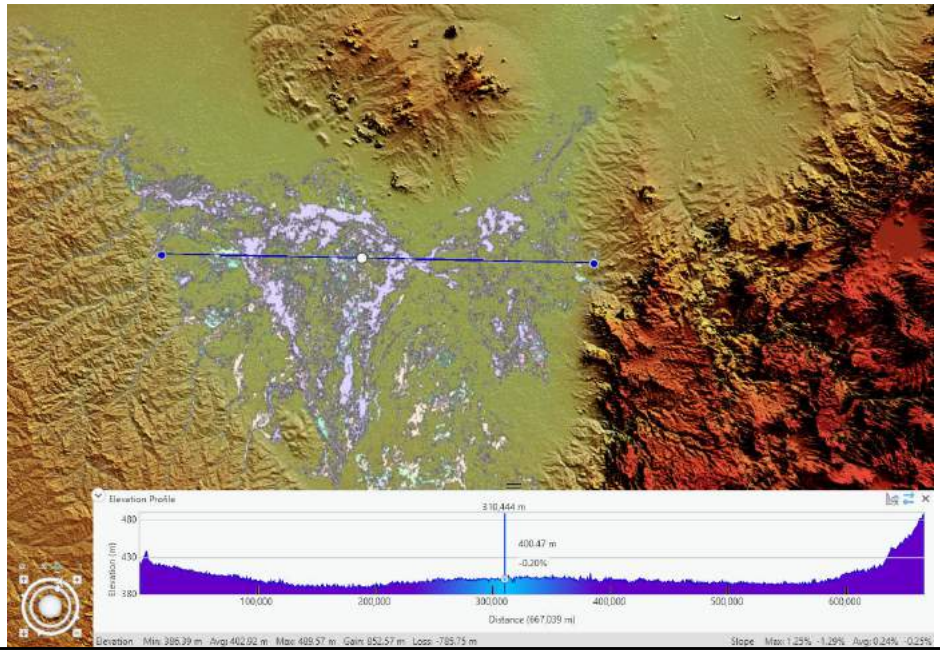
Remember, I'm about using CREATIVE THINKING, using structural details, geomorphology and physiography. Interpreting SRTM data is **not** that straightforward. Here, I'm suggesting a possible coastline at the edge of the mountains forming the southern and western cratonic regions of the African continent, with a suggestion that maybe the Chad basin initially formed as a delta. A river, flowing from the southern craton, follows the edge of the ranges, flows into the Chad Basin – it does appear to have a deltaic form, from a certain perspective. The basis of this thinking can be seen in the Sudd where I've overlain the data from the October 2021 floods.

THE SUDD…(4)



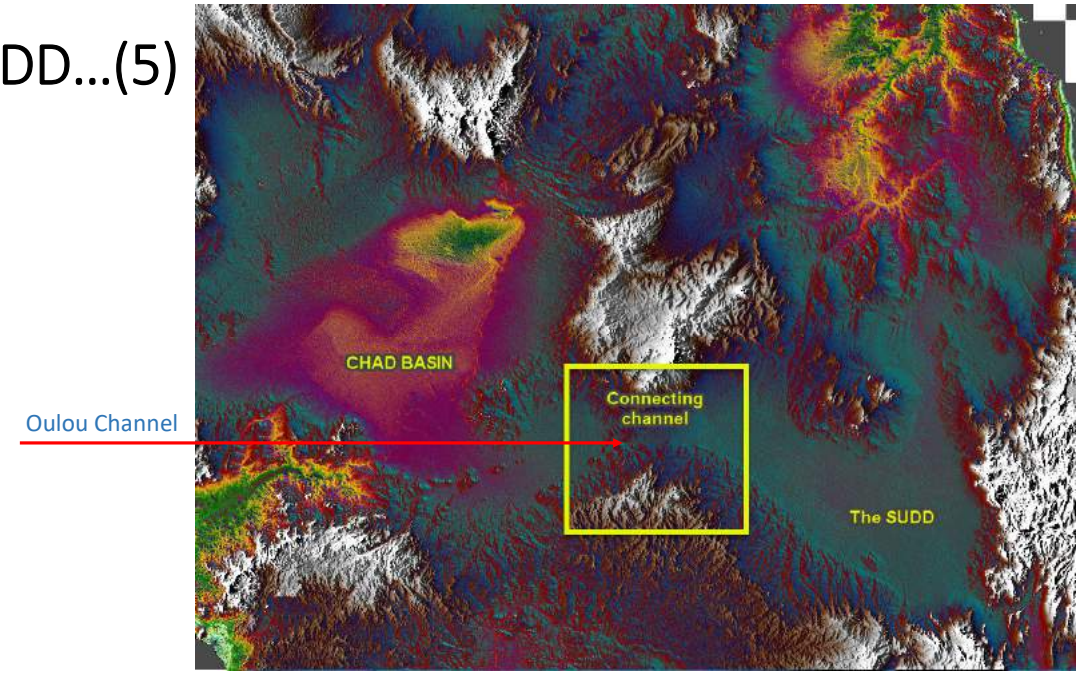
The floods show the influence of a structural feature on the river underlying the Sudd…apparently a rift basin. However, there appears to be 2 distinct directions of flow: one trending northerly towards the White Nile channel at Malakal, and a second trending north-westwards towards the Jebel Marra.

The SUDD…Topographic Profile



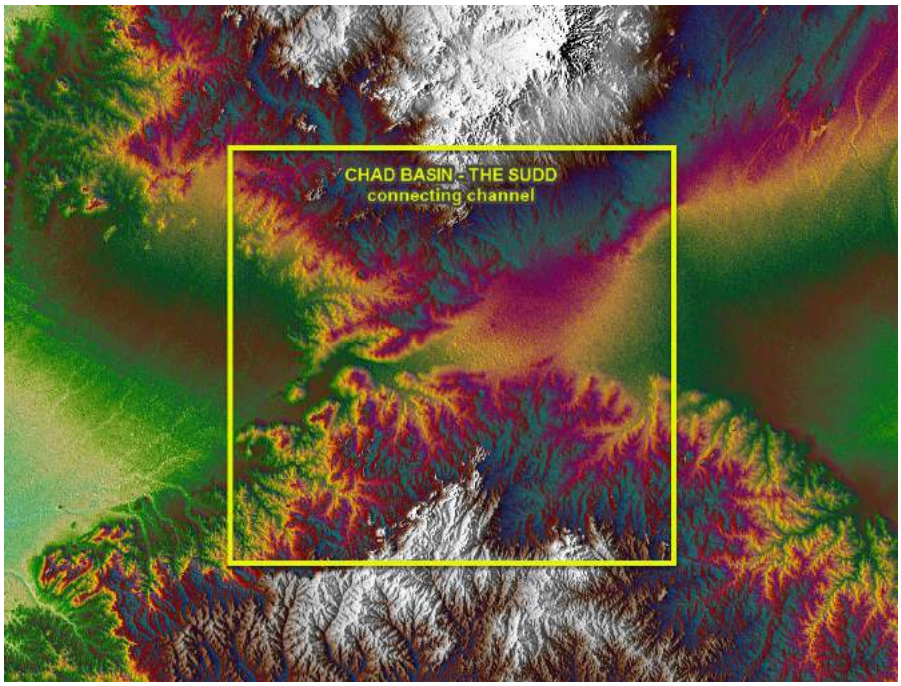
A topographic profile shows a definite splitting of the topography. The white dot location is the reference point of the vertical blue line in the profile.

