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Writer: Eivind Marius Stuvland	..... (Writer's signature)
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**Kalavryta and Kerpini Fault Block: Investigation into correlation and  
nature of sub-horizontal layers; Corinth Graben, Greece.**

By

Eivind Marius Stuvland, BSc.

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Eivind Marius Stuvland

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## **Abstract**

### **Kalavryta and Kerpini Fault Block: Investigation into correlation and nature of sub-horizontal layers; Corinth Graben, Greece.**

Eivind Marius Stuvland

University of Stavanger

Supervisor: Chris Townsend

The Gulf of Corinth is located in West-Central Greece and is the result of a Pliocene-Recent, asymmetric extensional rift system. The region offers an excellent opportunity to study rotated fault blocks and the various syn-depositional sedimentary environments that form within them. The focus area for this study are the two fault blocks: Kerpini and Kalavryta. These two fault blocks were studied in order to map a series of sub-horizontal sedimentary layers found in the two fault blocks, ascertain their nature, determine the relationship with each other and the relationship with surrounding sediment (which usually has a moderate to steep southward dip). Previous studies in the area have neglected to address the sub-horizontal sedimentary layers, and have classified them as basal conglomerate (Ford et al., 2013). In order to fully understand the sub-horizontal layers (assumed to be younger), the underlying sediment had to be mapped. Geological maps were created of the study area, mapping both structural and stratigraphic features. Maps were digitized and the data was later analysed with the aid of numerous images recorded in the field.

A total of 8 separate outcrops of sub-horizontal sediments have been identified; 2 of these were later dismissed as ‘dipping’ sediment during analysis. This was based on dip angle/dip direction and flow direction within these two units. The remaining 6 units have been correlated based on location, flow direction and texture. The lower-lying (older) sediment was determined to be part of a massive alluvial fan that originated from the Kalavryta Fault, flowing N/NNE, covering the area. This study places the lower-lying sediment to pre-Kerpini Fault. The sub-horizontal layers (late-syn / post Kerpini Fault) have a more fluvial character and show an E/NE flow direction, entering the fault blocks from the SW and are assumed to flow towards the Dhoumena Fault Block, but not continuing east towards the Vouraikos River. This study has provided a new model on the sedimentation of the Kerpini Fault Block by addressing a problem that was not previously answered. Additionally, it contradicts some previous ideas about the development of the Kerpini Fault Block.

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# Chapter 1: Introduction

## 1.1 Background

The Gulf of Corinth is located north of the Peloponnese peninsula in central Greece. The northern region of the Peloponnese has been heavily influenced by the rifting of the gulf which is estimated to have started ca. 5 Ma (Armijo et al., 1996; Ford et al., 2013; Ori, 1989). This has resulted in a series en echelon normal faults, striking WNW- ESE and dipping NNE, migrating from older to younger from the region of Kalavryta and north to the shore of the gulf (Moretti et al., 2003). Bounded by these extensive north dipping faults there are spectacular rotated fault blocks which provide an excellent opportunity to study the structural and sedimentological development within an extensional setting.

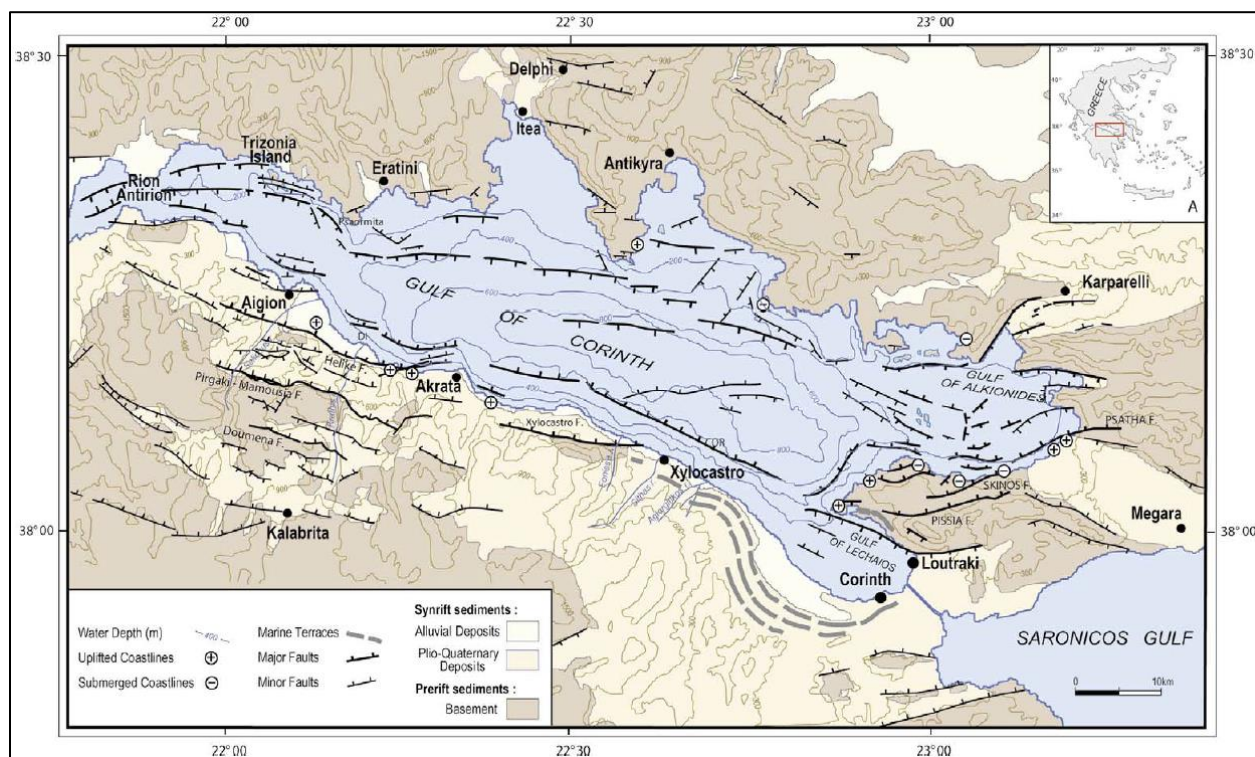
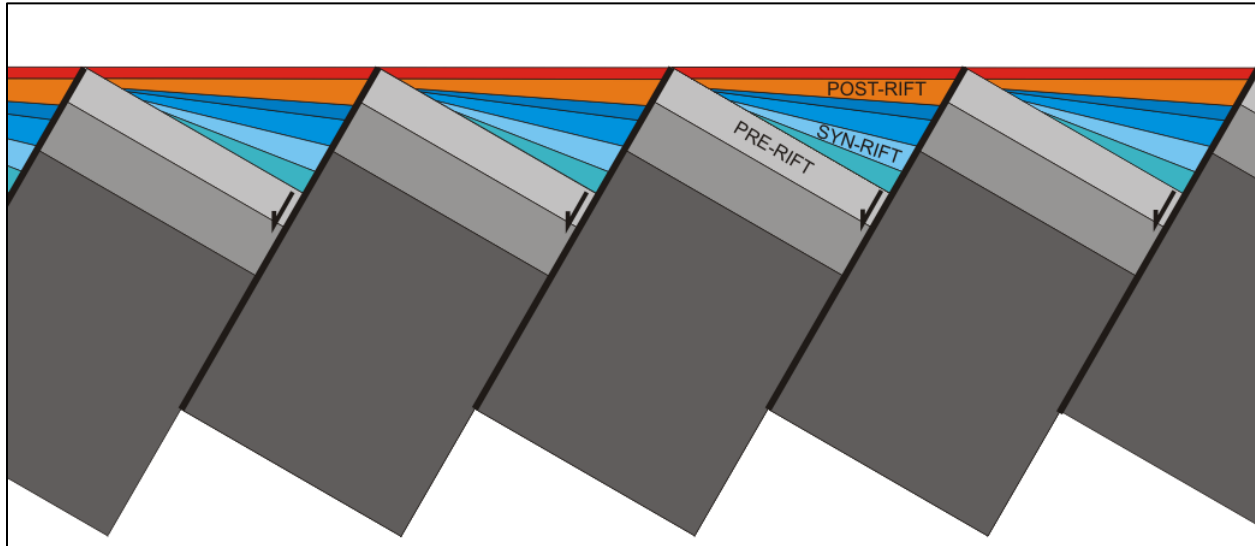


Figure 1-1: Structural map of the Gulf of Corinth. The red box indicates the area of interest. (Modified after Moretti et al. (2003)).

## 1.2 Geological Problem

Extensional systems are often associated with normal faulting creating half-grabens. As the faults within such a system migrate, the older faults' footwall is uplifted. This may then form what is known as a “domino” structure (Figure 1-2).



**Figure 1-2:** This shows a generalized “domino” structure. The sediments that are defined as syn-fault show a change in dip angle from older to younger, getting shallower as they become younger.

As the block is rotated and the footwall is uplifted, it creates accommodation space for sediment. These sediments, in a typical syn-fault depositional model, are expected to exhibit a change in dip from older to younger as the block rotates, i.e. growth strata (Figure 1-2). Furthermore the sediment should have a dipping trend towards the older fault, where the main depocentre is found. This is not observed in the Kerpini Fault Block, where one does not find any growth strata. In the Kerpini Fault Block the dipping sediment shows a constant dip angle, which is not consistent with a typical syn-fault depositional model (Syahrul, 2014). Moreover there is a sedimentary unit that sits high up, close to the Dhoumena fault. At first glance these sedimentary units appear to have been deposited during the tilting of the Kerpini Fault Block. However, these sedimentary units, which are of a conglomeratic nature, do not dip towards the Kerpini hanging wall, but are of a sub-horizontal nature and the dip trend often is found to be towards the north. This is in stark contrast to what would be expected of syn-fault deposits. These sub-horizontal sediments are also found in the adjacent Kalavryta Fault Block that lies to the south.

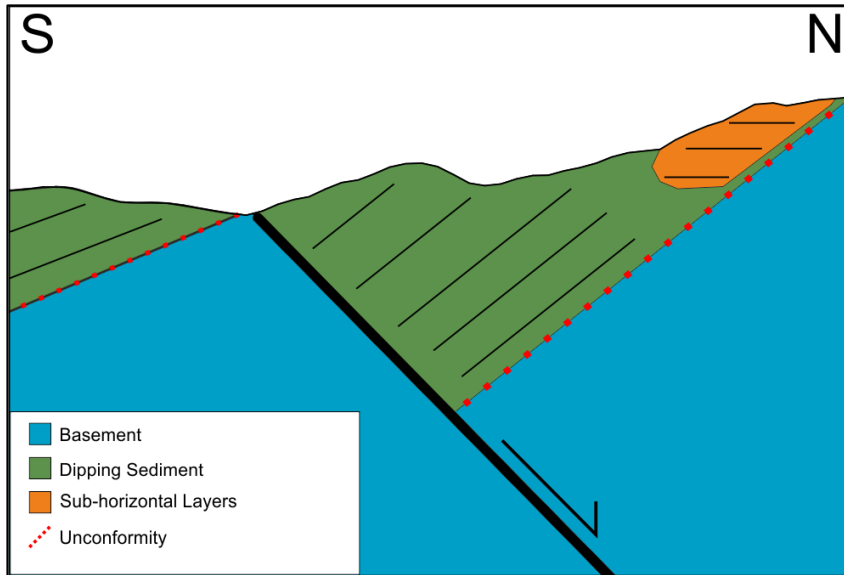


Figure 1-3: A sketch representing the definition of sub-horizontal sedimentary layers used in this study. The image shows the dipping sediment commonly found in rotated fault blocks, and the sub-horizontal sedimentary layers that are located further north in the fault block.

The sub-horizontal sediment raises several questions that will be addressed in this thesis:

- How did these sub-horizontal layers get deposited at such a high elevation?
- What is the relationship between the sub-horizontal layers, and the dipping conglomerate and basement? Are the sub-horizontal layers younger?
- Given the erosion that has taken place in the region, why have these layers not been eroded?
- Why are the dip angles not consistent with typical models for rotated fault blocks?
- Can these sub-horizontal layers that are found at several locations across two adjacent fault blocks be correlated?

### 1.3 Objectives

The objective of this thesis is to study the sub-horizontal sedimentary layers found within the Kerpini and Kalavryta Fault Blocks in order to attempt to:

1. Ascertain how they were deposited so high on the Dhoumena footwall and far from the main basin depocentre.

2. Determine if they can be correlated, both locally and at distance.
3. Establish if the sediments found east of the Vouraikos valley can be linked with those found in the Kerpini Fault Block<sup>1</sup>.

## **1.4 Methodology & Data**

This will be covered in more detail in Chapter 3. The methodology can be divided into three phases:

### Pre-Field Work

Prior to conducting the field work a thorough review of literature was conducted of published papers and journals. This was deemed critical prior to commencing any field work. Satellite imagery was studied in order to get a better grasp of the sheer scale of the area and to pinpoint specific localities of the sub-horizontal units. Google Earth proved to be an indispensable tool, especially with its 3D viewing capabilities.

### Field work

Field work was conducted over a 3 week period; this time was split between two researchers studying overlapping areas. Where possible, strike and dip were measured on the sub-horizontal layers. Faults that had been identified during the first phase were visited to confirm previous measurements. Lithology of the area of interest was logged, and detailed photographs were taken for later analysis. Each location where a measurement or photograph was taken was logged on GPS.

### Post-Field Work

Upon returning from the field work a database of the collected data was created. This tied the logged observations to photographs and GPS waypoints. The images were processed and

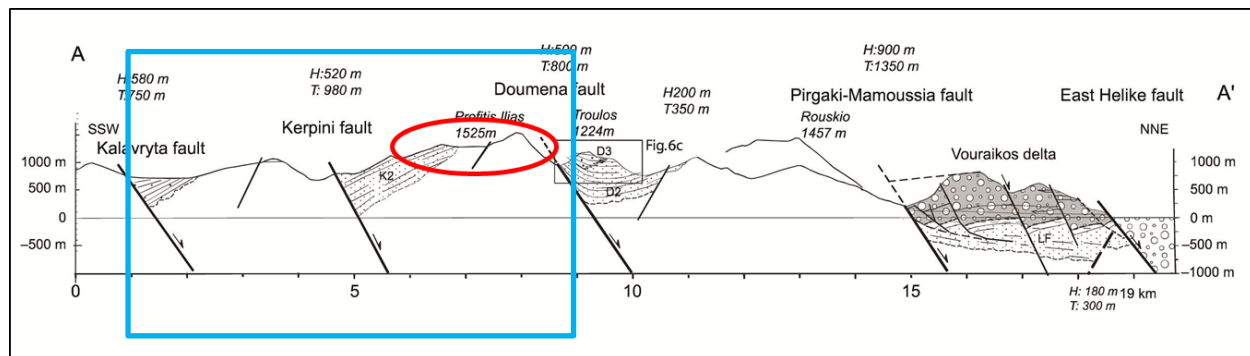
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<sup>1</sup> This third part of the thesis was conducted in the field; however the observations and interpretations for this third part have been left out of the main thesis on the recommendation of the authors' advisor.

panoramas were stitched together. These products were then analysed and a conceptual model was constructed to summarize the findings as well as attempt to answer the problem chosen for this thesis.

## 1.5 Previous Work

The region of Kalavryta-Helike has been the focus of study for many years by researchers eager to study the effects of an extensional system.



**Figure 1-4:** The blue rectangle shows the study area for this thesis and the red circle on the cross-section shows that the sub-horizontal layers have not been considered in previous work. In this particular paper they are referred to as basal conglomerates. (Modified after Ford et al. (2013)).

The area offers excellent outcrops for both structural and sedimentological studies. Many of the previous studies conducted have focused along the southern shore of the Gulf of Corinth with its remarkable Gilbert-type deltas. Until recently, few detailed studies of the area surrounding Kalavryta were conducted. However Ford et al. (2013) published a paper that covered the region from Kalavryta and northward toward the gulf. In their paper they offer their explanation for the sedimentation in the area (covered in Chapter 2), dividing it into 3 groups. However the sub-horizontal layers have simply been categorized as basal conglomerates (Figure 1-4) and they are never referred to as exhibiting a different dip/dip direction in comparison with the other sediment in the Kerpini Fault Block. In addition to offering a new take on the sediments, Ford et al. (2013) follow suit with others in believing that the sediment found overlying the basement are syn-rift deposits (Gulf of Corinth rifting). This supports previous work by Collier and Jones (2004) and

Sorel (2000) who also define the sediments as syn-rifting. Furthermore Collier and Jones (2004) describe the sub-horizontal sediment as being major landslips and progradational alluvial fans, which are considered to be part of larger structures. They describe the sedimentation in the region to be that of fluvial conglomerates that were deposited within the accommodation space created by the southernmost faults (Kalavryta, Kerpini and Dhoumena) accompanied by a significant alluvial fan north of the Kerpini fault (Collier and Jones, 2004).

For his MSc Thesis, Syahrul (2014), studied the Kerpini Fault Block to investigate fault controlled sedimentation. Although many of his conclusions raised more questions than they answered, Syahrul did conclude that the lack of changing dip angles, or slight change (not completely consistent) in the Kerpini block, could be explained by episodic movement of the fault. According to Syahrul, the source of sedimentation in the Kerpini block was determined to come from both south, southwest and northwest. From the south the source of sedimentation was the river of Vouraikos and its tributaries and from the westward direction it was a result of the Kerpini and Dhoumena footwall uplift.



## Chapter 2: Regional Geology

### 2.1 Introduction

This chapter will provide insight into the area this thesis is focusing on. It is important to have a general understanding of the complexity of the region. The reason for the eastern Mediterranean being so complex is closely related to the interaction between several plates: the African, Eurasian, Arabian and Anatolian (Agostini et al., 2010). The Anatolian plate can be further sub-divided into the Anatolian and the Aegean Plate (Apel et al., 2007).

It is this interaction, between these plates, that is significant in understanding the evolution of the area of interest, especially the collision of the African plate with that of the Anatolian plate. This collision of these plates creates the Hellenic or Aegean arc (Figure 2-1). The resulting subduction of the African plate, which happened faster than the northwards



Figure 2-1: Plate tectonics in eastern Mediterranean. Arrows showing plate movement relative to a fixed Nubia (African plate) (Apel et al., 2007).



movement of the plate, led to a slab pull southward movement of the Anatolian plate (Royden, 1993). This difference in migration velocity resulted in a back-arc extension, and the creation of the Aegean Sea. This extension started in Miocene times (Armijo et al., 1996; Jolivet et al., 1994; Le Pichon and Angelier, 1979). There is still debate on whether this can be considered a “typical” back-arc basin as described by Agostini et al. (2010). The paper reviews the current thoughts on the extension and provides new insight into the possible evolution of the Aegean.