THE SUDD…(5)



One of my earlier drifts across the DEM brought my attention to the northwestern corner of The Sudd below Jebel Marra and my idea of a river flowing on along a coastline or coastal plain into the Chad Basin. Managing to find data regarding the October 2021 floods was a fortunate pointer to flow direction. There is a connecting channel and is referred to as the Oulou Channel.

THE SUDD…(6)



X- really does mark the spot!

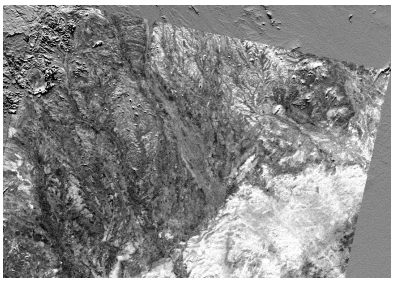
The Oulou Channel is quite clearly defined. The interesting feature is in the coarser texture on the eastern side that appears to be blocking the channel. What is it? Ash flow, debris avalanche, drainage debris? A combination?

What needs to be taken into consideration is that the Sudd Basin is surrounded by active tectonics and 2 volcanic environments, the EAR and the Darfur Dome, both of which commenced around 30 million years ago and both of which are active in today's world. Jebel Marra (the Deriba Caldera) was thought to have had an eruption about 2,000 years ago. However, it's not an amenable region to get to do field work, hence sparse information. Furthermore, it is thought that Jebel Marra (i.e. the Darfur Dome) formed by a separate mantle plume to the EAR plume. Heating from both plumes would have caused a combination of uplift and rifting. What is the effect of 2 separate plumes interacting on the Sudd Basin and on the progressive development of the Nile River?

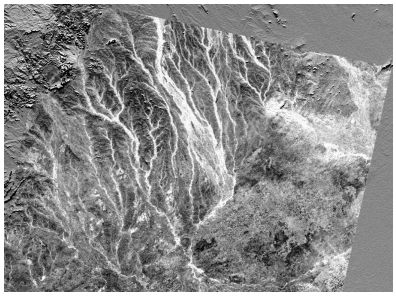
The 6000 km long Tibesti Lineament also comes right through this region. We still do not have a full understanding of this lineament.

THE SUDD…(7)

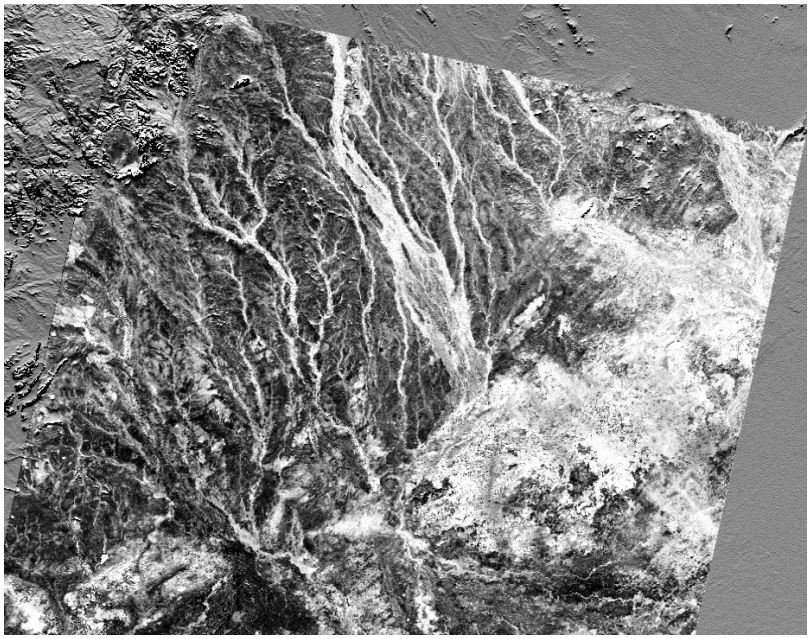
ICA2



ICA3



ICA2&3…blended in ArcGIS Pro

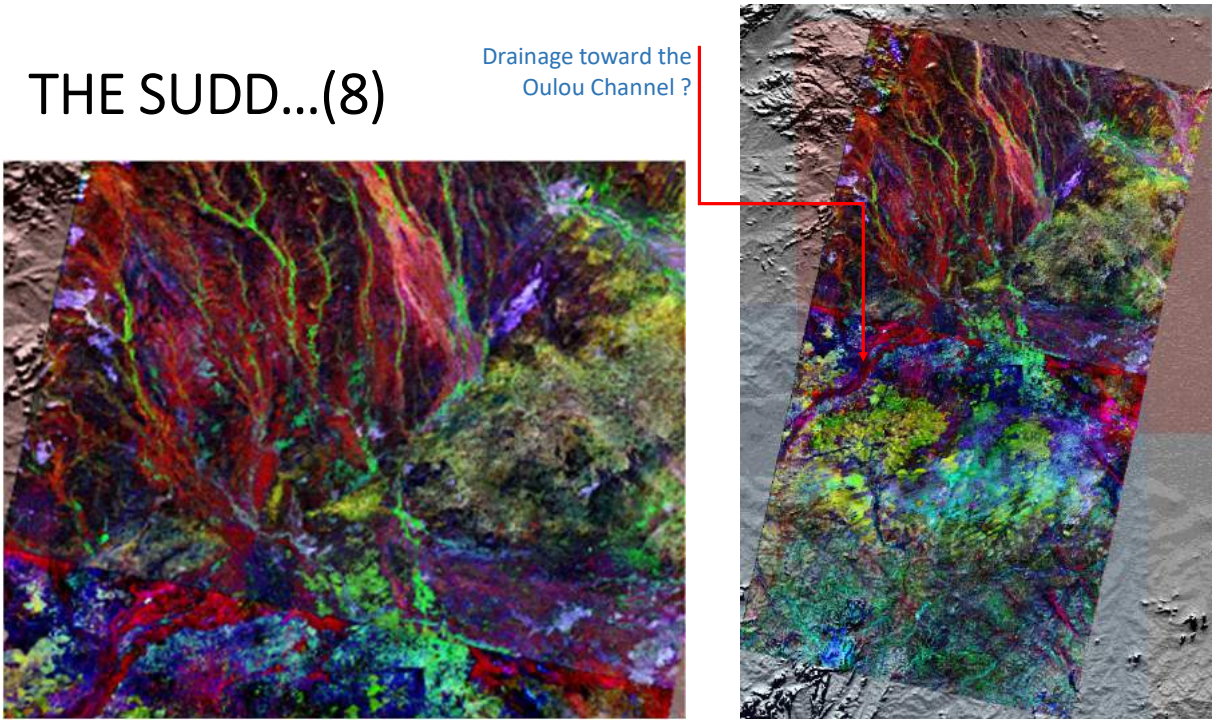


In the last month, I decided to apply my methodologies of using Independent Component Analysis and a band ratioing methodology to try to understand the debris using Landsat 8 imagery. In this case, the methodologies have been applied on the raw imagery bands, rather than the atmospherically corrected images…I need to re-apply for a licence extension for the ATCOR plugin.

Briefly, the ICA method provides a signal unmixing process which, applied to the surface, allows one to see different surface textures that create the whole surface physiography. The band ratioing technique helps to discriminate the FeOx, clay and carbonate components. In the band ratio method I've developed, this hopefully provides a better discrimination of the differing material components.

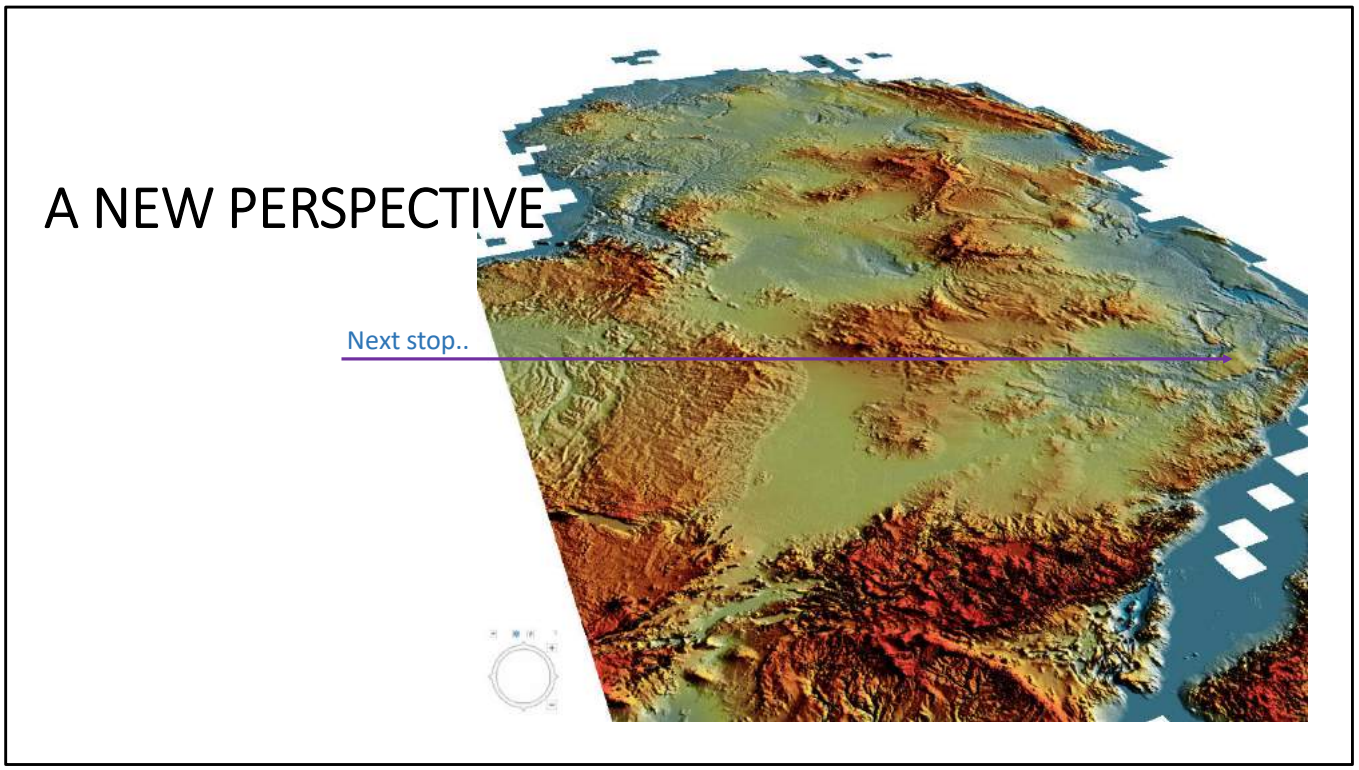
This slide demonstrates what I mean by unmixing surfaces, by showing the slope below Jebel Marra down to the coarse textured debris fill. In a 7-band layer stack, making up bands 1-7 of Landsat 8, that is, the visible, near infrared and short-wave bands, 7 different surfaces are produced – ICA 2 and 3 are featured. These basically represent a statistical mapping of what goes into making the whole surface through the unmixing of the 7 bands of the electro-magnetic spectrum. Clearly there is a strongly developed drainage system down the slope. So, are we seeing drainage debris as the cause of the channel blockage?

THE SUDD…(8)



When blending in the false colour composite of the ratio bands, there clearly is a structure of some type blocking and diverting the drainage down from Jebel Marra in this northwestern corner of the Sudd. As I've only just started working on this, I draw no conclusions, only that there is evidence of drainage diversion at eastern side of the Oulou Channel as well as evidence of structural control on the drainage into and/or from the Sudd. Much work needs to be accomplished on working through what my methodologies are picking up and showing and applying them to the wider area of the Sudd Basin and surrounds.

I can say that I'm quite satisfied with how my methodologies are able to discriminate the features I really need for a comprehensive investigation of this scale. As an aside, I have also processed the adjacent northerly image of the Deriba volcanic centre and surrounding older calderas, and the methodologies do discriminate a wide range of features providing the ability to map out the volcanic region.



One must consider the possibility that the Nile River is in the process of *currently forming,* by river capture, in the Sudd Basin, hence, why the mapping of a Nile River channel is important for describing the length of the Nile.

However, from a human perspective, what are today's implications? Water in the Sudd Basin is surrounded by volcanic heat and active tectonics. What might happen to the marshland's groundwater if sub-basin rifting due to EAR and Darfur Dome tectonic and volcanic activity continues? The Sudan and Egypt are already under stress with waterflow and water retention schemes on various parts of the Nile River, as well as those caused by climate changes. The re-activation of geological and geodynamic forces may have adverse consequences. We do not have this geological information nor the ability to get a complete knowledge and understanding of the geology of this regional area due to accessibility by a regional conflict. Significant geological effort is required if organisations are to help with the provision and access of water in the wider region. How do we get it? On top of the ongoing socio-political climate, natural climate change is, therefore, just one natural global issue this region faces.

Perspective and view direction can only aid and help with creative thinking. Covering the whole of the North African continent helps provide one with the understanding of just how inter-connected all the topography and physiography is. One direction of thought I've had, since starting this project, is that the topography may have at some time in the

past been affected by a mega flood. A number of authors have mapped and postulated individual mega lakes, including the Sudd, and have suggested a mega flood from the individual lakes themselves…but…what if all the lakes were affected at the same time? Maybe through a combination of climate,such as glacial melting (in the Quaternary) combined with tectonic and volcanic activity? This will be followed up, to an extent, in my talk to the Geologists' Association in March. It's a direction of thought that will require time to look at a substantial portion of the project area for the evidence, possibly needing to incorporate all the African continent to resolve this idea!