As the African plate subducted, it led to an uplift event in the region. This took place pre-Miocene, and resulted in the northern Peloponnese being uplifted at a rate of 1.6 mm/yr (Collier et al., 1992). However current uplift is set to be 1 – 1.5 mm/yr (De Martini et al., 2004; McNeill and Collier, 2004). The total uplift is estimated to be ca. 2km (Sorel, 2000).

## **2.2 Structural Framework**

The Gulf of Corinth or the Corinth Rift, located in Central Greece on the peninsula of Peloponnese, is an extensional rift system that separates the Peloponnese from mainland Greece. It stretches from the Rio straits in the west to the Alkyonides Gulf and Corinth in the east. It is a very young basin and is a N100°E oriented elongated symmetrical graben (Moretti et al., 2003). The region has been the centre of geological study for many years. It presents well exposed seismic scale outcrops and offers excellent opportunities within structural and sedimentological studies, and has been used as an analogue for hydrocarbon exploration within rift systems.

The region south of the Gulf of Corinth is dominated by a series north dipping rotated fault blocks; these fault blocks form a series of half-graben structures and are filled with Pliocene-Quaternary deposits which sit unconformably on the basement (Moretti et al., 2003). Sorel (2000) suggested a detachment model to aid in the explanation of the presently active earthquake region along the southern coast of the gulf. Sorel suggests that the Chelmos fault, the oldest of the north dipping faults, is detached at depth and therefore creates a shallower angle fault that is necessary for active earthquake seismology. This hypothesis of a shallow detachment has been disputed due to the lack of evidence (Collier and Jones, 2004; Moretti et al., 2003; Westaway, 2002). Westaway (2002) on page 280 argues: “A third argument, by Sorel (2000), reinterprets the structure south of the Gulf to include a major low-angle normal fault. However, virtually all this hypothetical structure is below the level of exposure in the field, and what little

outcrop evidence exists can be interpreted (and has been: e.g., Westaway (1996)) as indicating back-tilting of normal fault-bounded blocks when slip on an initial set of moderately-steeply-dipping normal faults was superseded by slip on a steeper set.” (Figure 2-2)

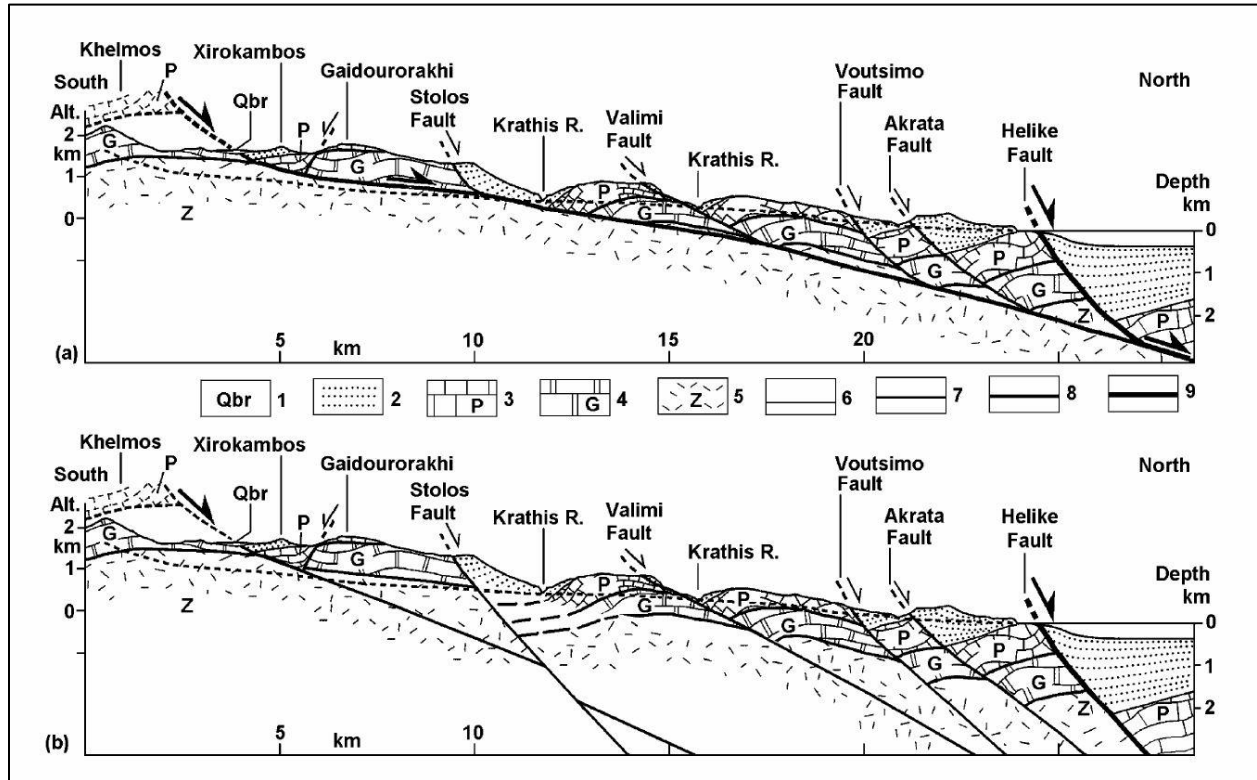


Figure 2-2: (a) From Sorel (2000), this shows the interpreted low-angle normal fault, from Chelmos in the south to the Gulf in the North. (b) Alternative interpretation from Westaway (2002), using the same evidence but without the low-angle fault. (Westaway, 2002)

The region to the north of the gulf is only affected by minor antithetic normal faults (Ori, 1989), and has not been studied to the same extent as the southern area.

## 2.3 Structural Evolution

### Pre-Miocene

From Cretaceous to Miocene the region was subjected to the Pindos thrust sheet (Auboun, 1959; Richter, 1976). This sheet is comprised of Upper Triassic-Jurassic pelagic carbonates with minor red and green radiolarites and Upper Cretaceous-Cenozoic sandy turbidites, which is what forms the “basement” or pre-rift substratum in the Kalavryta area

(Degnan and Robertson, 1998; Skourlis and Doutsos, 2003). During this time period the region was dominated by the subduction of the African plate. This resulted in extensional events, as well as compressional events in the Miocene (Le Pichon and Angelier, 1979) and as mentioned earlier, uplift of the Peloponnese in the Miocene (Sorel, 2000).

### Miocene

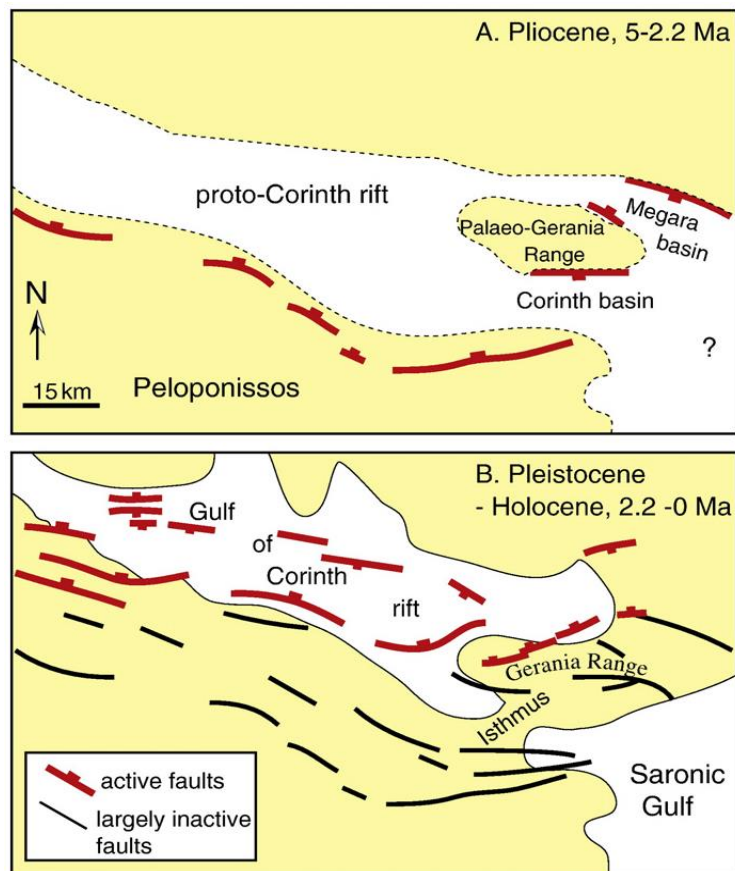
During the Miocene the region was dominated by the extension of Aegean, which was the result of the collision of the Anatolian and African plate (Le Pichon and Angelier, 1979). As the back-arc extension took place east of the Peloponnese, the region was affected in the form of uplift.

### Pliocene

It is during the Pliocene that the rifting of the Gulf of Corinth started ca. 5 Ma. Figure 2-3 shows the initial active faults as they developed along the proto rift.

### Pleistocene - Holocene

Within the Pleistocene-Holocene period, as the active faults migrated northwards, the southern faults became inactive (Figure 2-3). It is also during this time period that, due to the subduction of the African plate, the uplift of the Peloponnese accelerated.



**Figure 2-3: Sketch showing sequential development of the Corinth rift by northward migration of active faulting (Leeder et al., 2008).**

## 2.4 Stratigraphic Framework

The Gulf of Corinth and that of the surrounding area has been studied and published by several authors throughout the years. Le Pichon and Angelier (1979), Moretti et al. (2003), Ori (1989), Skourtsos and Kranis (2009), Backert et al. (2010) and Bell et al. (2009) are but a few who have contributed to further the understanding of the region.

Ori (1989) describes two sedimentary cycles into separate phases during the basin development, in Miocene and early Pliocene, and that these are separated by an angular unconformity. The first cycle show facies ranging from alluvial fans to shallow-water lacustrine environments. This cycle occurred during the first phases of the evolution of the Corinth Rift. The deposits are found along the coast; however they become more prolific further inland. During the first cycle it is suggested that the basin was very shallow with little or no connectivity with the open ocean. The second cycle of sedimentation is composed of the deposition of the large Gilbert-type deltas that are found outcropping along the southern coast of the gulf. The present-day configuration is comparable with that of the gulf during second cycle deposition.

Many of the papers written about the region have focused on the southern shore with its spectacular sets of Gilbert-type deltas. However, Ford et al. (2013) published a paper which also took into account the southern region, from the Chelmos Massif in the south to the Gulf of Corinth in the north. (Figure 2-4) In their paper they provide a more complex stratigraphy, and have divided it into three informal groups: *Lower*, *Middle* and *Upper*.

*Lower* – The lower group lies unconformably over the Pre-rift Pindos thrust sheet and is composed primarily of coarse alluvial conglomerates; fluvial sandstone and conglomerates; and fluvio lacustrine (Ford et al., 2013). This group is found throughout the area of interest, especially in the southern areas.

*Middle* – The middle group lies unconformably on the lower group. The unconformity is said to be of an erosional nature as the region has undergone severe uplift events. The group is comprised of the massive Gilbert-type deltas of coarse conglomerates, and shows interbedded sandstone layers (Ford et al., 2013).

Upper – The upper group is confined to the northern area, along the Helike fault (Figure 2-4). It is comprised of coarse to sandy conglomerate present day Gilbert-type deltas. The upper group unconformably overlays the two other groups (Ford et al., 2013).

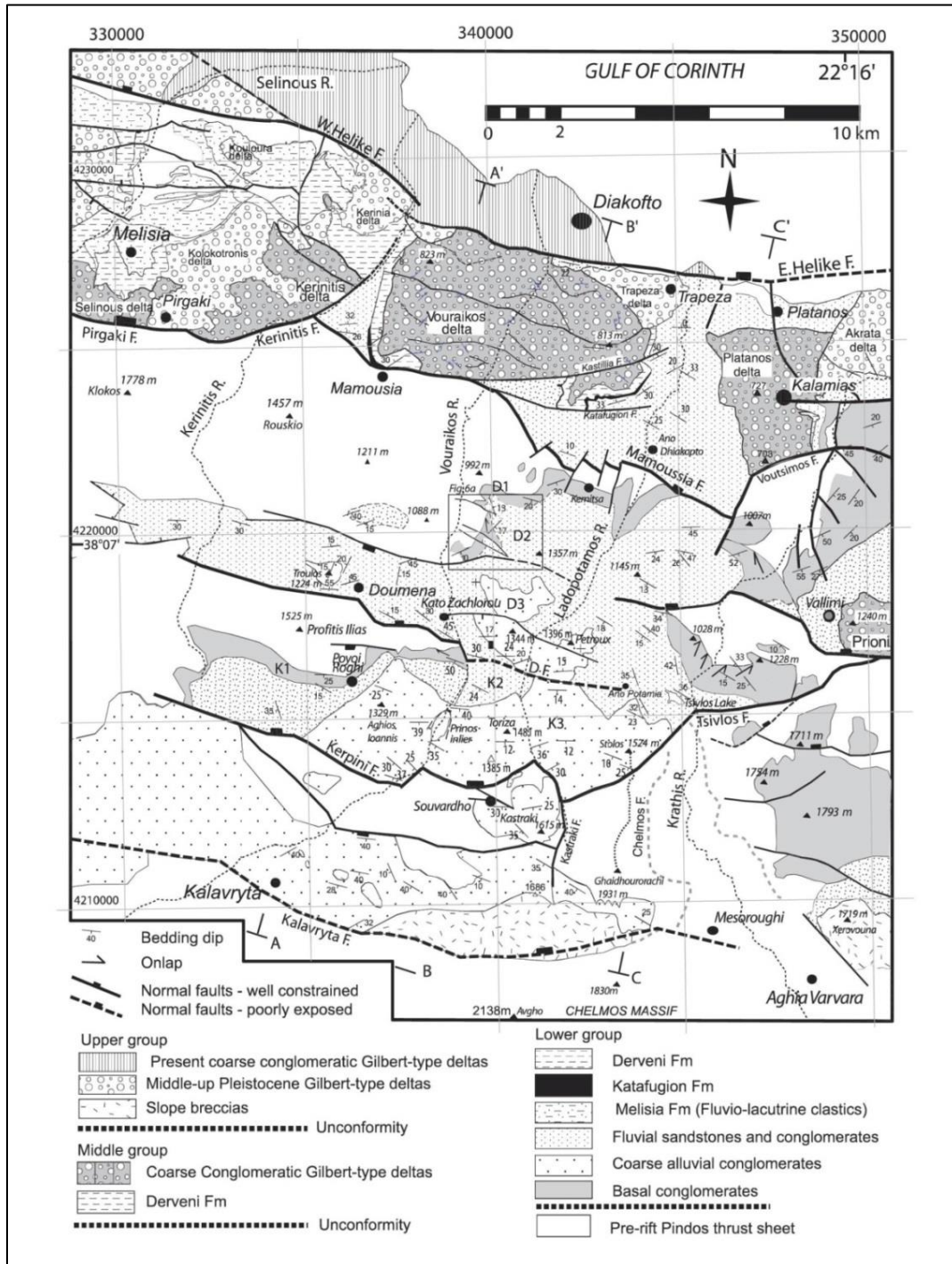


Figure 2-4: An overview of the mapping; from Chelmos in the south to the gulf in the north. (Ford et al., 2013)

## 2.5 Stratigraphic Evolution

The stratigraphic evolution, like the structural, has been under constant study and revision. It is still not fully understood what has happened in the region of Kalavrita-Helike, and the reason is that this can be closely linked with the issues surrounding the relative timing of the faults as there is poor to sparse dating available.

The region that this thesis is focusing on is dominated by the *Lower Group* which is composed of alluvial conglomerates, fluvial sandstone and fluvio lacustrine. The dating of these sediments and the timing of the faults is problematic due to the lack of biostratigraphic markers. However, intermontane lacustrine sediments within boreholes were found to contain lignite facies that have been dated to the Lower Pliocene (5.32-3.58 Ma) within the Kalavrita area (Papanicolaou et al., 2000).

## **Chapter 3: Methodology**

### **3.1 Introduction**

This chapter is divided into two parts. The first section addresses the methodology used to collect field data and how the data was processed. The second section reviews the understanding of sedimentation within rotated fault blocks.

### **3.2 Data Collection and Mapping**

#### **3.2.1 Pre-Field Work**

In order to address the questions that this thesis is attempting to answer, the sub-horizontal layer had to be mapped. Previous mapping of the area was conducted on a large scale, and did not offer enough detail of the two fault blocks, Kalavryta and Kerpini, that were being studied. Prior to travelling to Greece for the field work, a thorough map study was conducted. Attempts were made to use a DEM within ArcGIS; however the resolution of this DEM (30m) was not adequate to isolate smaller features in the terrain. Therefore the primary tool used was Google Earth. Google Earth provided an excellent platform to view the terrain from various angles and to pinpoint possible locations that might have sub-horizontal layers.

#### **3.2.2 Field Work**

The majority of the mapping conducted during a 10-day fieldtrip was done on foot. The mapping involved identifying lithology and faults, and locating possible contacts between the sub-horizontal layers and basement/dipping sediment. Dip angles and dip directions were measured using a “Silva Expedition w/clinometer” compass. This compass allows for a fairly accurate measurement of exposed bedding. In order to avoid measuring apparent dips an effort was made, where possible, to view the bedding from various angles to get the most accurate reading. This was often not possible and therefore there is some uncertainty in the measurements. Every point that was measured was recorded on a geological map and by a GPS waypoint.

The data collected for flow direction within the sediment was done by searching for clast imbrication within the tabular clasts. The consolidated tabular and disc shaped clasts that showed a 3:1 length-width ratio were used to judge flow direction. Several sections of the outcrop were observed to look for trends in the various layers, and, based on that, note down the direction of



flow. Although this might not be the preferred method of obtaining flow direction, it did provide a flow trend within nearly all the conglomerate outcrops visited. Figure 3-1 is an image taken at Unit C (See Chapter 4), the purpose of which is to briefly show the method used to obtain a flow trend within the conglomerate outcrops. The image shows the tabular clasts highlighted with red circles.