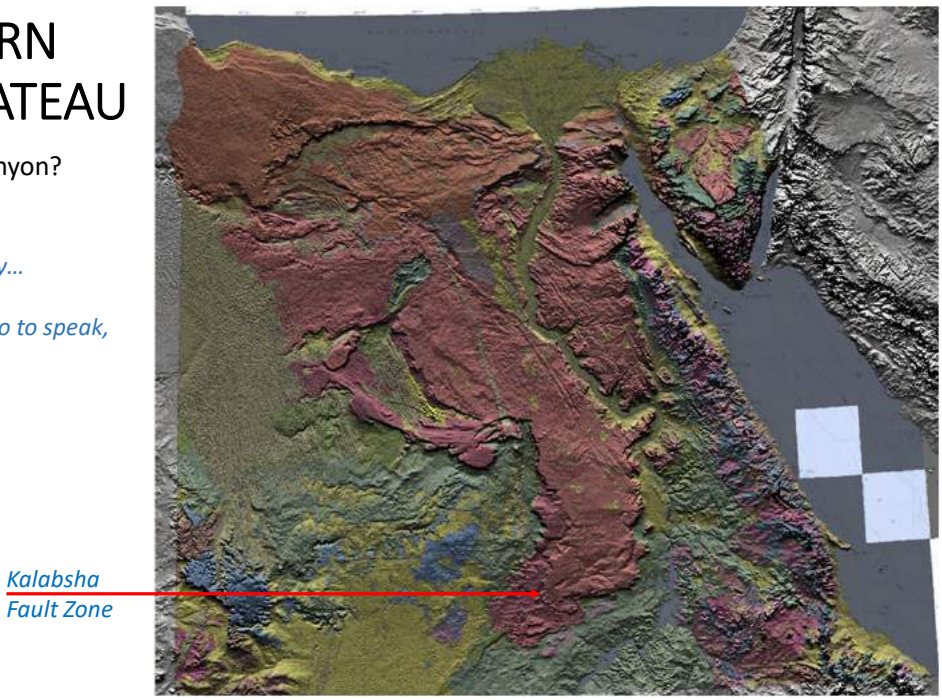
I just wish to briefly cover one more area, the Western Limestone Plateau of Egypt, which is where I started the project, and as a continuation of the Nile River theme to this talk.

EGYPT…WESTERN LIMESTONE PLATEAU

Was there really a Nile Canyon?

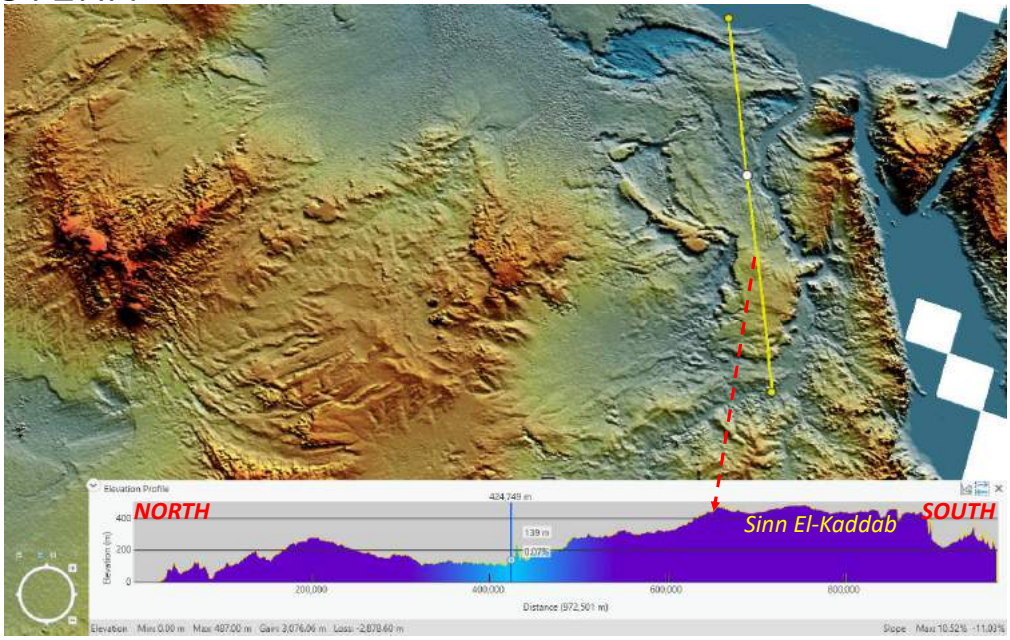
A lesson in Egyptian Mythology…

DRAW your own conclusions, so to speak, of the landscape formation!!!



The Western Limestone Plateau, forms the escarpment and high ground to the west of the Nile and from the Qattara Depression in the north to Aswan and Tushka Lakes in the south. Supposedly, the Nile canyon formed during the Messinian, extended down to Aswan from the Nile delta, and was filled from the east and the west once the sea level rose again. Given the fact that this was supposedly a deep canyon, dwarfing the Grand Canyon, that's a lot of space to fill in a short period of time. Currently my sub-surface knowledge is not (*well*) developed. It's not easy/possible to get hold of the petroleum data to build up a comprehensive subsurface picture. Nor have I yet delved into the literature fully. All I'm analysing and interpreting is what I can see and describe on the imagery.

EGYPT…WESTERN LIMESTONE PLATEAU

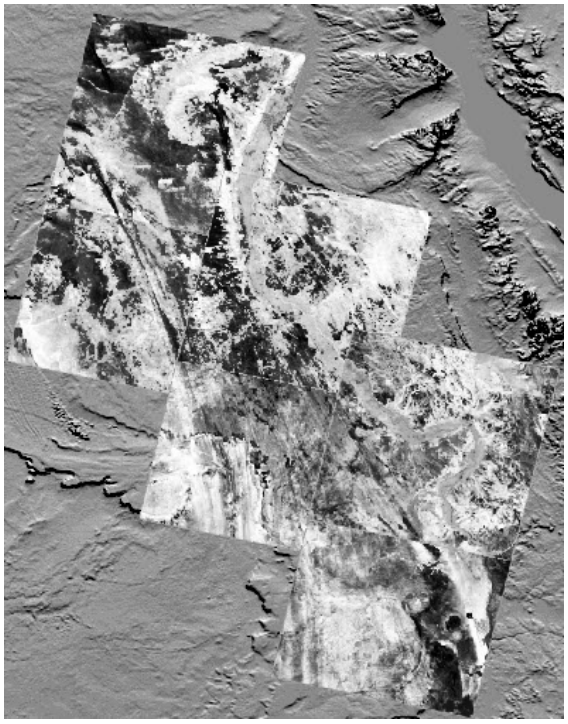


There has been a large number of investigations around and on the edges of the plateau (*not* to mention the petroleum exploration), particularly in and around the depressions: Qattara, Bahariya, Farafara, Dakhla, Kharga, Tushka Lakes and the Nile Valley itself. Also, some remote sensing work has been done mapping the *Desert Eyes* (fault formed/bounded domal structures found on the plateau) as well as mapping of the Kalabsha fault zone. Yet the surface morphology of the plateau is still not mapped and yet shows really interesting physiographic and structural details.

There is a great deal of difference in surface morphology between the southern Sinn El-Kaddab plateau region and the lower northerly plateau region in both structure and drainage.

EGYPT…WESTERN LIMESTONE PLATEAU

ICA Imagery of the Western Limestone Plateau



Screenshots of the imagery covering the plateau do not do the physiography of the plateau any justice: the *devil is really in the details* and zooming in and looking through the length and breadth gives you a better comprehension how complex the surficial features are. Mapping the plateau and discerning the complex interaction of structure, drainage/palaeo-drainage, aeolian landscape processes, lithological variations and karst geology will be a long and time-consuming process – I've been on and off the plateau since 2019 wondering the best place and way to start and still can't think of the best approach. The band ratio methodology I've only devised in the last 6 months to which I haven't completed the processing for all the imagery.

Mapping will not be as simple as doing some form of classification, which has been used, or AI processes, which appear to be the way the technology and research direction is driven. Human eyeballing for close observation and using variations of ICA surfaces and various band ratio combinations will need to be applied to build up the individual surface features of at least 9 Landsat images to fully map the surface landscape of the Western Limestone Plateau.

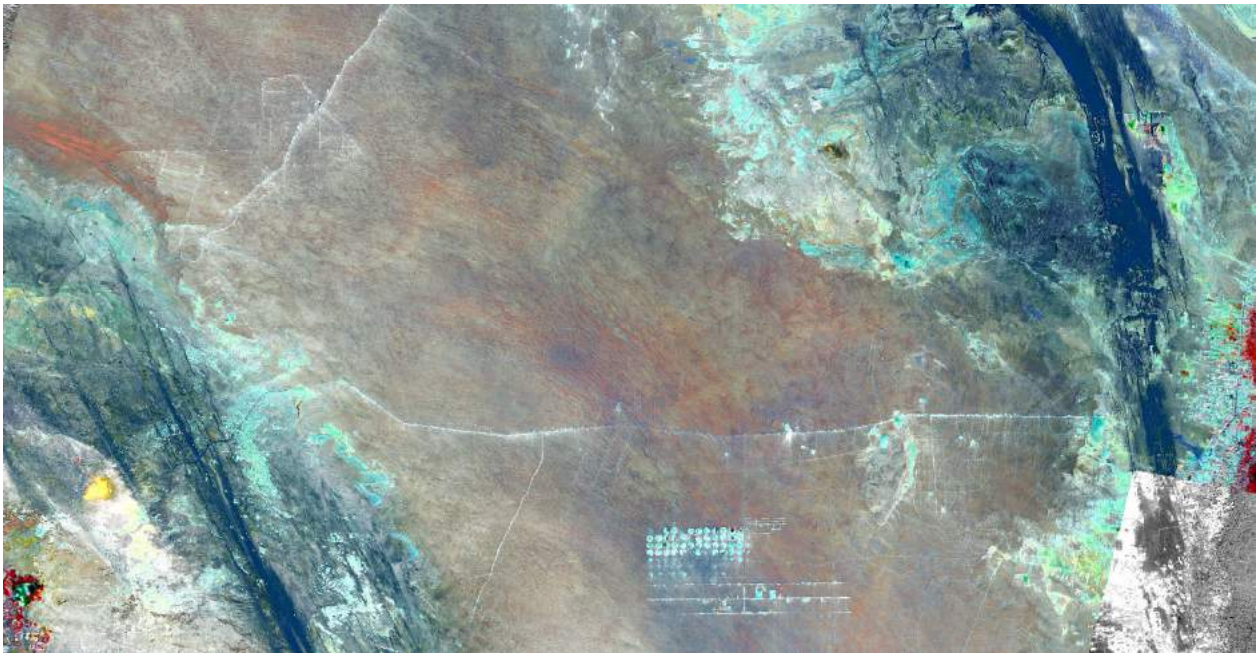
Why should this effort be accomplished? H_2O, Di-hydro Monoxide, Water – call it what you will.

I have a suspicious inkling, that given the complex structural nature of the plateau and

that water-sapping around the edges of the plateau seems to be a dominant, active process, as well as the drainage complexity of the surface, then the question needs to be asked as to whether there is a structural aquifer hidden in the plateau. I can't say nor could I comment on the quality of the water that might/hopefully be there. Would the effort be worth it? The only way to know is to put some effort in mapping the plateau and eventually getting on top of it and doing what geologists do best!

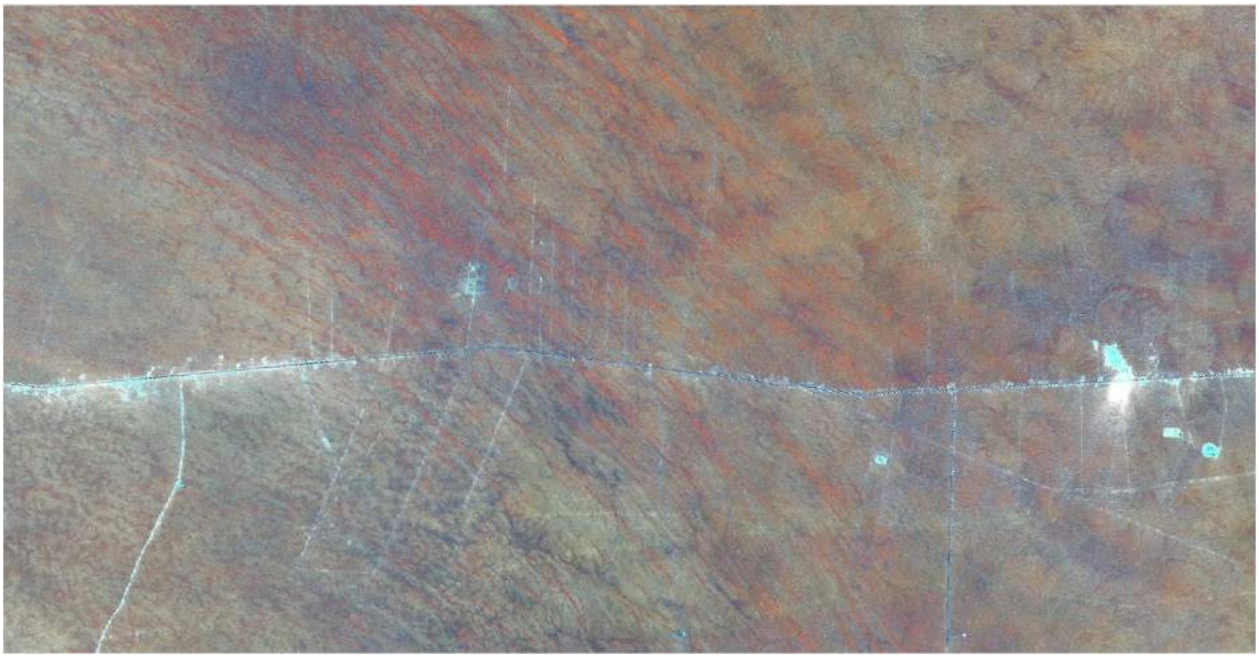
I'll endeavour to quickly show some of the features in a few slides that follow. I won't locate the images, but I'll try endeavour to keep a north to south direction.