**Figure 3-1:** This image is taken at Unit C (See Chapter 4). It shows how the imbrication was observed at the various outcrops. Note that a few of the tabular clasts are highlighted with a red oval.

With regards to clast and grain size, clast measurements were conducted by determining a 1x1m section of the outcrop and measuring the ten largest clast sizes within that 1x1m area. An average was then taken based on these measurements. Where possible an attempt was made to measure at various height intervals, however this was often difficult due to steep terrain. In order to review the data locations at a later date, a total of 2262 images were taken. All images were taken using a Nikon D800 at various focal lengths.

### **3.2.3 Post-Field Work**

Geological maps created in the field were digitized into ArcGIS, during which special care had to be taken to ensure that the maps were correctly geo-referenced. Once correctly geo-referenced, the GPS data points were imported into ArcGIS. Quality checks were conducted on a



random selection of data points. As each data point had a coinciding image, the image was reviewed to ensure that the data point was placed correctly on the map. All images taken were processed in Adobe Photoshop. Minor corrections were made to exposure and sharpness. Finally the processed images were annotated and interpreted in CorelDraw Graphics Suite.

### **3.3 Sedimentation within Rift Basins**

#### **3.3.1 General**

When discussing sedimentation within rift basins it is important to separate between rifting and faulting. Although one may refer to sediment as being pre-rift, a basin within the rift area may be bounded by faulting. Therefore in this thesis when discussing pre-rift, it is discussing the Gulf of Corinth rifting and references to pre-, syn- or post-faulting will be tied specifically to a fault by name.

Figure 1-2 showed a generalized conceptual sketch of sediment infill within a series of rotated fault blocks controlled by a series of normal faults. As the displacement of the normal fault increases, it will also increase the accommodation space for sediment. The sediment that is deposited within the fault process can then be broken down into three phases.

#### **3.3.2 Sedimentation Phases within Fault Blocks**

##### **3.3.2.1 Pre-Fault**

As the name suggests this is sediment that is deposited before any movement of the fault. What is common in pre-fault deposits is a symmetrical trend within dip angles and thickness, i.e. they have not been affected by faulting.

##### **3.3.2.2 Syn-Fault**

Syn-fault sediment is deposited during the course of the movement of the fault. These can be further subdivided into: early, mid and late syn-fault. Certain traits that are commonly found within syn-fault deposits are: decreasing dip angle (towards the controlling younger fault) from older to younger sediments, as one moves away from the controlling faults' footwall the thickness of the sediment becomes thinner, similarly they are thicker on the controlling younger faults' hanging wall.

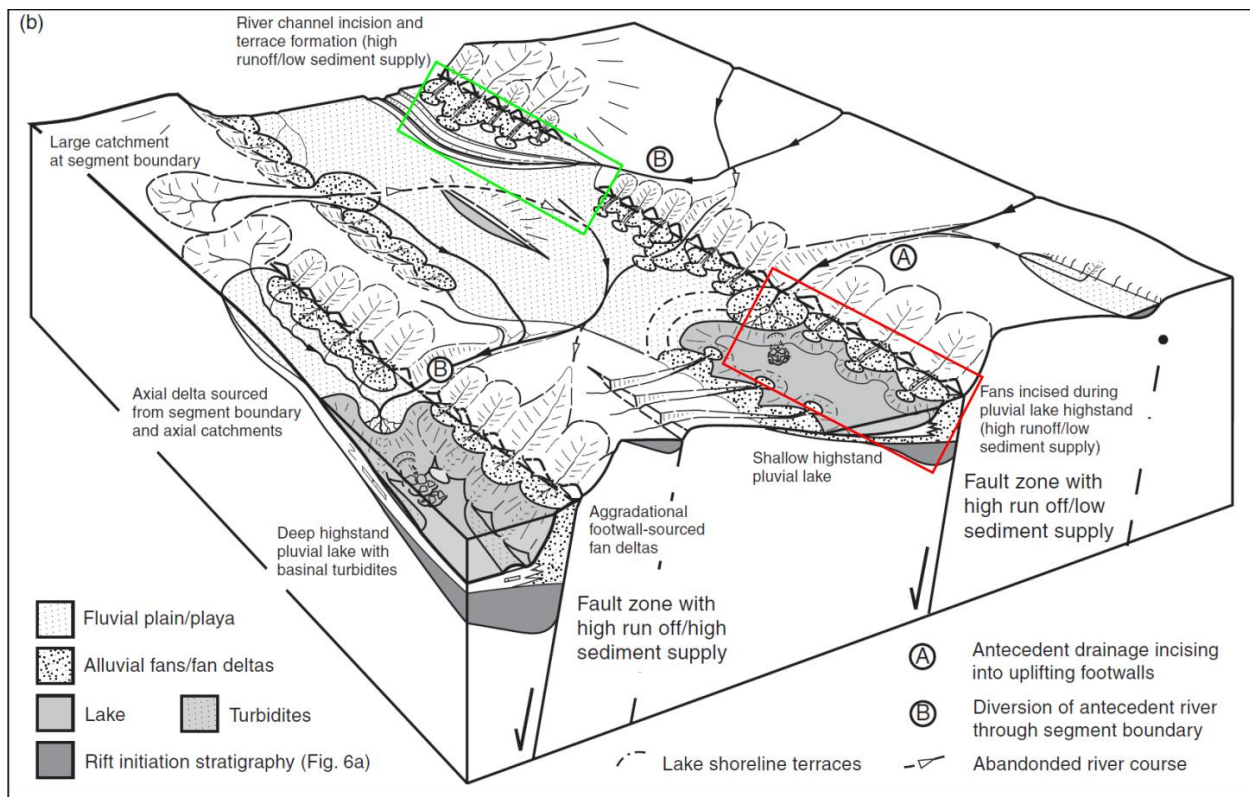
### 3.3.2.3 Post-Fault

Lastly there is the post-fault sediment; these are usually deposited once the fault is considered “dead”, in other words when the fault is no longer active. Commonly these show a consistent dip angle within bedding as there is no longer any tectonic movement to displace beds.

### 3.3.3 Extensional Tectono-stratigraphic Models

Gawthorpe and Leeder (2000) proposed an evolutionary model in their paper for continental environments. The intermediate stage and the final stage, “fault death”, model will be shown.

#### 3.3.3.1 Intermediate Stage



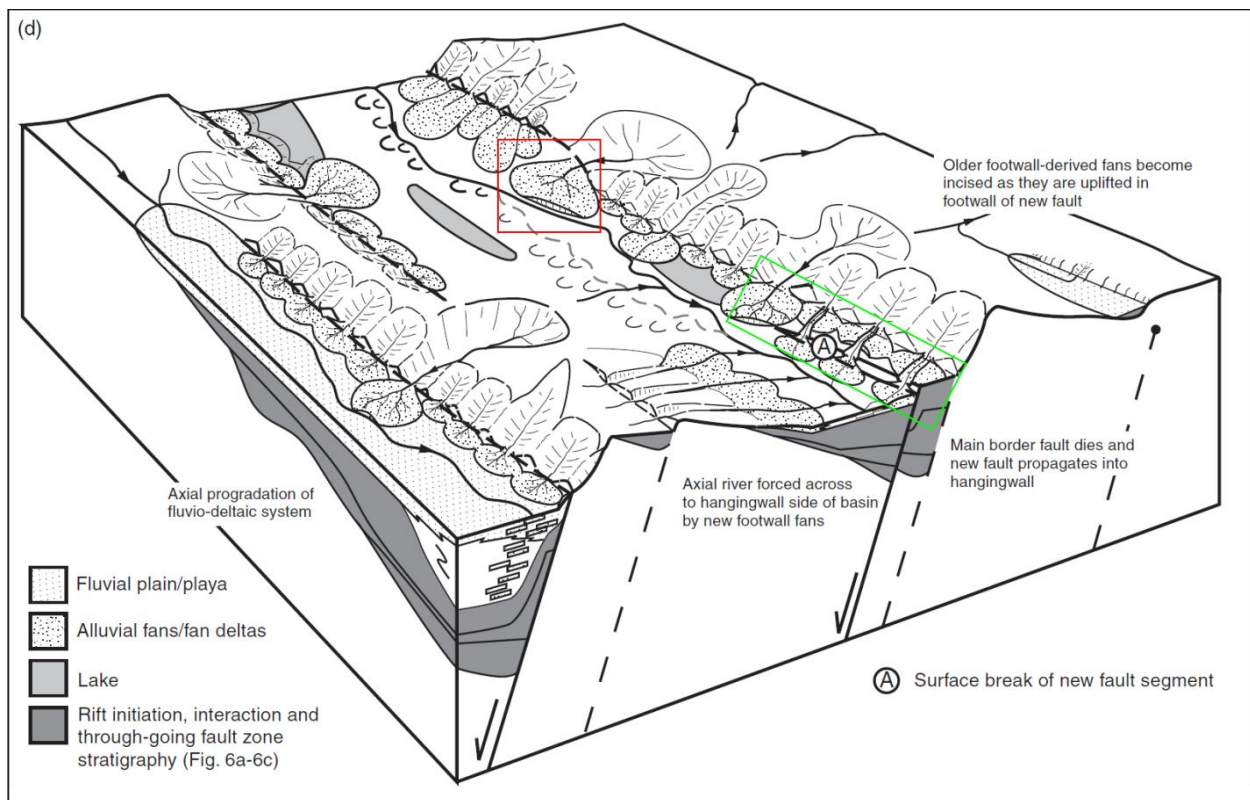
**Figure 3-2: This image represents the intermediate stage with in a tectono-sedimentary continental environment evolution. At this stage in the evolution there is lateral progradation and interaction between the fault segments. As a fault becomes inactive the sediment in the basin adjacent to this fault (red square) becomes buried and persevered or they can become uplifted, incised and reworked. The green square shows a diverted river through a fault segment. (Modified after Gawthorpe and Leeder (2000)).**

Figure 3-2 is an image from Gawthorpe and Leeder (2000) and shows the intermediate stage in the evolution of a normal fault continental environment. Although there is no scale to this image, it is there to show that in a classical model the sediment influx may arrive from

several areas within the rotated fault blocks. The image shows sediment from the uplifted footwall flowing “down” into the basin, gathering at the main depocentre in the basin, and fans that have come off the fault face (red square). More importantly it displays an antecedent river (green square) as it is diverted through two fault segments creating a fluvial system running almost parallel with the fault. This diversion of the fault segments could be viewed as a possible ramp structure between the two fault segments.

### 3.3.3.2 Final Stage

In the final stage the main fault has died, become inactive, and there is a shift in sediment transportation running more parallel in the basin created by the main fault. The previous antecedent river shown in Figure 3-2 is now depicted as a fan coming off the inactive fault face (red square, Figure 3-3).



**Figure 3-3: The final stage of the tectono-sedimentary continental environment evolution model. At this stage the fault segments have linked and the controlling fault has become inactive. As the fault segments have linked the previous antecedent river is now depicted as a fan coming off the inactive fault (red square). The green square shows that the sediment transport is now moving more parallel with the inactive fault within the basin. (Modified after Gawthorpe and Leeder (2000)).**

## Chapter 4: Field Observations

### 4.1 Introduction

This chapter presents the observations made during a 10-day field trip that was conducted in August 2015 in the region. It provides a general description of the sedimentological and structural elements found in the area before delving into the units of a sub-horizontal nature and describing these in more detail. In order to understand the nature of these sub-horizontal layers, and if they can be correlated, which is one of the goals of this study, it is important to understand the sedimentation within the two fault blocks: Kalavryta and Kerpini. Therefore by understanding the underlying sedimentation (older?), it will give a better understanding of the later sediment (younger?) in the fault blocks.

### 4.2 Stratigraphy

#### 4.2.1 Basement

In the area of interest, it is the Pindos Carbonate that is considered to be the basement in the region (Ford et al., 2013). This carbonate layer shows reddish to grey/yellow colour. It appears very chaotic in nature and it exhibits numerous folds and fractures. Due to this deformed nature of the basement it is virtually impossible to obtain any certain measurements from it.



**Figure 4-1:** Image showing basement in the area. This outcrop is located close to the assumed depocentre in the Kerpini Fault Block. The basement is very chaotic in appearance.



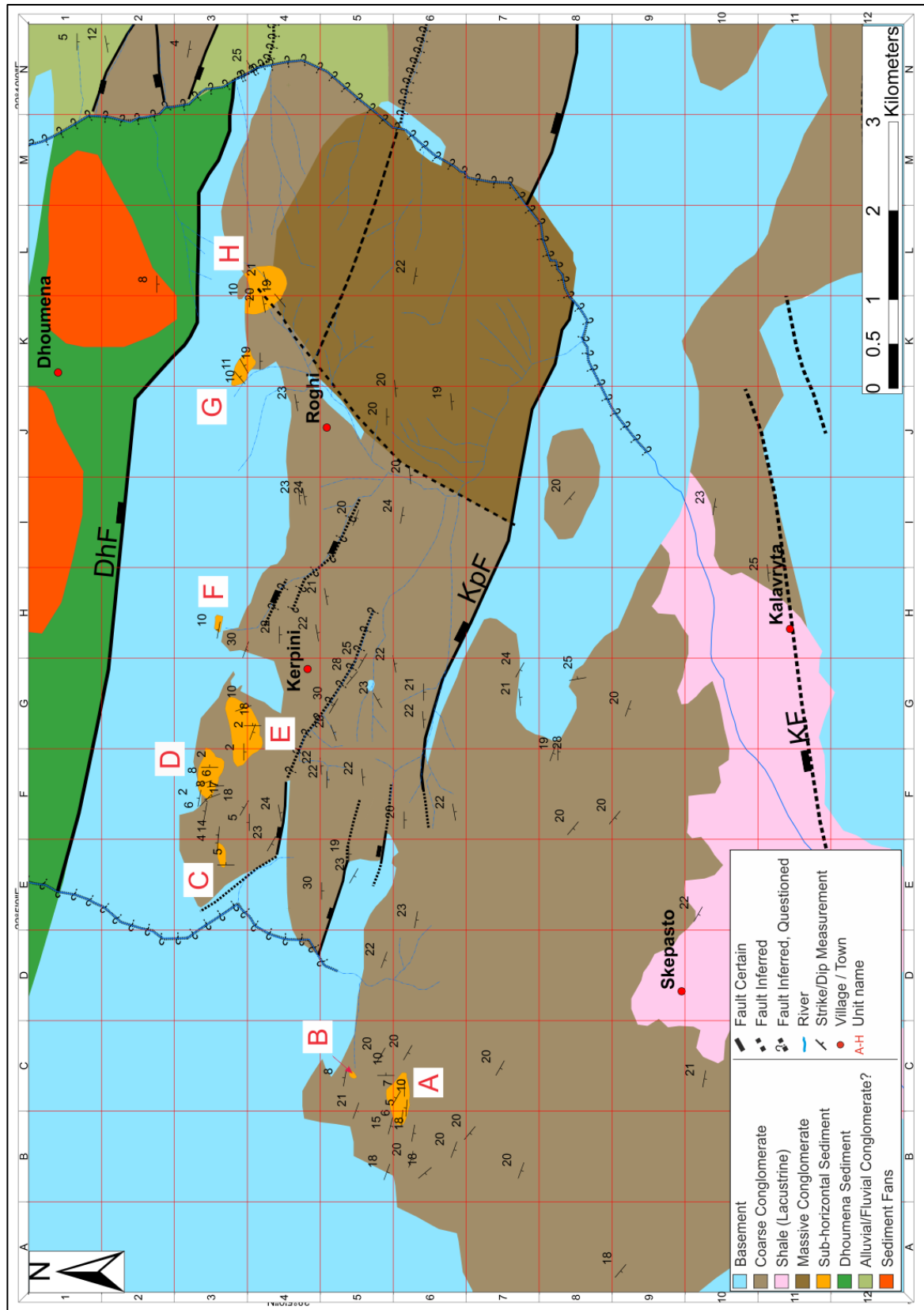


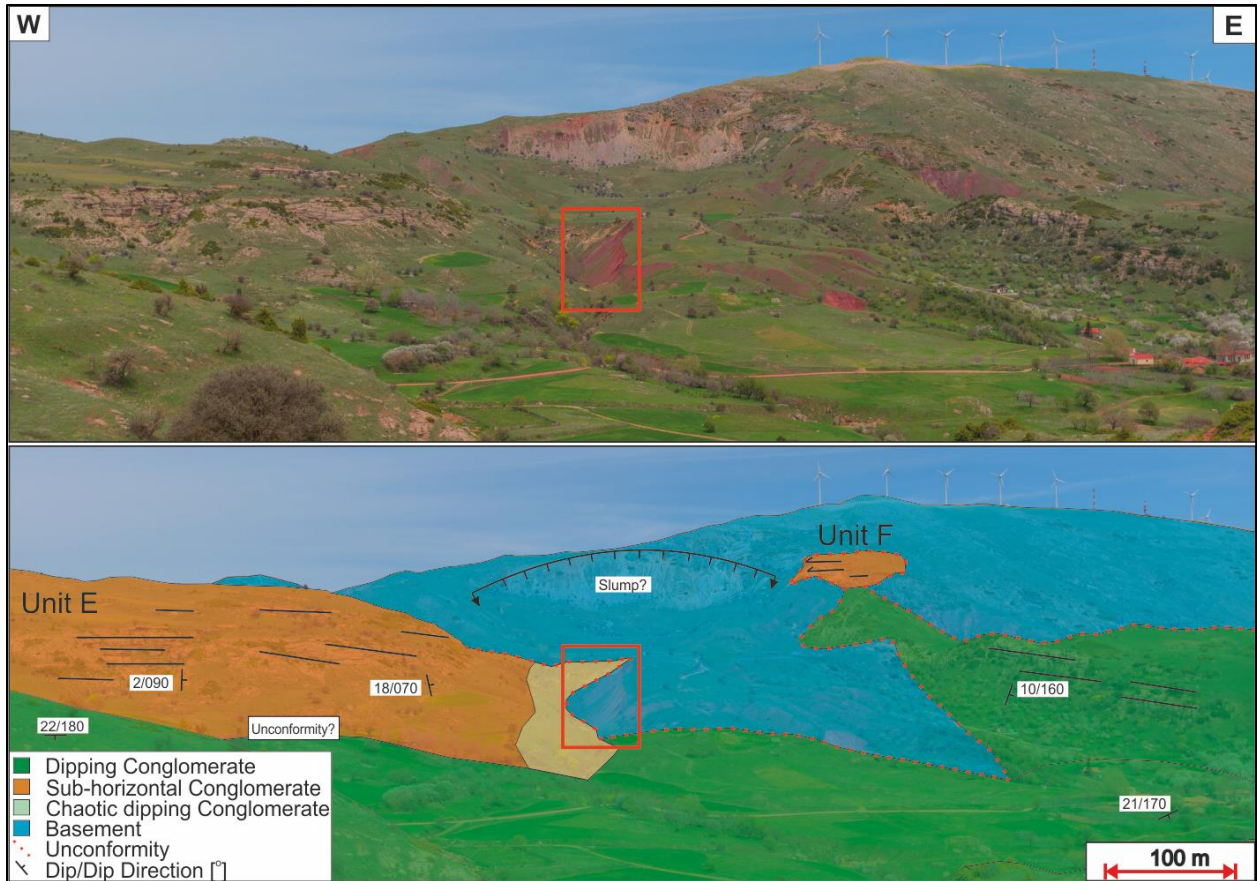
Figure 4-2: Map showing the distribution of main depositional units and faults. This map also shows the observed dips with in the area. The grid reference seen along the border of the picture is to easily pinpoint any observations to its location on the map.