EGYPT…WESTERN LIMESTONE PLATEAU



Below Qattara, the plateau appears to be a fold surface with small reddish brown sand dunes being structurally controlled. These will probably be older than the blue dunes emanating from the basins.

EGYPT…WESTERN LIMESTONE PLATEAU



The curvi-linear nature of the dunes developed on top of a karst influenced surface near the turn of the folded surface.

EGYPT…WESTERN LIMESTONE PLATEAU

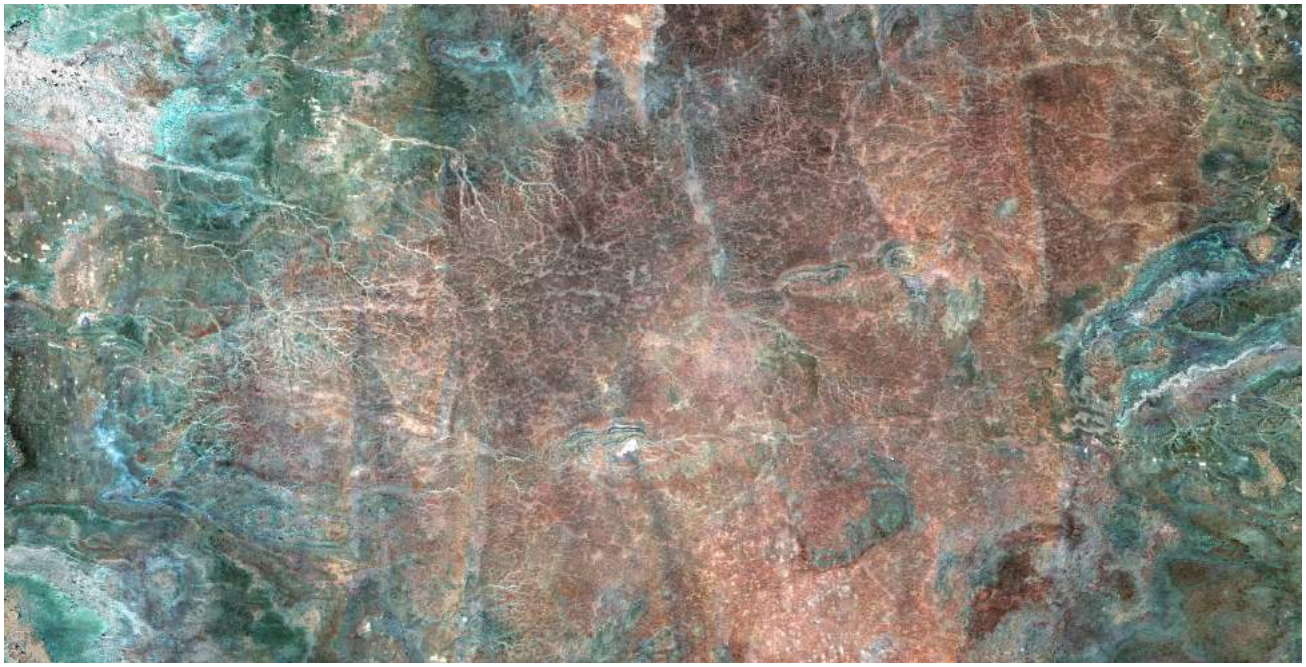
Focussing on the aeolian features of the dunes coming down into the Kharga Depression and along the top of the Western Limestone Plateau. Appears to be structurally controlled. The question to ask is whether the extensive Yardang fields encountered on the plateau surfaces were formed by aeolian activity, or whether they were pre-existing structural features enhanced by aeolian action which channelled sand to form the elongated dunes, thus modifying the rock along the way.

Are we seeing just a figment of imagination or are the dunes highlighting a pre-existing large-scale structure?

EGYPT…WESTERN LIMESTONE PLATEAU

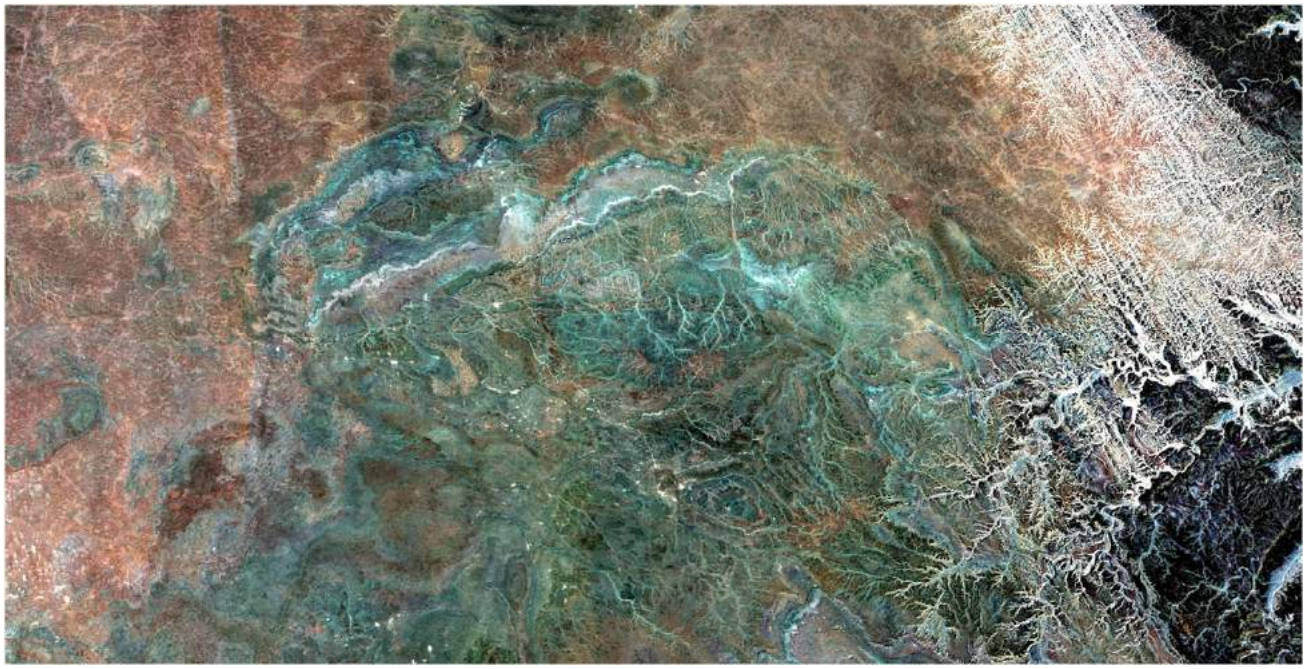
There is definite evidence of a pre-existing drainage surface prior the dune formation as well as earlier cross-cutting structural trends. This is one area where the low but lengthy scarps became a focus of my interest.