The Pindos Carbonate Basement is exposed at several locations including:

- South of the Kalavryta Fault as it stretches up towards Mt. Chelmos
- In the eastern section of the Kalavryta Fault Block, north towards the Kerpini Fault
- East across the Vouraikos River towards the villages of Souvardho and Vrachni.

Within the Kerpini Fault Block it is well exposed in the northern area close to the Dhoumena footwall, where an unconformity is easily distinguished between the basement and overlying sediments. In the south-east corner of the Kerpini Fault Block (Figure 4-2), in the location of the main depocentre of the Kerpini Fault Block, there is an outcrop of basement which shows the chaotic nature of the basement. In the eastern section of the Kerpini Fault Block, the basement is exposed at two locations. One lies east of the village of Roghi (Figure 4-2, J5) where the basement is exposed in the bottom of the river valley, and further east close to the Vouraikos River there is an inlier of Pindos Carbonate Basement (Figure 4-2, M6). This inlier lies very close to the present day valley floor in the Vouraikos Gorge, however on the opposite side of the river (east) it is found at a higher elevation. Additionally more of the basement is exposed on the eastern side of the Vouraikos River.

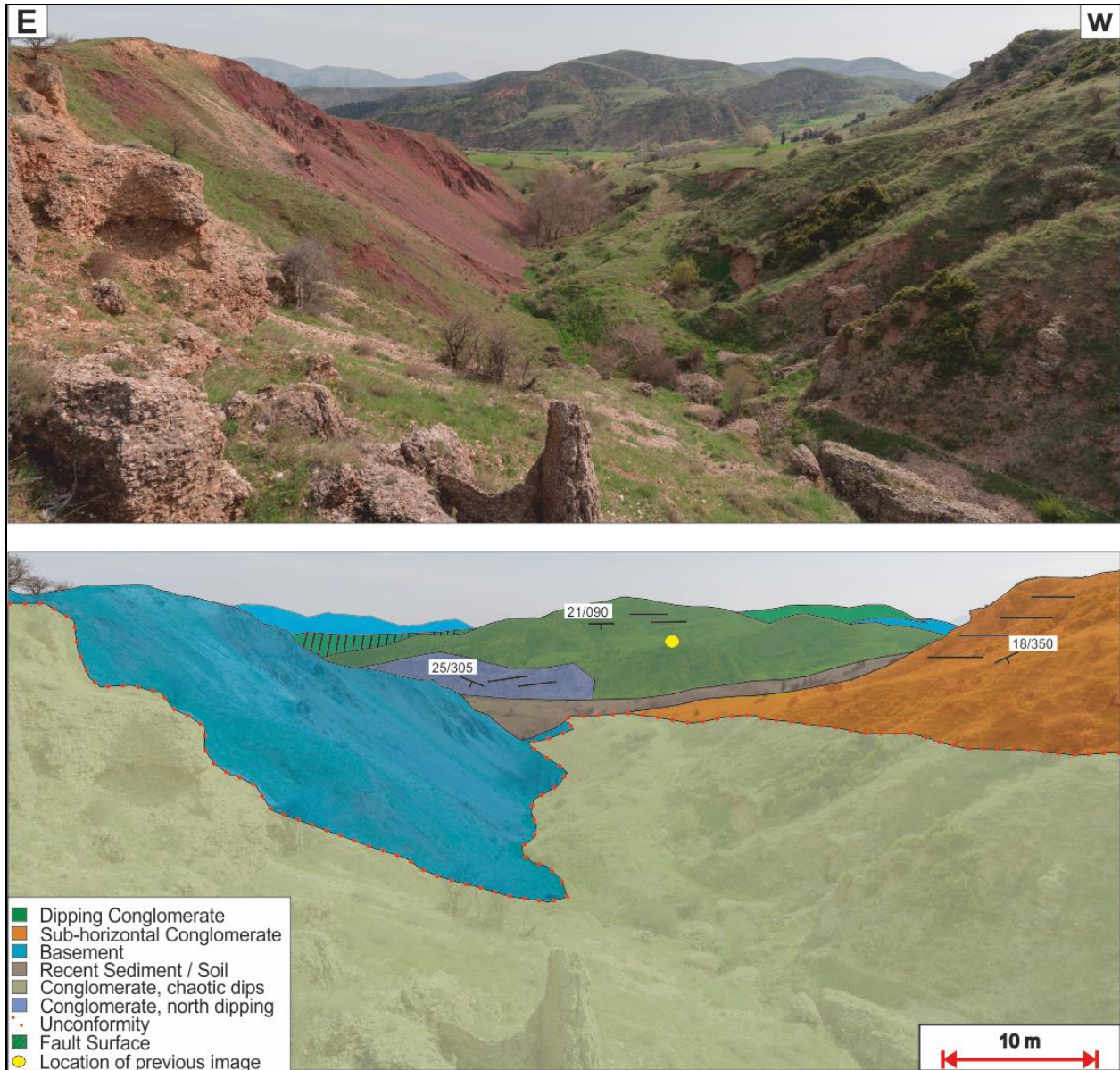
Moving west in the Kerpini Fault Block, the basement is exposed south of the village of Kerpini (Figure 4-2, G5) in between the south dipping conglomerate to the south and the northeast dipping conglomerate to the north. Northwest of the Kerpini Village there is a long north-south oriented river valley (Figure 4-2, G4). On the east side of the small river valley the red chert basement is exposed and on the west side conglomerate. Figure 4-3 shows a view from the south looking north onto the basement “scar”. The unconformity runs along the northern valley side until it makes a dramatic drop to the south, almost entering the village of Kerpini before it migrates northwards and behind the Unit E as shown in Figure 4-3.



**Figure 4-3: Image looking north into Kerpini Fault Block; Kerpini village is visible in the lower right corner. The image shows the basement "scar" that is in the centre of the upper image (marked with red square). The lower image is an interpretation showing the various contacts of the sediment and basement. Note the gap between the leftmost sub-horizontal conglomerate (Unit E) and the rightmost (Unit F).**

The contact between the dipping conglomerate and the sub-horizontal is difficult to observe due to recent soil and vegetation. Between Unit E and Unit F there is a scoop like feature on the hillside. Figure 4-4 shows the same "scar" from the north looking south. The basement that is visible is consolidated, bedded, red chert. The conglomerate found north of the basement in the "scar" is consolidated. However, it is difficult to ascertain any dip measurements as there is a lot of break off. If one walks in the scar towards the south, one starts in conglomerate overlying basement, then enters a long stretch of basement (ca. 300m) before finding conglomerate again below the basement. 100m west of the basement "scar", there is consolidated bedded non-horizontal conglomerate; this conglomerate will be discussed in "Unit E" section.





**Figure 4-4:** This image shows a view of the “scar” from the north looking south. The bottom image is an interpretation of the image. The conglomerate on the left that is overlying the basement, and as one moves south one finds conglomerate underlying the basement. On the right in the image there is conglomerate dipping 18° towards the E/NE, named Unit E. The light green shading on the image signifies the chaotic consolidated conglomerate found in the “scar”. The yellow dot indicates the location Figure 4-3 was taken from, at this location the layers are dipping northward.

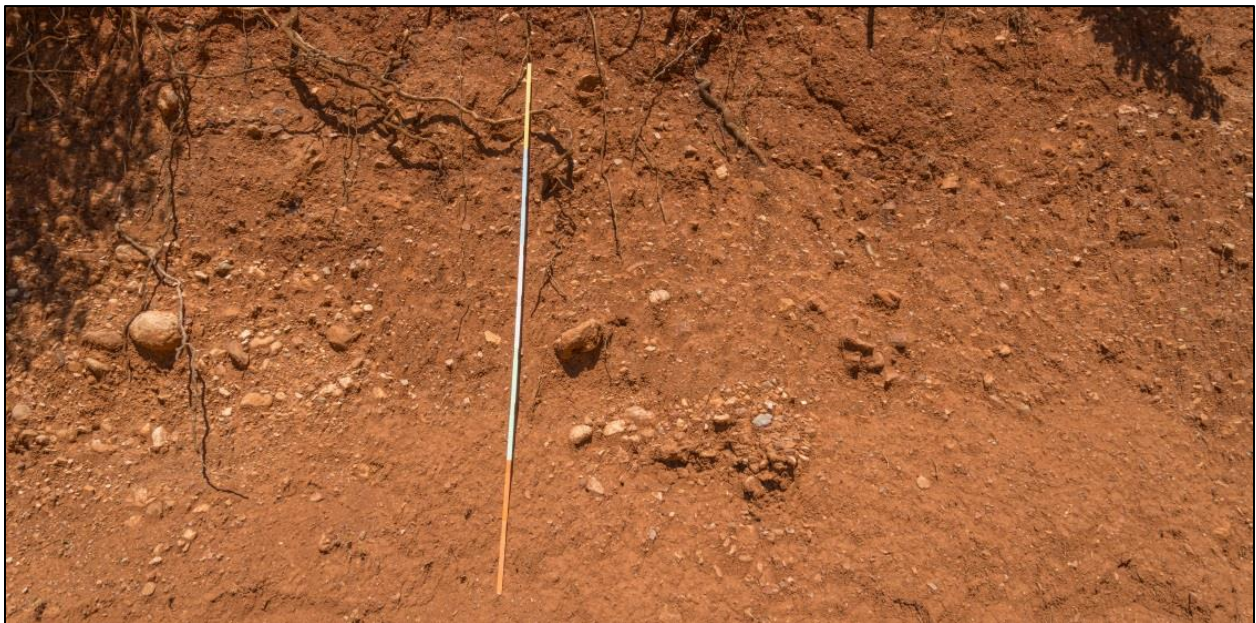


## 4.2.2 Sediment

There are three distinct types of sediment found in the Kalavryta and Kerpini Fault Blocks: shale, coarse grained conglomerate (alluvial?) and sandstone-conglomerate (fluvial?).

### 4.2.2.1 Shale

The shale is mainly found in the southern part of the Kalavryta Fault Block. It is distinguishable by its red to grey colour and its predominantly unconsolidated top surface. The sediment was tested with 10% HCl and there was no indication of effervescence. This test indicates that the red sediment contains <35% carbonate as is therefore shale, not marl. Similar shale deposits are found distributed in various quantities in the fault block. Within the Kerpini Fault Block the red shale is chiefly found in the south-central to south-western/western region of the fault block where it appears to drape over the underlying conglomerate. On the surface the shale sediment appears unconsolidated, weathered and brittle. However as one digs into the sediment, it becomes “wetter”, i.e. it retains moisture and shows plastic attributes making it pliable by hand. The grain size of the shale is clay/silt. Figure 4-5 shows the red shale.



**Figure 4-5: The reddish shale that is present in several areas of the region. The sediment is found with interlayered beds of unconsolidated conglomerates and isolated pebbles-boulder sized limestone and chert. The yardstick is 2m for scale.**



## 4.2.2.2 Coarse Grained Conglomerate

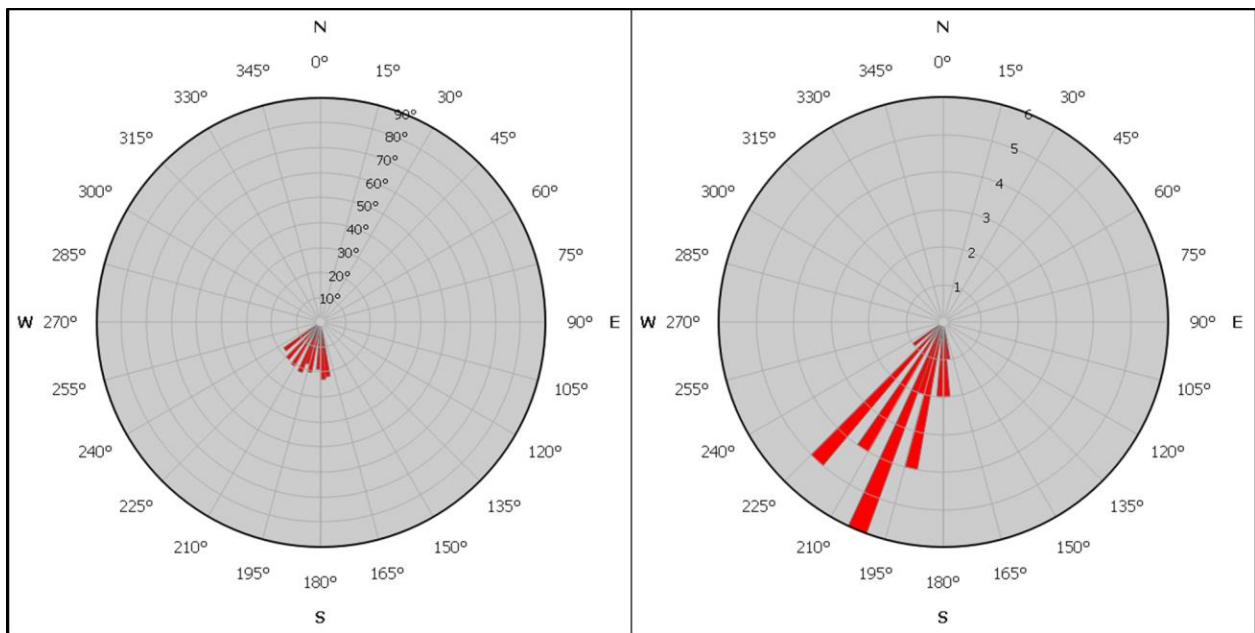
### 4.2.2.2.1 Kalavryta Fault Block

The coarse grained conglomerate make up the bulk of the sediment within the two fault blocks, Kalavryta and Kerpini. In the Kalavryta Fault Block, the coarse-grained conglomerate is the dominating lithology. It is brown to greyish in colour, and sizing ranges from cobble to boulder (few); average size 15cm. The conglomerate appears to be polymictic, polymodal and predominately clast supported with a very poorly sorted matrix. The clasts are limestone (sub-rounded to rounded) and chert, possibly jasper, (sub-angular to sub-rounded). The chert is reddish in colour and comprises less than 15% in the outcrops visited. Very few consolidated sandstone clasts (rounded) are observed in these conglomeratic outcrops.



**Figure 4-6: Image of an outcrop of the dipping, coarse grained conglomerate found in the northern region of the Kalavryta Fault Block.**

The outcrop in Figure 4-6 is facing south and layering can be difficult to distinguish from outcrop to outcrop, however, there is a general coarsening upward trend within these conglomerates. As explained in Chapter 3, imbrication was found to suggest an N/NNE flow direction in the lower-lying coarse grained conglomerate packages. The coarse grained conglomerate is interlayered with thin sandstone beds. However it does not appear as frequently as in the sub-horizontal conglomerate. The coarse grained conglomerate in the Kalavryta Fault Block shows a general trend of dip direction of  $\sim 210^\circ$  and dip  $\sim 21^\circ$  (Figure 4-7).



**Figure 4-7: Rosediagram depicting the dip and dip direction of the coarse grained, dipping conglomerate found in Kalavryta Fault Block. From these measurements the general trend is a dip of  $\sim 21^\circ$  and direction  $\sim 210^\circ$ .**

#### **4.2.2.2.2 Roghi Mountain, Eastern Kerpini Fault Block**

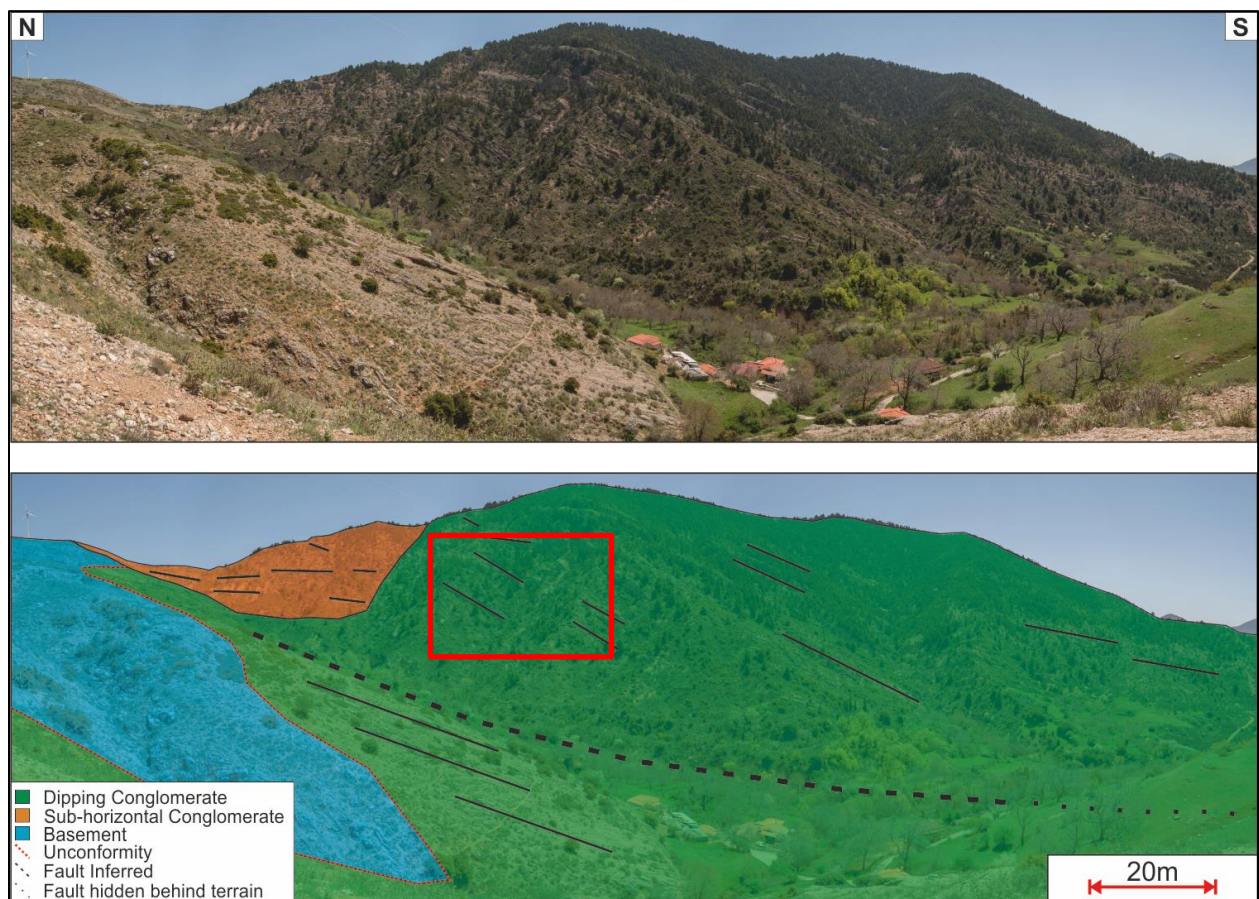
In the Kerpini Fault Block the large stand-out feature is the massive conglomerate found in the eastern region of the fault block, referred to in this thesis as Roghi Mountain. In this study when referring to Roghi Mountain it is the area bounded in the west by the north-south running fault and in the east the Vouraikos River. In the south it is bounded by the Kerpini Fault. Figure 4-2 shows Roghi Mountain, and the faults, which is shaded in a darker shade of brown.

This mountain is comprised primarily of conglomerate and, like the conglomerate found in Kalavryta Fault Block, it also features interlayered sandstone bedding. The clasts are pebble to



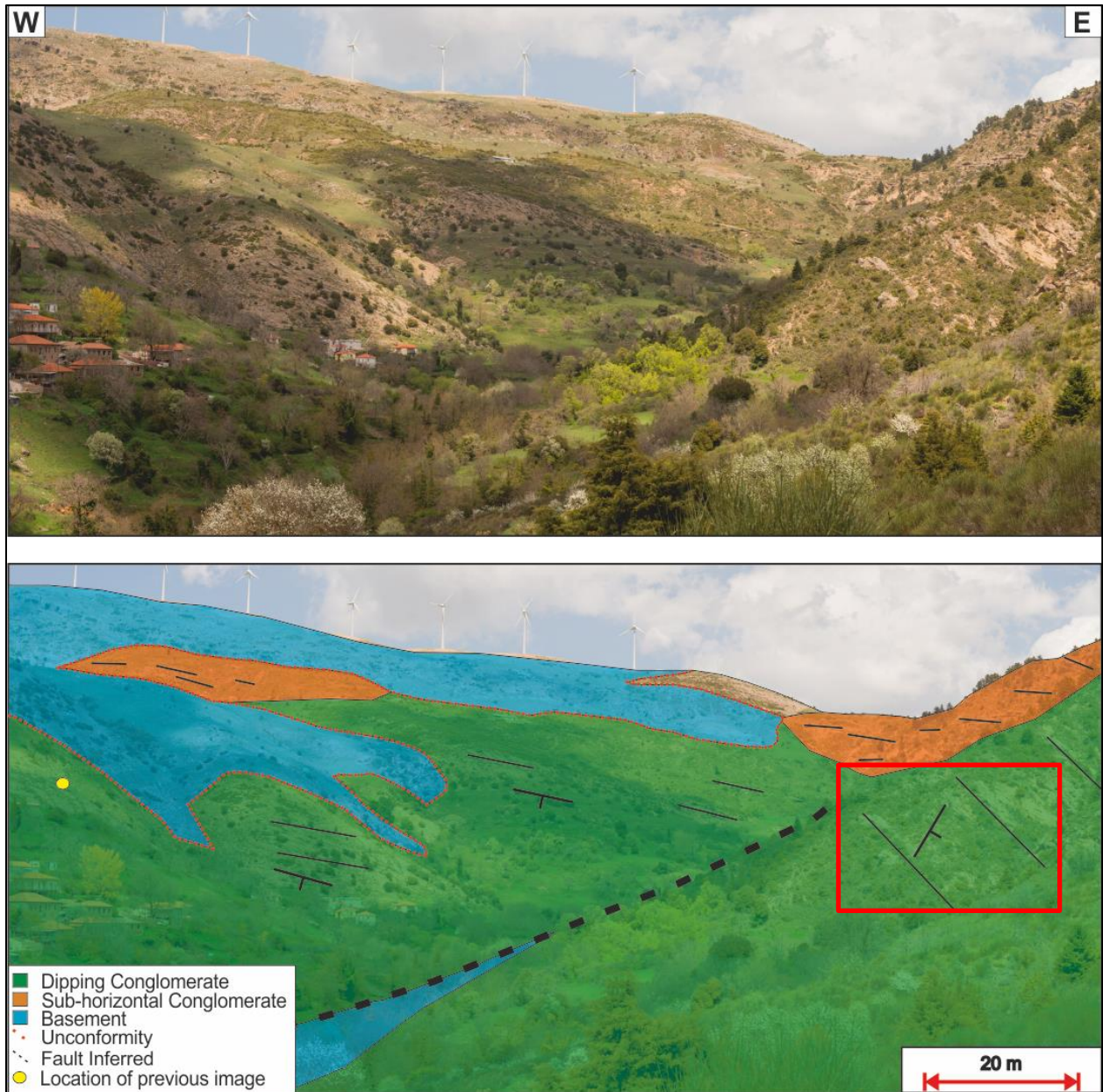
boulder sized, occurring from 1cm to 40cm. It appears to be polymictic, polymodal and clast supported with a very poorly sorted matrix. The matrix appears to be largely sand dominated. The clasts are predominantly limestone (sub-rounded to rounded) ranging from greyish to white in colour. The chert (sub-angular to sub-rounded), possibly jasper, which occurs in much lower quantity, appears reddish.

The massive conglomerate (Roghi Mountain) in Kerpini Fault Block shows clear indication of layering. Figure 4-8 shows an eastern view of Roghi Mountain, where the layering is clearly visible. There is also appears to be a change in dip of the beds as one goes from north to south when looking at Figure 4-8. However this could be the result of the angle at which the photograph is taken. The beds vary in thickness from 1m – 10m, often separated by interlayered sandstone beds. The bedding can then be used as a leading line for dip measurements.



**Figure 4-8:** Image looking directly east at Roghi Mountain. From this angle the layered bedding is clear and is trending towards the south. The orange shaded area shows a more horizontal nature to the layering. The inferred fault that runs left – right is due to the exposed basement that is present in the bottom of the valley by Roghi Village (not visible on image). The scale is applicable for the mountain side above the visible houses.

Figure 4-9 shows a northern view along the western side of Roghi Mountain. It shows that the apparent south dipping layers in Figure 4-8 (the red box) are possibly dipping more to the east than south. This phenomenon has been observed other places along the western side of Roghi Mountain and reveals that many of the dip measurements made from afar cannot always be trusted as these may indicative of a more apparent dip than the actual dip of the beds.



**Figure 4-9:** Image standing on the western edge of Roghi Mountain and looking north. What is worth noting here are the beds on the right hand side on the image, from this angle they appear to be dipping steeply towards the east south-east. The yellow dot indicates the location from which Figure 4-8 was taken. Scale is applicable for centre of image.



Viewing Roghi Mountain from the south, Figure 4-10, an erosional feature is observed. It appears to erode in and under the sediment leaving a “lip” hanging over. This feature is visible in several locations as indicated on the image. It is not found on the western side of Roghi Mtn.

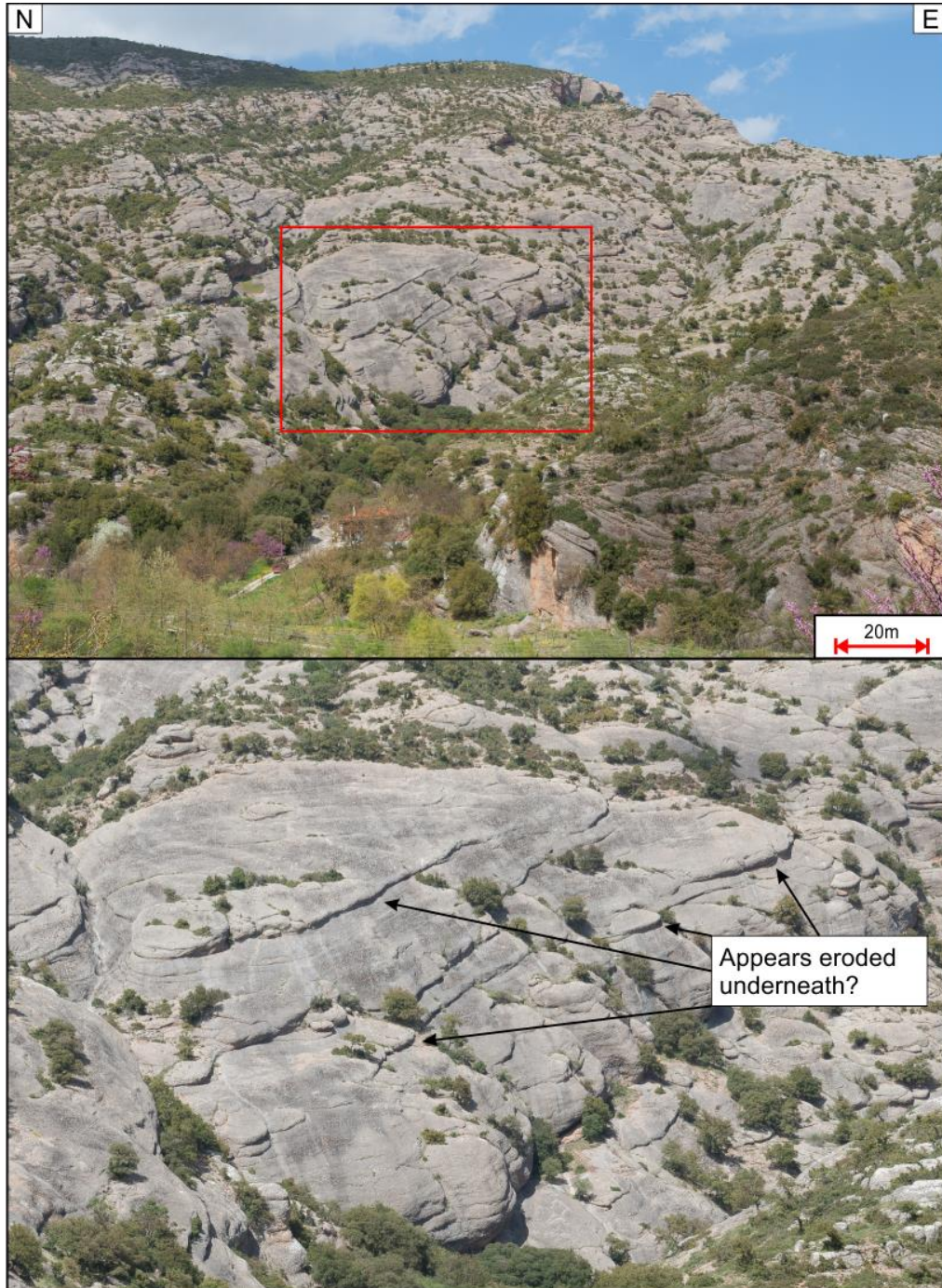
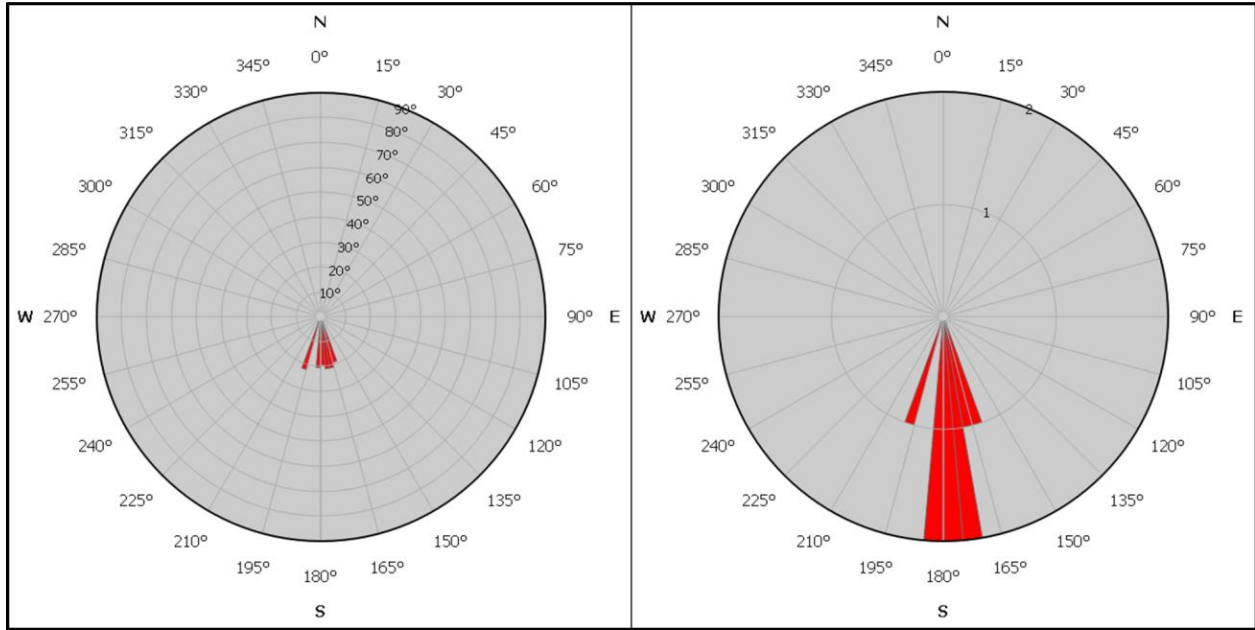


Figure 4-10: Roghi viewed from the south. The red box in the top image is enlarged in the bottom. This shows an erosional feature, creating a “lip”. This lip appears to follow the dip of the conglomerate. The scale is applicable for the top image.

A couple of dip measurements were conducted, as Roghi Mountain is not the centre of this study, these are shown in Figure 4-11. These measurements give a dip direction of ~170-180° and a dip of 21°. Given that some of these are taken at a distance there is an inherent uncertainty in the measurements, of +/- 5° for the dip direction and +/- 3° for the dip angle. The outcrops that were visited up-close did show a general N/NNE trend in flow direction based on imbrication.



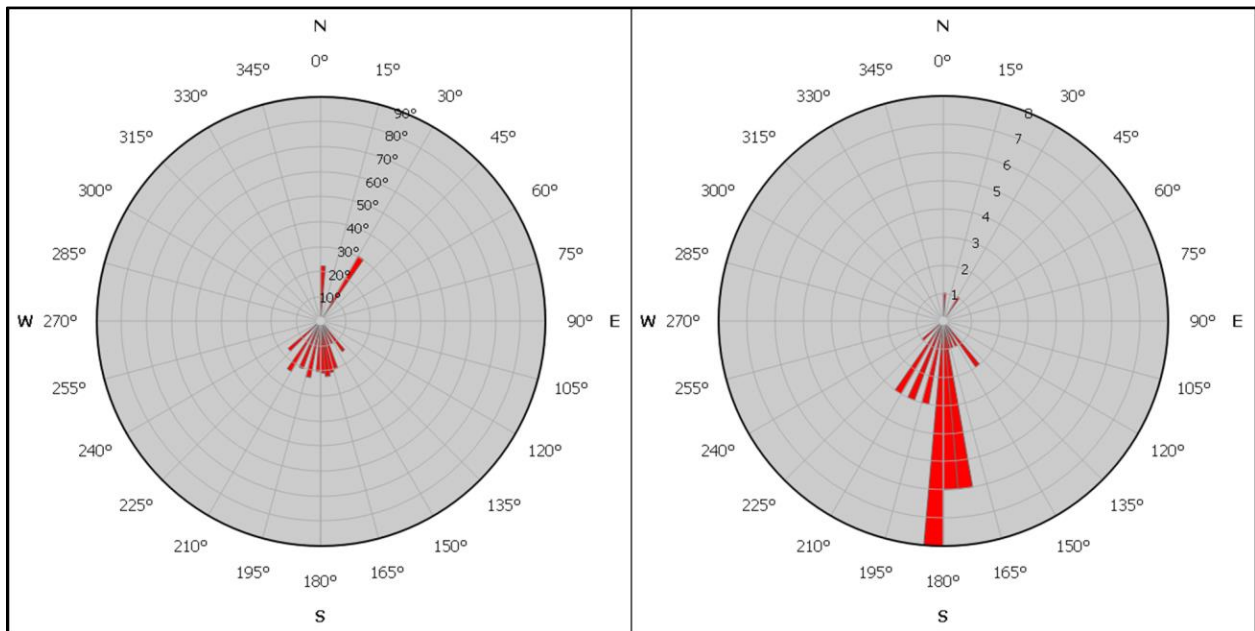
**Figure 4-11: Rosediagram depicting Dip and Dip direction of Roghi Mountain, showing a dip angle trend of 21° and a dip direction of 170-180°.**

#### **4.2.2.2.3 Kerpini Fault Block - West of Roghi Mountain**

Roghi Mountain, which lies in the eastern region of the Kerpini Fault Block, forms a portion of the conglomerate found in the block. Figure 4-2 shows the conglomerate as it stretches from Roghi Mountain in the east to the Kerinitis River valley in the west. The clast size of the alluvial conglomerate within the Kerpini Fault Block (disregarding Roghi Mountain) varies from boulder to pebble size. Trying to obtain an average is difficult as there are several layers within the conglomerate and it is difficult to follow these layers throughout the fault block. Therefore it is challenging to ascertain whether there is a northward fining within the fault block.