EGYPT…WESTERN LIMESTONE PLATEAU



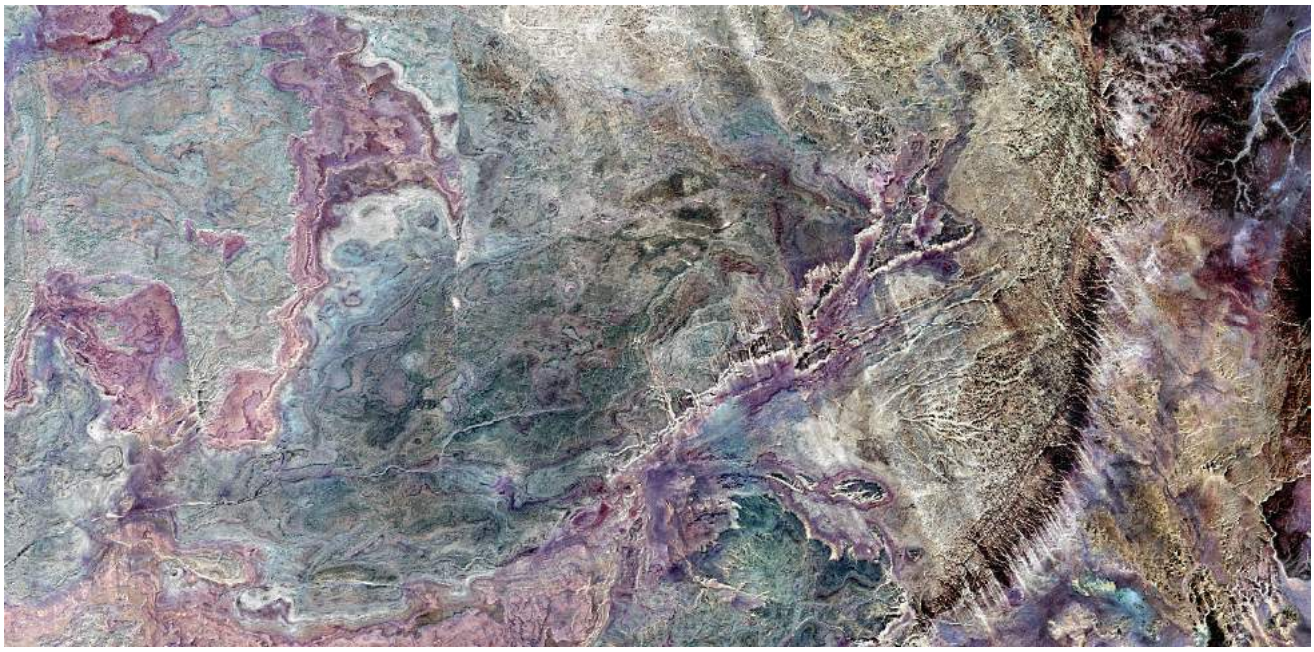
The weird one: ghost folds, just before you get to the northern edge of the Sinn El-Kaddab section of the plateau. Needs quite some effort to work this out. Hence my previous comment of the bigger picture being an imagination for the eyeball…

EGYPT…WESTERN LIMESTONE PLATEAU



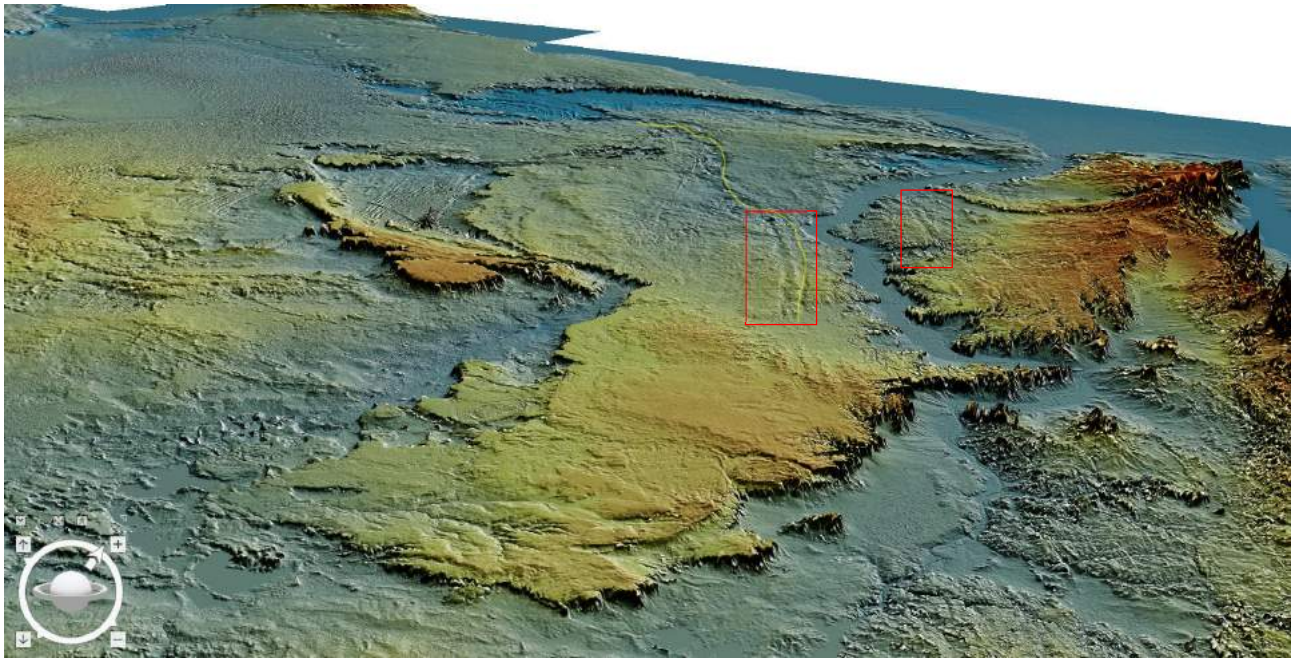
The drainage and basin system below the ghost folds… closer views show the scarp formations…

EGYPT…WESTERN LIMESTONE PLATEAU



The surface features common on top of the Sinn El-Kaddab Plateau. Low scarps form from some form of drainage basin system. Again, these scarps became a focus for the overall investigation