The conglomerate appears polymictic, polymodal and clast supported with a very poorly sorted matrix. The matrix is chiefly very-coarse/coarse sand. The clasts are predominantly

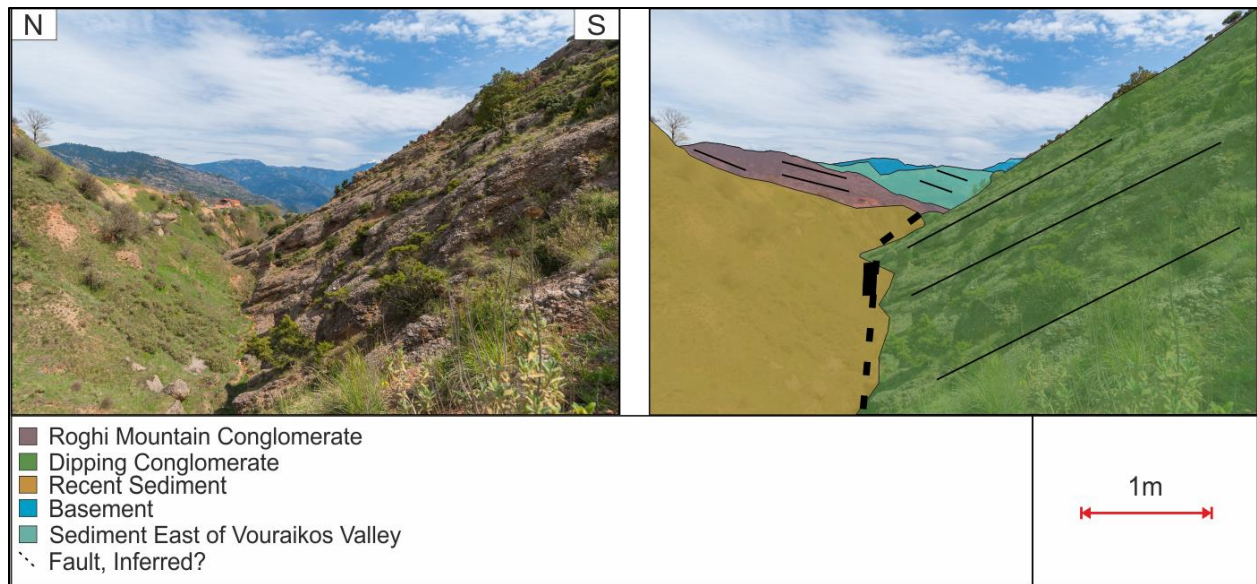
limestone (sub-rounded to rounded) ranging from greyish to white in colour and also occur tabular in sphericity. The chert (sub-angular to sub-rounded), appears predominantly reddish in colour and occurs less frequently than the limestone (<~10%). Similarly to Roghi Mountain and the conglomerate found in the Kalavryta Fault Block, there appears to be very few reworked consolidated sandstone clasts within the conglomerate. Dip measurements conducted on the conglomerate found in the Kerpini Fault Block are displayed in Figure 4-12. The trend shows a 170-180° dip direction with an average 21° dip angle. The north dipping measurements shown in the rosedigram is from the area south of Kerpini Village (Figure 4-2, G5).



**Figure 4-12: Rosediagram depicting dip and dip direction of the conglomerate found in Kerpini Fault Block, not including Roghi Mountain. It shows a dip angle trend of 21° and dip direction of 175°.**

These northward dipping beds in Kerpini Fault Block are shown in Figure 4-4 by the purple shaded area. These differ in their dip angle from the surrounding conglomerate; however they do show a flow pattern, indicated by imbrication, to the N/NNE. The following figure is an image looking down the valley side showing the layers (Figure 4-13). This image shows the north dipping conglomerate on the right and in the centre there is an inferred fault. This fault will be addressed in 4.5.2.2.1. From the image one can see the north dipping layers end abruptly in the more recent soil on the left. As one follows this valley further to the east, a gap develops between the dipping conglomerate and the recent soil.





**Figure 4-13: Image taken looking east, down a small valley south of Kerpini Village with an inferred questioned fault (Figure 4-2, G5). South of the valley the layers are dipping steep at 25°-30° in a NE direction (045°). The imbrication found in these layers indicate a flow of N/NNE. On the northern side of the valley there are a lot of slabs and break off as well as recent soil. The closest southern dipping in situ conglomerate is found at a western positioned church in Kerpini Village. The southern extent of Kerpini Village is visible in the centre on the left image.**

If one follows the ridge on the right (Figure 4-13) southward, one ends up in an east-west running valley. In this small valley there is a small outcrop of exposed basement, no more than 40x50m (Figure 4-2, G5). Immediately to the south of this exposed basement, there is a large outcrop of south dipping (21°) conglomerate layers. Like the north dipping layers, this south dipping section also shows a N/NNE trending flow direction.

Figure 4-14 is an image looking NNW into Kerpini Fault Block, which shows the unconformity that sits up north towards the Dhoumena Fault. Furthermore it gives a view of the large alluvial conglomerate that is found in the centre of the fault block. This large outcrop shows a ~21°/170° dip angle and dip direction. This feature, which is circled in the upper image, was interpreted by Syahrul (2014) to be a fan with apex in the upper left edge of the red circle. Observations during this study found a flow direction of N/NNE within this structure. Four of the sub-horizontal layers are shown in this panorama, and as seen they sit high up, close to the Dhoumena footwall. Figure 4-15 is another view of this large alluvial conglomerate feature in the Kerpini Fault Block. This image is taken when standing on the north dipping conglomerate. In this image the “fan” is highlighted with a red circle and the assumed apex is marked.



Figure 4-14: Panorama looking from atop the Kerpini Fault footwall, north into the Kerpini Fault Block. In the east (above the scale bar) is Roghi, and in the west is the village of Kerpini. In the centre of the image there is a large conglomeratic outcrop that is clearly visible; it is circled red in the upper image. This large outcrop has previously been interpreted as a fan. The orange shading shows the sub-horizontal conglomeratic outcrops that are being investigated. From west to east are: Unit E, F, G and H



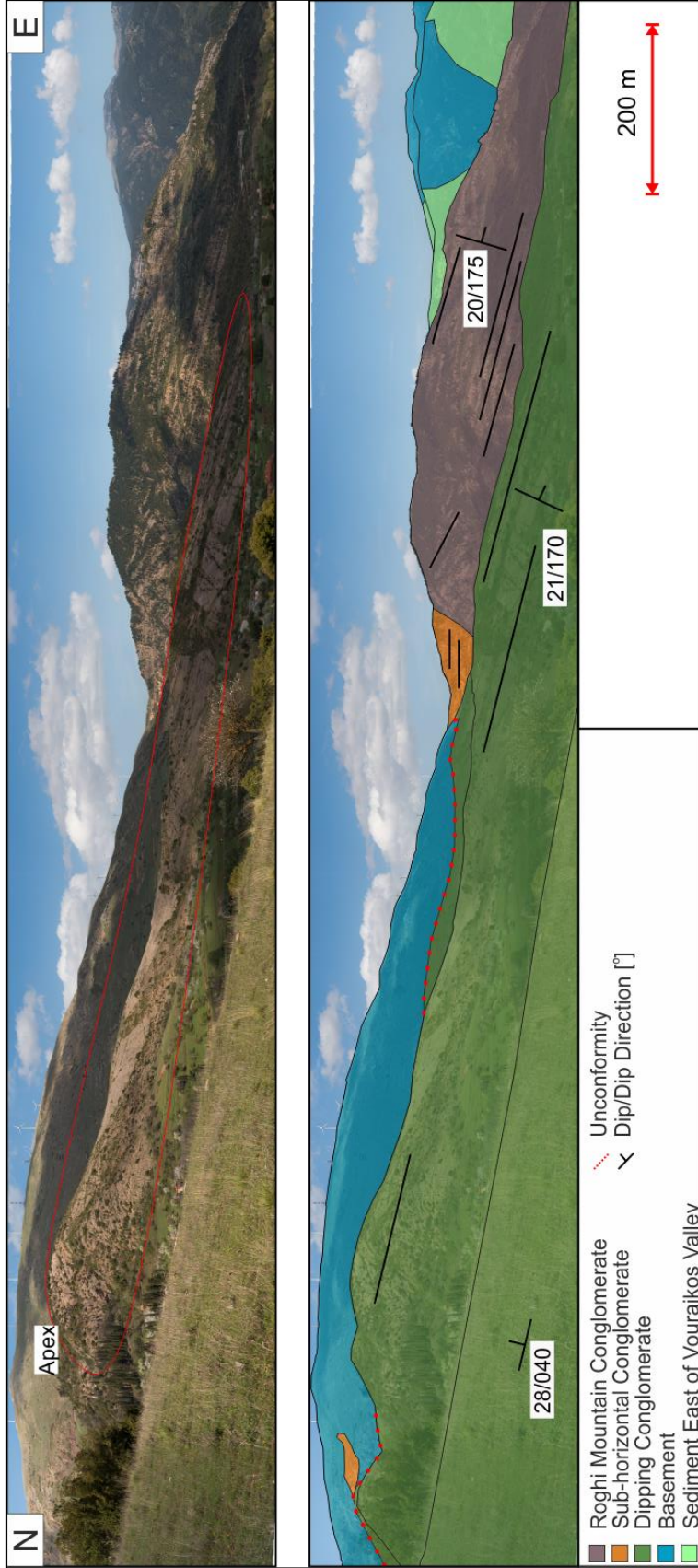


Figure 4-15: Image taken standing on the north dipping conglomerate found south of Kerpini Village (Figure 4-2, G5). The figure shows the large conglomerate that dominates the centre of the fault block, previously interpreted as a fan (circled in upper image). This conglomerate shows a trend of 21° towards S/SE (170°), and when looking at the imbrication at several locations it shows a flow direction of N/NNE. Incidentally from this view angle, Roghi Mountain is visible in the far. Looking at the lower lying sediment layers, which trend 20° towards S/SE (175°), the layers appear remarkably similar. This lower part of Roghi Mountain shows a flow direction of N/NNE based on imbrication.

### 4.3 Sub-Horizontal Sedimentary Units

#### 4.3.1 Introduction

This section will present the identified sub-horizontal sedimentary layers found in the two fault blocks: Kalavryta and Kerpini. The general trend among the coarse conglomerate found in the Kalavryta and Kerpini Fault Blocks is a dip angle of  $\sim 21^\circ$  towards the S/SW. The sub-horizontal, as the name suggests, are outcrops that show a dip angle of close to horizontal,  $0^\circ$ - $10^\circ$ . Prior to travelling for the field work three were known: one in the Kalavryta Fault block and two in the Kerpini Fault Block. During the field work an additional five were identified, bringing the total number of sub-horizontal outcrops to eight. These outcrops were labelled A-H. They are labelled from west to east, A and B are in the Kalavryta Fault Block while C to H are in the Kerpini Fault Block. The labelling and position are shown in Figure 4-16.

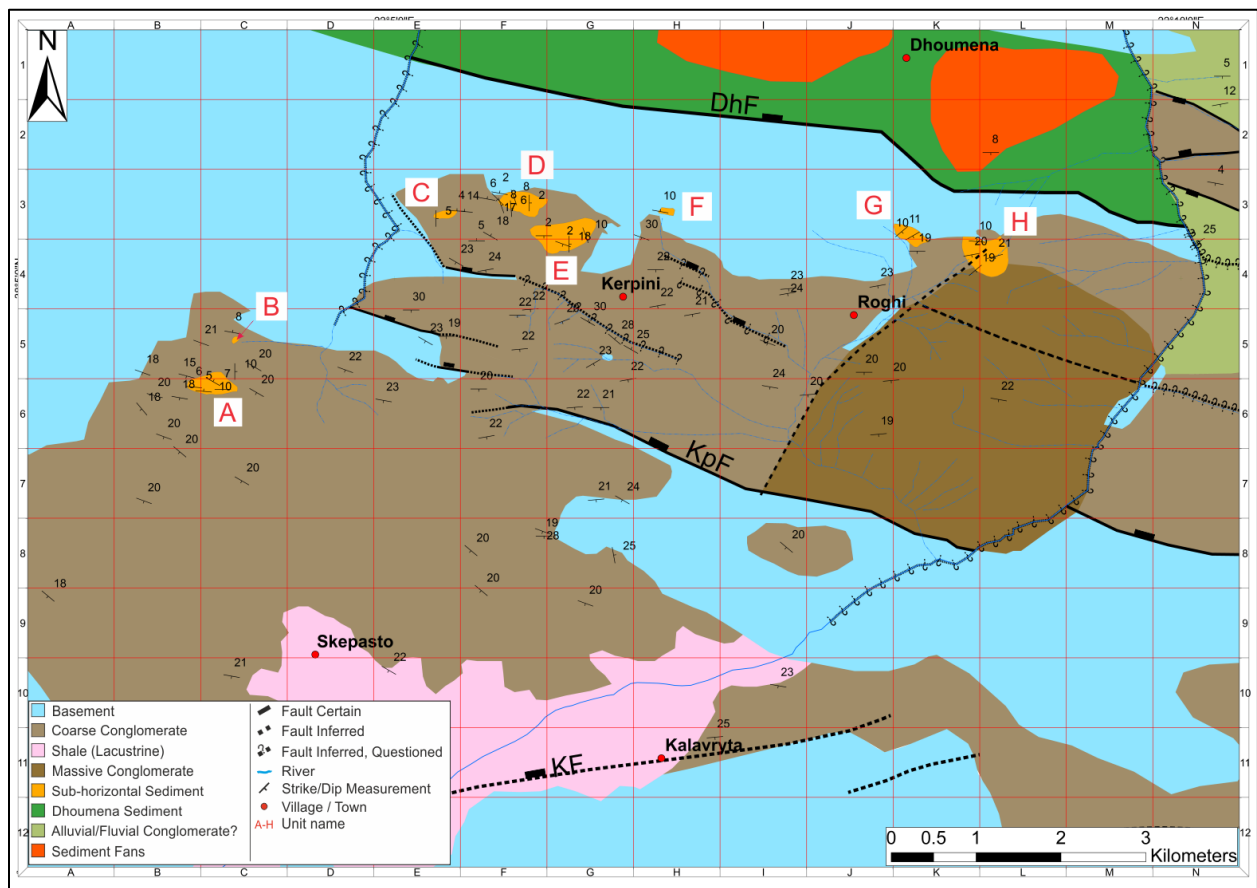


Figure 4-16: Map showing the location of the Sub-horizontal layers with labels.

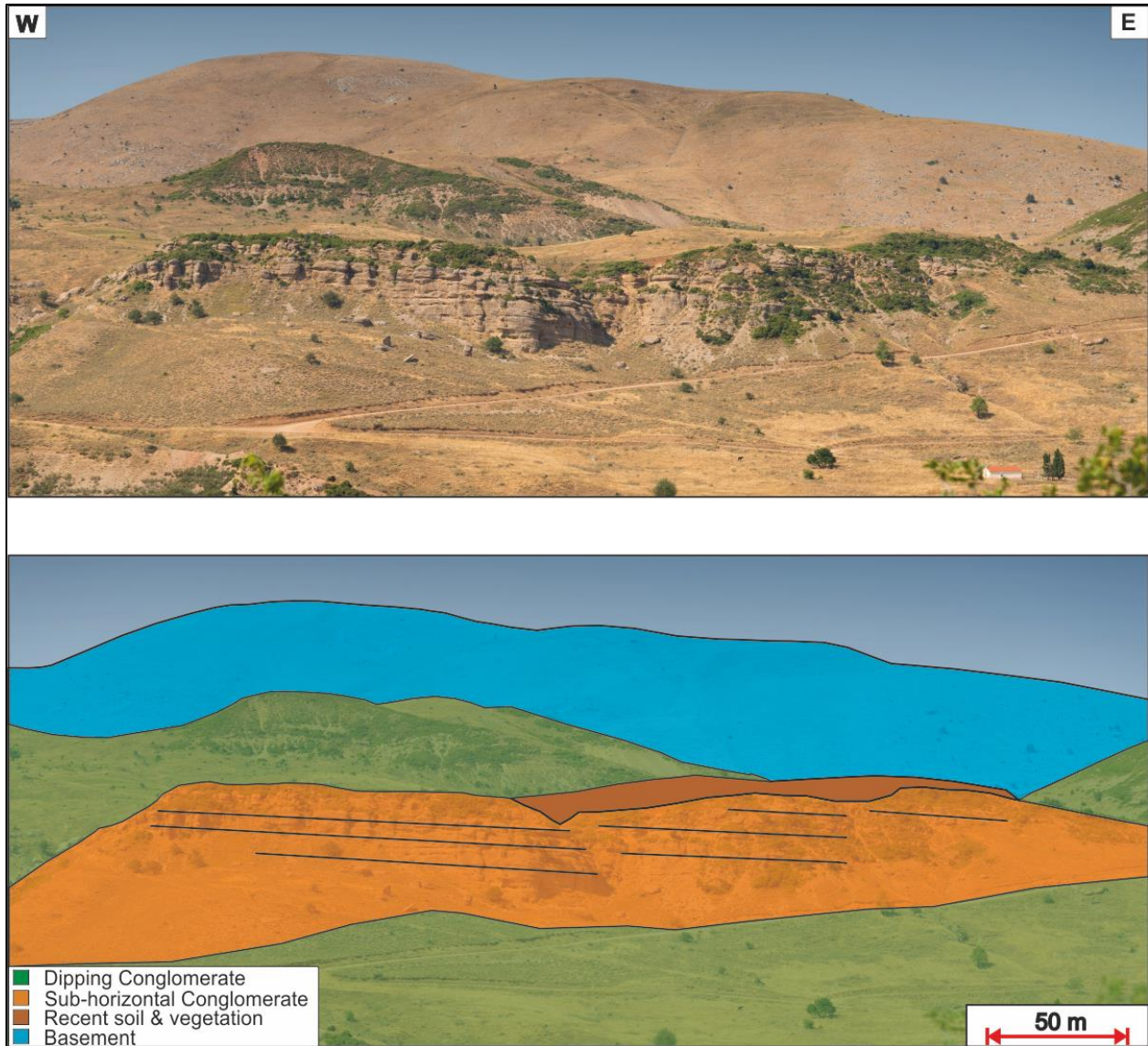
### 4.3.2 Unit A (Figure 4-16, C6)

Unit A lies in the north western area of the Kalavryta Fault Block, approximately 3.5km north from Skepasto Village. It is a fairly large outcrop, measuring ~450m (east-west) and ~250m (north-south). It is only on the southern and western edge that the outcrop is exposed. The northern edge it is not visible as it is covered with vegetation and recent soil. Due to this covering, the contact between the sub-horizontal and the dipping conglomerate is not exposed.

<b>Unit A</b>		
<b>Location (centre outcrop)</b>	N38°04.322' E022°3.849'	
<b>Elevation at base (approx.) [m]</b>	1204	
<b>Max preserved thickness (approx.) [m]</b>	49	
<b>Colour</b>	Grey to light brown	
<b>Clast size</b>	Pebble to Cobble (~137mm)	
<b>Clast type</b>	Limestone with ~10% Chert, ~5% Consolidated Sandstone clasts	
<b>Grain fabric with sorting</b>	Clast-supported with a poorly sorted matrix	
<b>Grain morphology</b>	<b>Limestone</b>	Sub-rounded to rounded
	<b>Chert</b>	Angular to sub-angular
	<b>Sandstone</b>	Rounded
<b>Dip / Dip Direction [°]</b>	8/030	
<b>Paleo flow (Imbrication)</b>	E/NE	
<b>Contact</b>	The outcrop appears to onlap the dipping conglomerate along the northern edge, the contact is not exposed.	

**Table 4-1: Summary of Unit A**

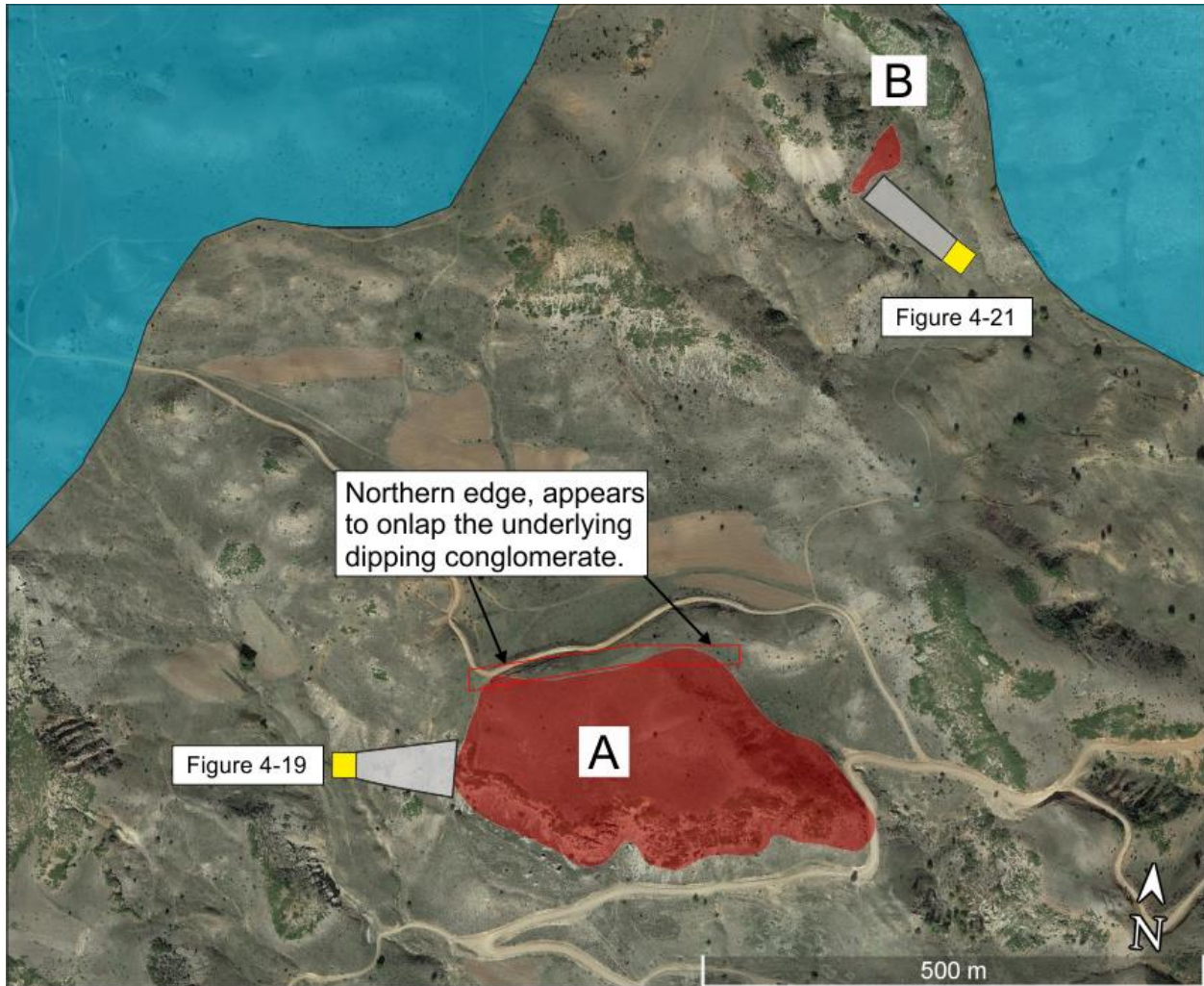
The outcrop has clearly marked and exposed layers/bedding of sandstone, which are visible from the west, south and partially east. The sandstone beds are found throughout the outcrop and occur at irregular intervals. The sandstone beds vary from 5cm – 50cm in thickness. As with many conglomerate measuring dip angles is difficult due to poor contacts between the beds. However using the sandstone beds as a guide, this unit shows a dip direction of 020°-040° and dip angles of 6°-10° respectively. Figure 4-17 is an image from the south looking north showing the trend of the visible layers dipping in an easterly direction.



**Figure 4-17:** The top figure is an image looking towards the north of Unit A, on this image the bedding is easily visible. The bottom image has highlighted the various sediments. It appears to overlay the dipping conglomerates, although there is no clear contact. The darker shade of orange (brown) simply highlights the top of the outcrop that stretches northward and is recent soil and vegetation.

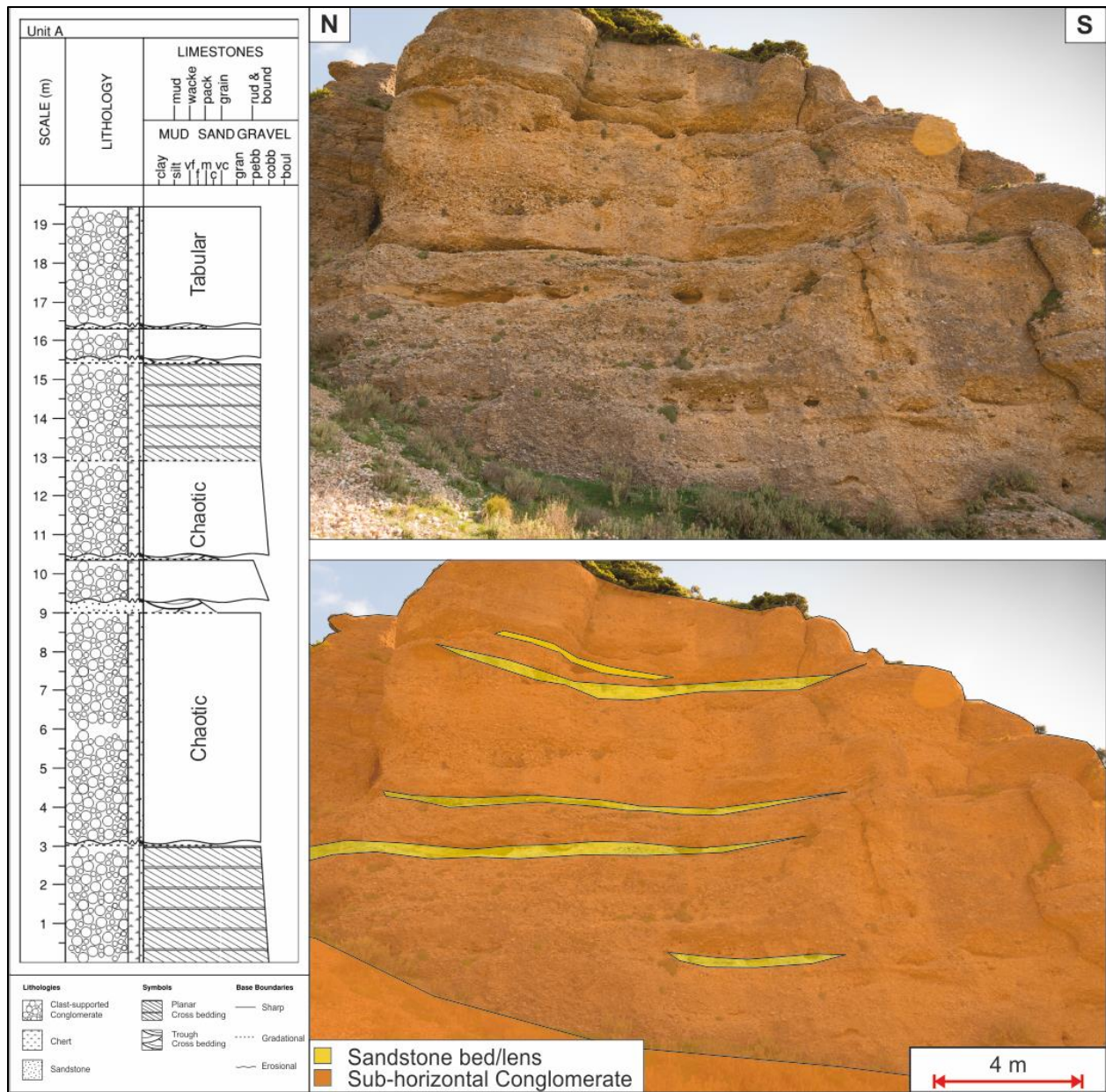
The next image shows an overview of Units A and B (Figure 4-18). The red shaded area marks the sub-horizontal units and the blue shaded area marks the basement. The unshaded area depicts the areas of dipping, coarse grained conglomerate and areas of recent soil. The area where Unit A appears to onlap the dipping conglomerate is marked. Although, as mentioned earlier, the contact between sub-horizontal and dipping conglomerate is not exposed, however it is assumed that it onlaps in along the northern edge. This has been marked on the image.





**Figure 4-18:** An image from Google Earth showing an overview of the two units A and B, which are marked by the red shaded area. The blue shaded is the Pindos Carbonate basement. The unshaded is the dipping, coarse grained conglomerate and recent soil.

Figure 4-19 is an image taken from the west looking east into Unit A. The log depicted on the left in the figure is a rough representation of the outcrop as a whole. Sandstone beds/lenses are visible throughout the outcrop. Unfortunately, the angle of the photograph makes it difficult to view into the higher lying sandstone beds/lenses. From this view angle, it appears that one is looking at the “cross-section” of the lenses. However, looking from the south, one looks at them longitudinal, or lengthwise. The tabular clasts found are oriented such that it indicates a flow direction of E/NE. Additionally, as the sandstone beds are at “cross-section” when viewed from the west, it could indicate the flow pattern that caused this may have had a W-E direction.

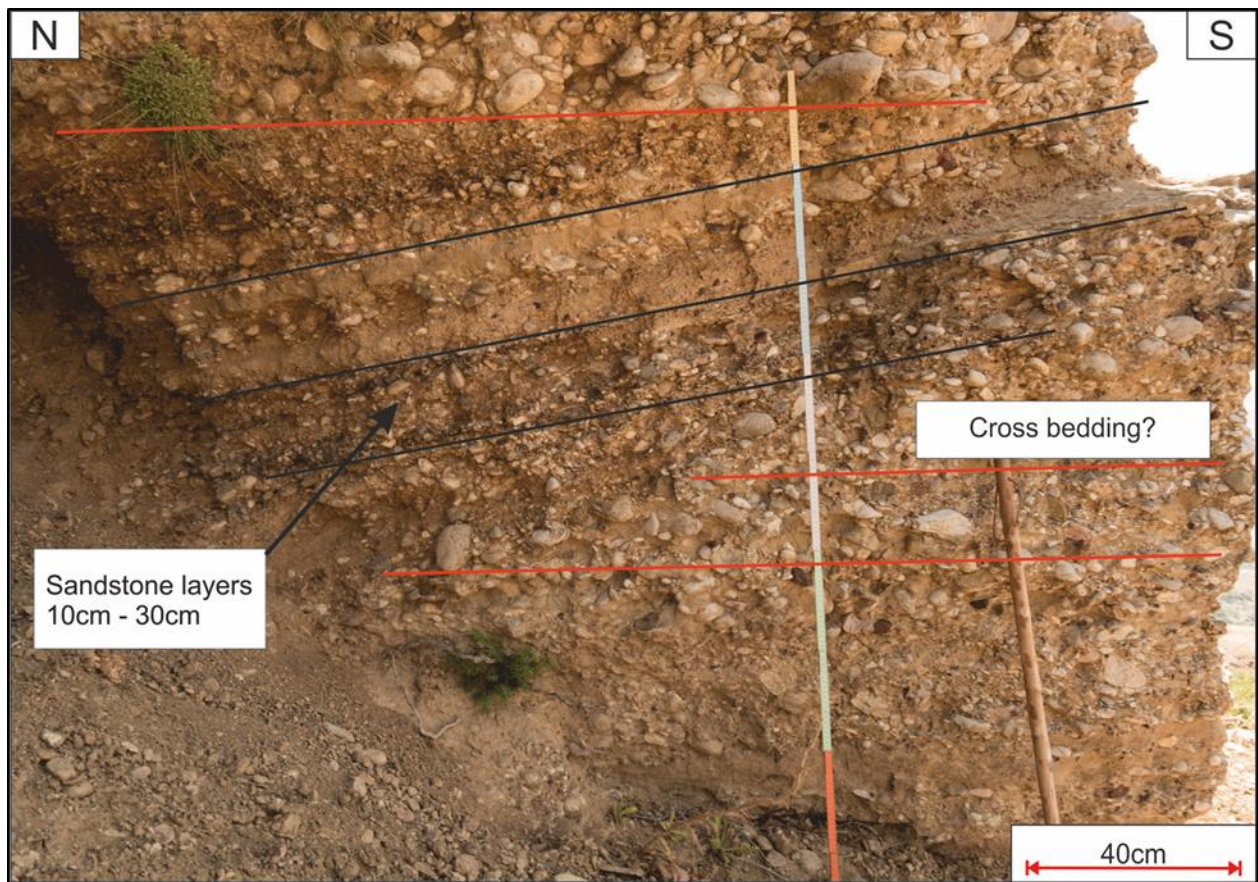


**Figure 4-19:** The left portion of this figure shows an approximate log of the outcrop. The photo is looking directly east into the outcrop; the sandstone lenses are clearly visible at the base. Higher up they are slightly masked due to the angle of the photo, however the interpretation below gives an indication where they are. The thickness of the log is representative of the visible western view of the outcrop.

Moving in closer to the outcrop, Figure 4-20 shows a close-up of a section of one of the thinner interbedded sandstone beds/lenses. The layers exhibit a grain size of fine to coarse grained sand, and show channel lag in the form of pebbles. The figure shows indications of possible planar cross-bedding above and below the sandstone beds. This cross-bedding is also found elsewhere on the outcrop. Within the thicker sandstone beds, trough cross-bedding is



possibly found, although not as prominent as the planar cross-bedding in the conglomerate layers.



**Figure 4-20:** Taken from the western side of Unit A looking east. The interbedded sandstone beds are clearly visible up close to the outcrop. There are possible indications of planar cross bedding found within the conglomerate layers.

### 4.3.3 Unit B (Figure 4-16, C5)

Unit B is a much smaller outcrop that appears sub-horizontal and is located ~600m further north from Unit A (~4km north from Skepato Village). Figure 4-18 shows Unit B in relation to Unit A. The outcrop sits on the southern sloping hillside. It outcrops in two places, and these exposed outcrops are no larger than 3m by 3m. Figure 4-21 shows the western one of these two outcrops as it is on the hillside, where there appears to be 1, possibly 2 sandstone beds/layers present. These layers are very thin and have been heavily weathered. The outcrop that is visible in the background does not show any layering and therefore cannot be measured. The remaining hillside is covered in recent soil and vegetation, and several broken off slabs/boulders of conglomerate are visible. Compared to Unit A, which is the closest sub-horizontal unit, the clasts appear slightly more angular in Unit B. The sandstone beds/layers in Unit B are much thinner than those found in Unit A (5-10cm), and the clasts are more pebble than cobble. A log for this outcrop has not been created as it is poorly exposed. There are no exposed contacts for this outcrop as all sides are covered with recent soil and vegetation.

<b>Unit B</b>		
<b>Location (centre outcrop)</b>	N38°04.677' E022°3.988'	
<b>Elevation at base (approx.) [m]</b>	1281	
<b>Max preserved thickness (approx.) [m]</b>	2m	
<b>Colour</b>	Grey to light brown (Chert appears as both red and black/grey in colour)	
<b>Clast size</b>	Pebble to Cobble (~112mm)	
<b>Clast type</b>	Limestone with <10% Chert. Very little consolidated sandstone clasts.	
<b>Grain fabric with sorting</b>	Clast-supported with a poorly sorted matrix	
<b>Grain morphology</b>	<b>Limestone</b>	Sub-rounded
	<b>Chert</b>	Angular to sub-angular
	<b>Sandstone</b>	Rounded (very few)
<b>Dip / Dip Direction [°]</b>	10/060	
<b>Paleo flow (Imbrication)</b>	E	
<b>Contact</b>	Assumed to onlap dipping conglomerate, poorly to no visible exposed contact.	

Table 4-2: Summary of Unit B.



Figure 4-21: Image of Unit B, a smaller outcrop north of Unit A. It is a very isolated outcrop that shows a dip of  $10^\circ$  and dip direction of  $060^\circ$ . The imbrication was measured to be eastward directed.