EGYPT…WESTERN LIMESTONE PLATEAU



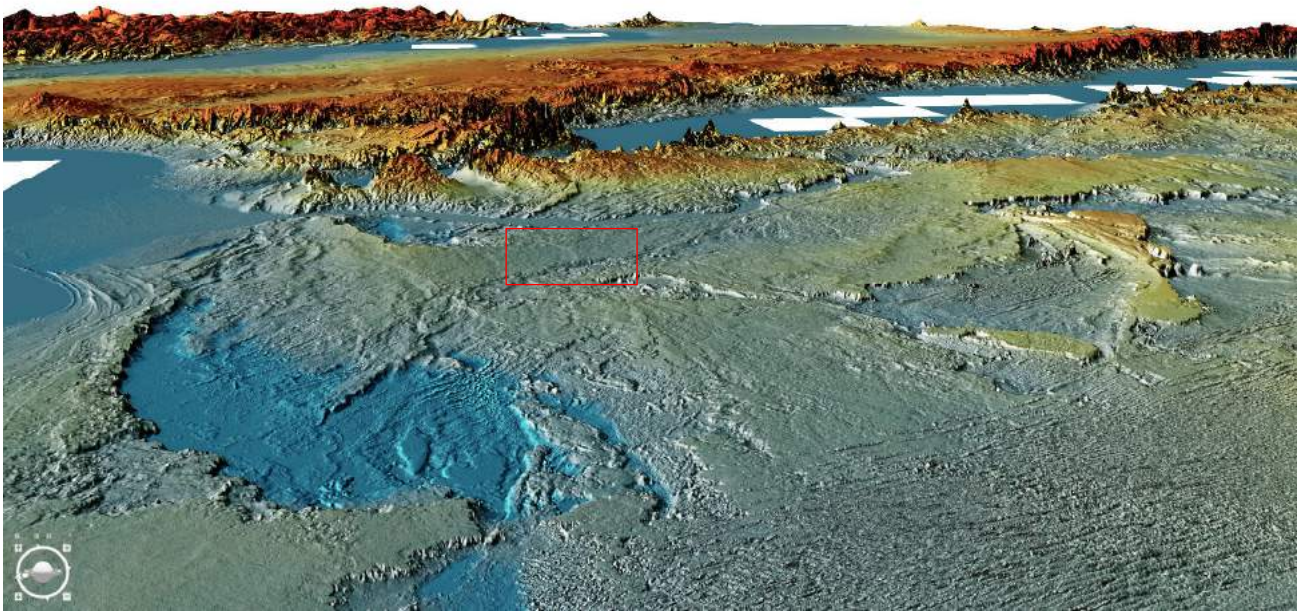
Everywhere you look, there are scarps at different scales. Why?

From the few images seen previously, it's hard to say for certain whether you could find any evidence for a previous Nile River Canyon. I could hint at a strong structural control of a possible shear zone, or are we seeing the surface effects of flexural slip on thin lithological units that have been modified by aeolian activity? Much work is to be done.

This image: The Western Limestone Plateau from the southeast from over Lake Nasser, looking north westwards. There appears to be an eroded low cliff (pale yellow line) coming down out of the Qattara Depression through the middle and ending down at the front of the Sinn El-Kaddab Plateau. Within the red boxes, the twin railway tracks, as I call them, may be suggestive of being dextrally fault displaced. The question remains whether they are of the same structure.

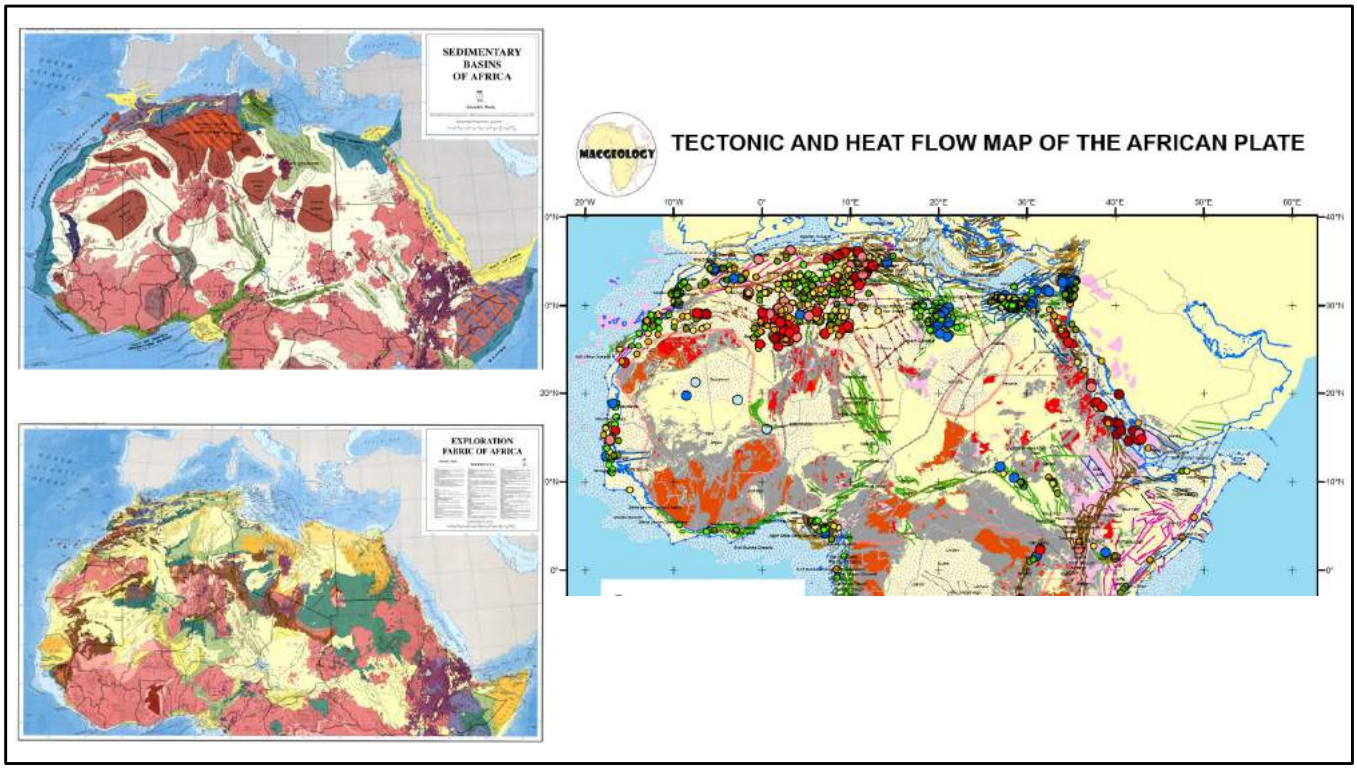
Overall, one can see a suggestion of some form of fault-bounded circular basin.

EGYPT…WESTERN LIMESTONE PLATEAU



The opposite perspective. No obvious circular basin but definitely appears to be some doming of the Western Limestone Plateau, just to the south edge of the Qattara Depression, a Syrian Arc feature, as well as doming at the start of the Sinn El-Kaddab Plateau region.

The red box is where there is the suggested older dunes are formed on the top of what maybe an open fold surface. A pre-Syrian Arc surface?



Evidently there is a lot of geology that can be georeferenced to help build up a comprehensive picture of North Africa. I know that Duncan McGregor is compiling data over Africa from a petroleum/sedimentary basin exploration perspective. Gratefully, he has provided me with some of his GIS data files. Whether anyone is doing the remote sensing geomorphological/physiographic/palaeo-drainage/structural geological work over a continental scale such as this project, I don't know.

This is a very large and complex project. Anybody willing to take on board some aspect is very welcome to.

Finally, one of my favourite Saharan stories, the plateau of Abu Tartur, Egypt … Is this the location of the entrance to Tarturus from Greek mythology???

There are always some fascinating stories that are embedded in the landscape, which can only be visually expressed when we view the surface from above.

With this, I come to the end of showing you how I'm using remote sensing technology in mapping the surface of North Africa. I hope that it has made you think about observing this planet from a different perspective and in a different light. I thank you for allowing me the opportunity to present this talk and wish you all a good evening.