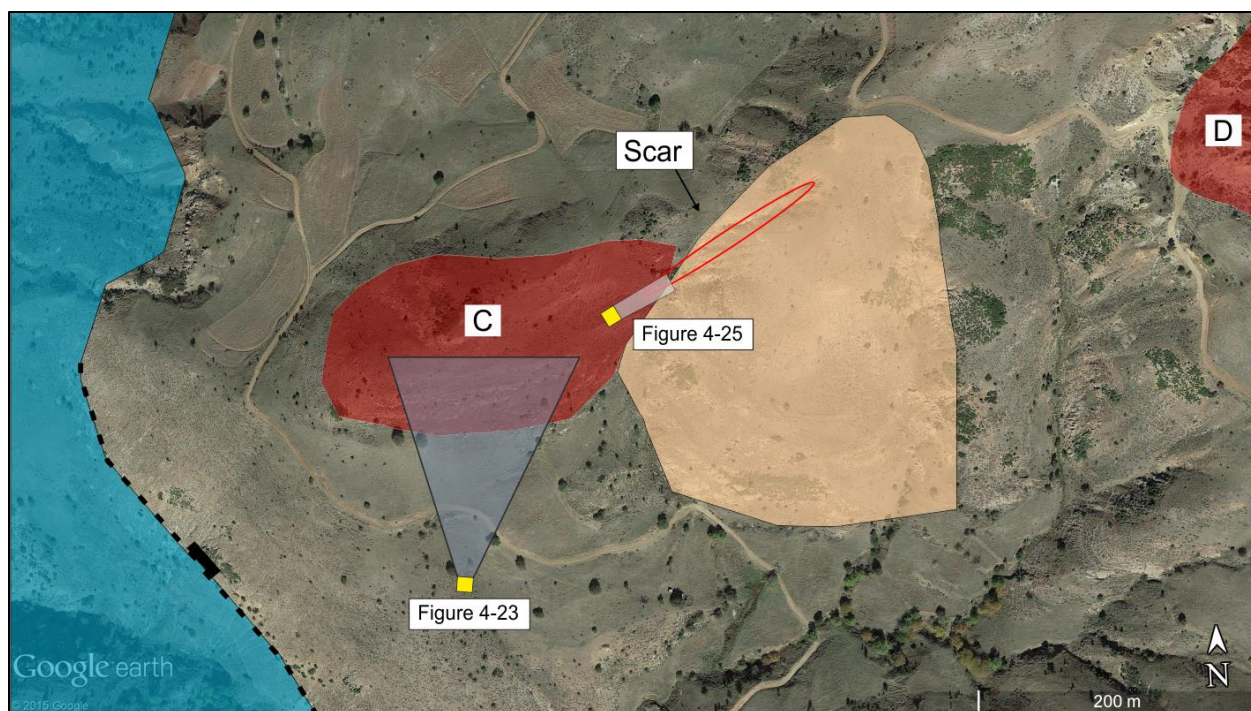
#### 4.3.4 Unit C (Figure 4-16, E3)

Unit C is located in the western edge of the Kerpini Fault Block, approximately 2km west-northwest from Kerpini Village. This outcrop is poorly exposed, however exhibits characteristics of being part of the sub-horizontal layers. As Figure 4-23 shows, the outcrop is covered with recent soil and vegetation on almost all sides. There are sandstone beds present in the outcrop. These beds vary in thickness and have been significantly eroded and are difficult to follow within the outcrop. However they do give some indication that would lead towards a north and east oriented dip and dip direction. Littered around the outcrop are large slabs/boulders that appear to have broken off a larger structure. These slabs/boulders all show erratic dip angles and are therefore not included in the measurements.

<b>Unit C</b>		
<b>Location (centre outcrop)</b>	N38°05.403' E022°5.310'	
<b>Elevation at base (approx.) [m]</b>	1189	
<b>Max preserved thickness (approx.) [m]</b>	20	
<b>Colour</b>	Light brown to grey	
<b>Clast size</b>	Pebble to Cobble (~171mm)	
<b>Clast type</b>	Limestone with <15% Chert, ~5% consolidated sandstone clasts.	
<b>Grain fabric with sorting</b>	Clast-supported with a poorly sorted matrix	
<b>Grain morphology</b>	<b>Limestone</b>	Sub-rounded to rounded
	<b>Chert</b>	Angular to sub-angular
	<b>Sandstone</b>	Rounded / Tabular
<b>Dip / Dip Direction [°]</b>	4/040	
<b>Paleo flow (Imbrication)</b>	E/SE	
<b>Contact</b>	Contact is not exposed, and has not been estimated due to heavy covering of vegetation.	

Table 4-3: Summary of Unit C





**Figure 4-22: An image taken from Google Earth to show the location of Unit C in relation to Unit D and other sediment. The beige shaded area is a north dipping outcrop of conglomerate. The red marked area is a scar/gulley discussed later in this section.**

Figure 4-22 shows the location of Unit C in relation to Unit D and the surrounding sediment. The beige shaded area differs in that this area shows a  $14^{\circ}$  dip angle to the north. Thus this outcrop differs from the coarse grained, south dipping conglomerate found abundantly in the Kerpini Fault Block. Additionally, the sub-horizontal, as the beige shaded area shows, has a much steeper dip angle than Unit C. The contact between the sub-horizontal and the south-dipping conglomerate is not exposed and neither side shows any indications of a contact. However, it is assumed that Unit C overlays the south-dipping conglomerate. The closest south-dipping conglomerate is located ~400m south of Unit C, immediately north of a fault (Figure 4-24).

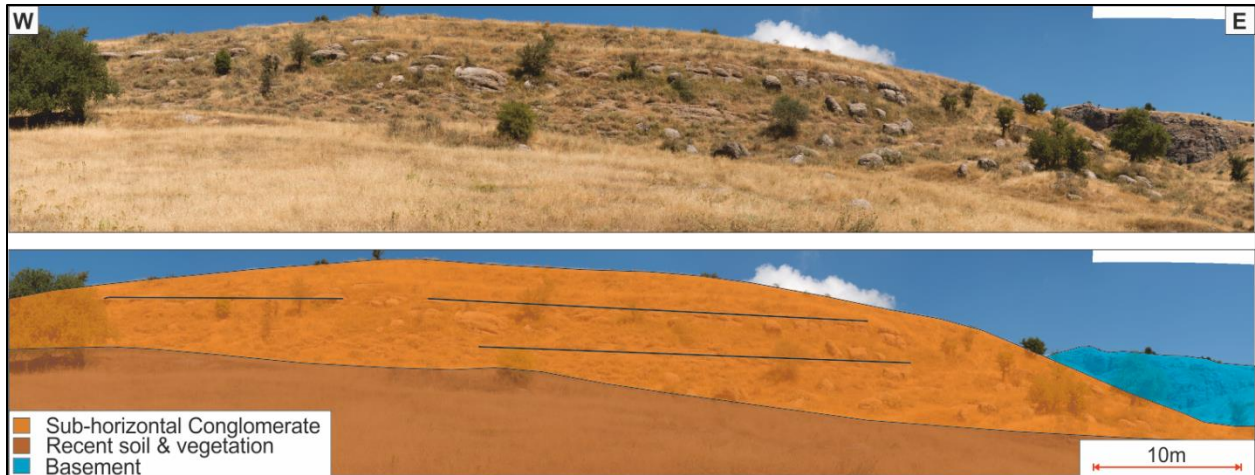


Figure 4-23: Image taken looking north towards Unit C. The outcrop is poorly exposed, and it appears to show elements of sub-horizontal sediment. These sediments appear broken up and covered with recent soil. In the background on the right, the basement (which sits at a higher elevation) is visible.

Moving east and north from the outcrop shown in Figure 4-23, one enters the scar or gully that runs north-south (N38°5.438' E022°5.430) shown in Figure 4-22 and Figure 4-24. This gully separates the sub-horizontal sediment (Unit C) from north dipping sediment. However this outcrop of dipping sediment dips 14° to the north. This is in stark contrast to the general trend of the dipping, coarse grained conglomerate in the Kerpini Fault Block that dips ~21° towards the south. Figure 4-24 shows the location of the scar with respect to Unit C and D

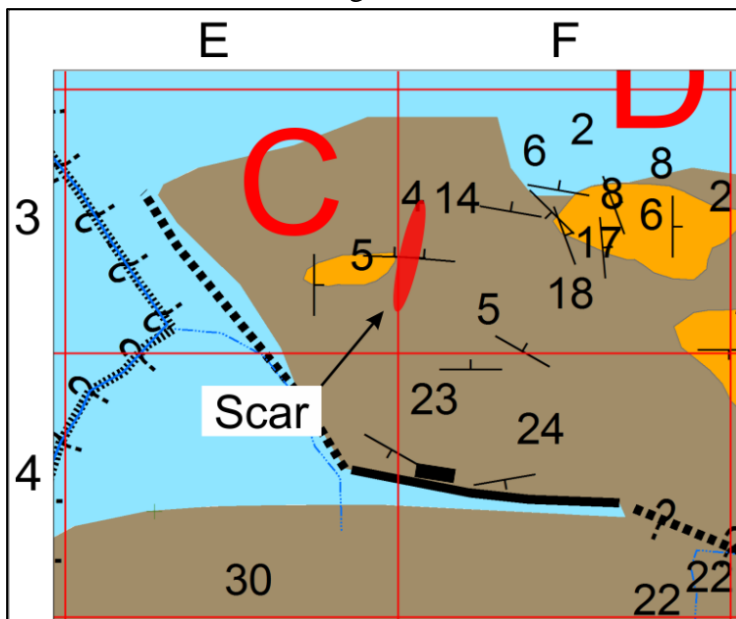


Figure 4-24: Cropped from Figure 4-16, showing the location of the scar/gully with respect to Unit C and D. Note that on either side of the scar the dip angle changes from 4°N to 14°N.

and is a crop from Figure 4-16. Figure 4-25 is an image looking east at the scar. It shows a 60-70cm thick sandstone bed in the dipping sediment. This sandstone layer can be correlated across the scar/gully to the sub-horizontal sediment and was used as the marker for dip measurement. The gully runs northward towards the apex of the beige shaded, north dipping conglomerate mound were it fades into the recent soil and vegetation.



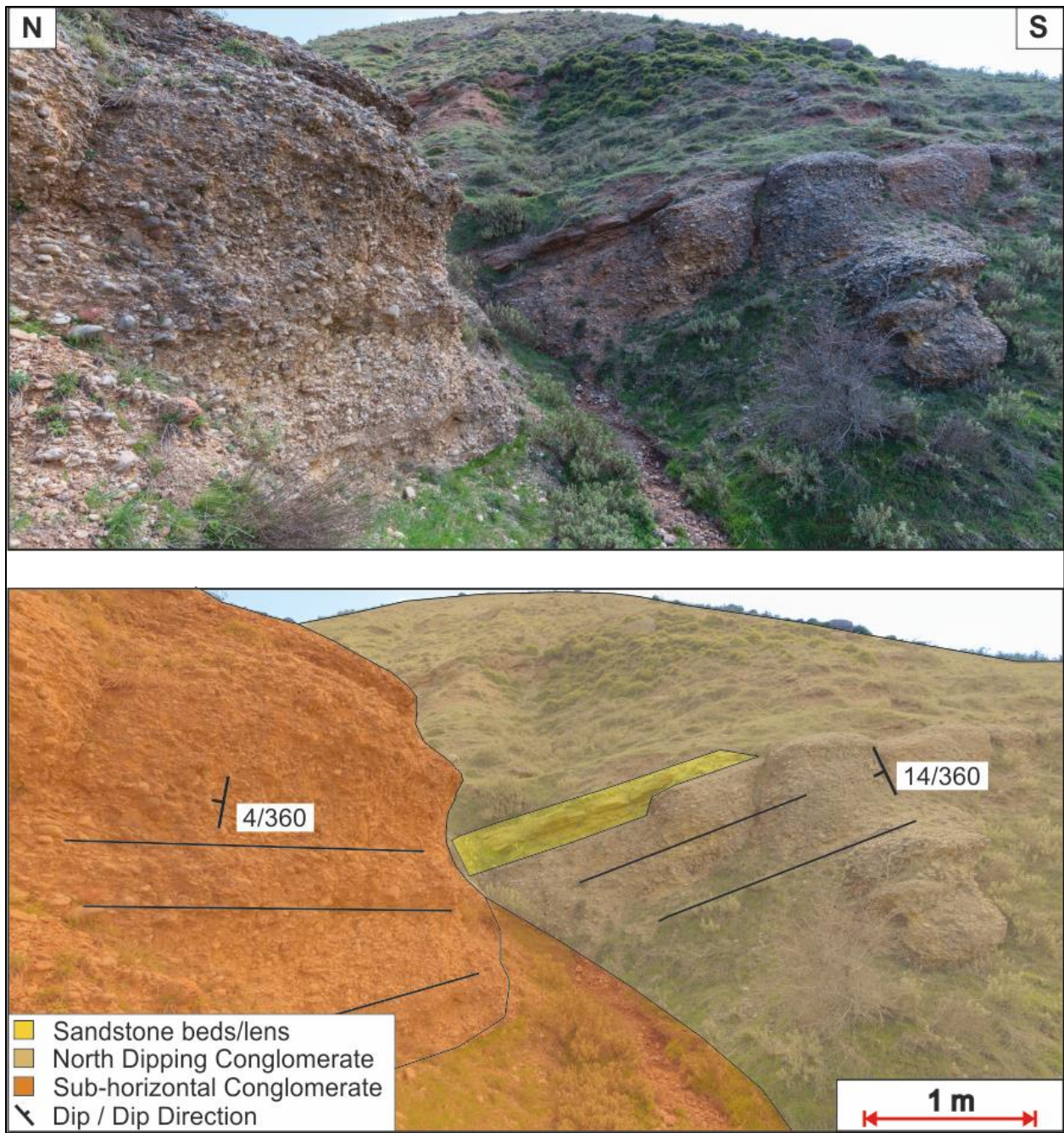
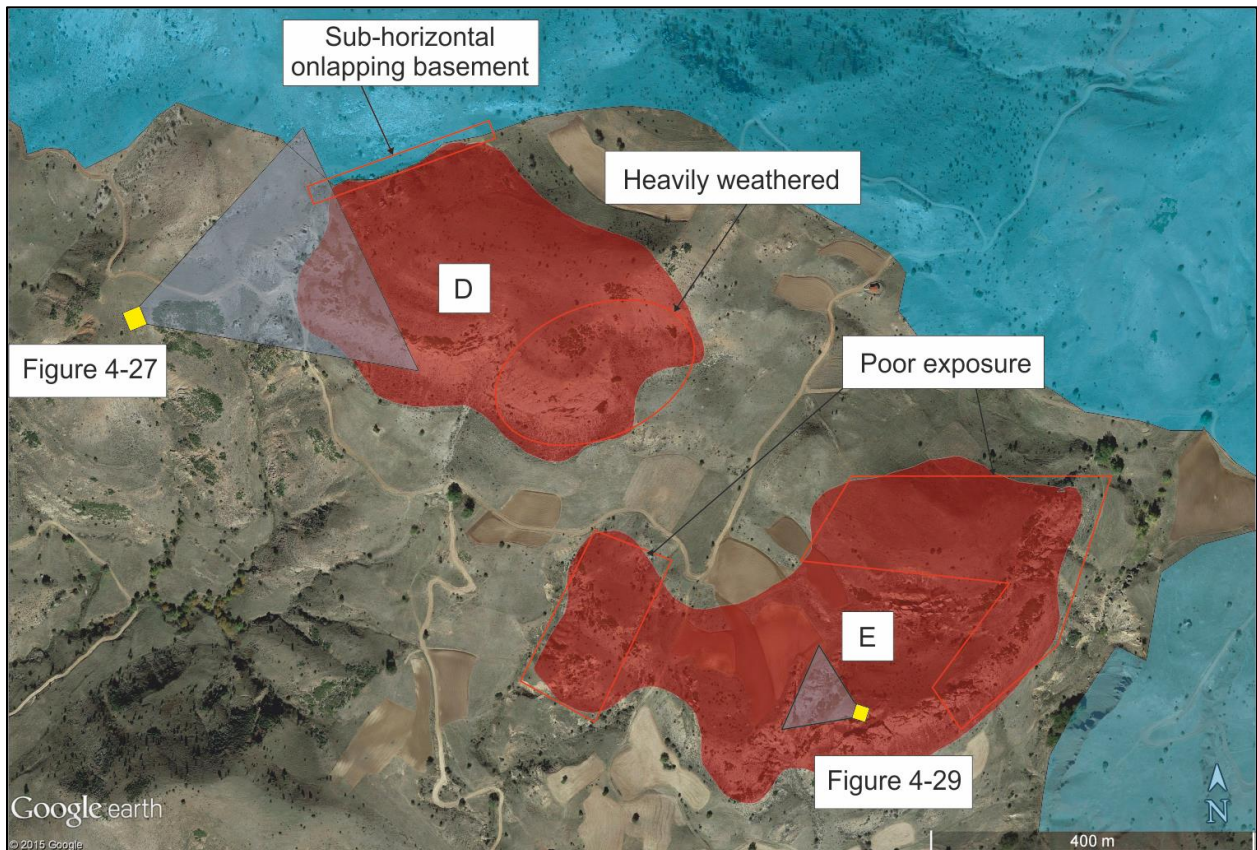


Figure 4-25: Image showing the scar/gulley. It separates the sub-horizontal sediment from the north dipping. A thick (60-70cm) sandstone layer can be traced across the gulley. The dip difference between the two outcrops is  $10^\circ$ .



#### 4.3.5 Unit D (Figure 4-16, F3)

Moving eastward in the Kerpini Fault Block ~1km from Unit C, Unit D is located. It is located approximately 1.5km northwest from Kerpini Village. The outcrop is well exposed on the west and southwest edge; the east and south-east edges of the outcrop are heavily weathered and covered with vegetation. The northern edge of the outcrop clearly onlaps basement. However, the direct contact with basement is not exposed as there is ~5-7m of recent soil and vegetation in between the exposed basement and exposed sub-horizontal sediment. Similarly the top of the outcrop is covered with vegetation. Any contacts between sub-horizontal and south dipping are poorly exposed. However, it is assumed that the sub-horizontal sediment is overlying the coarse-grained, south-dipping conglomerate. Figure 4-26 is an image taken from Google Earth and shows an overview of Units D and E. Units D and E are only separated by ~100m of recent soil and vegetation.



**Figure 4-26:** This is an image taken from Google Earth to show the proximity of Unit D and E (red shaded), the blue is basement. It also shows the location of Figure 4-28 and Figure 4-29. As the image shows, D and E are separated by ~100m of recent soil and vegetation.

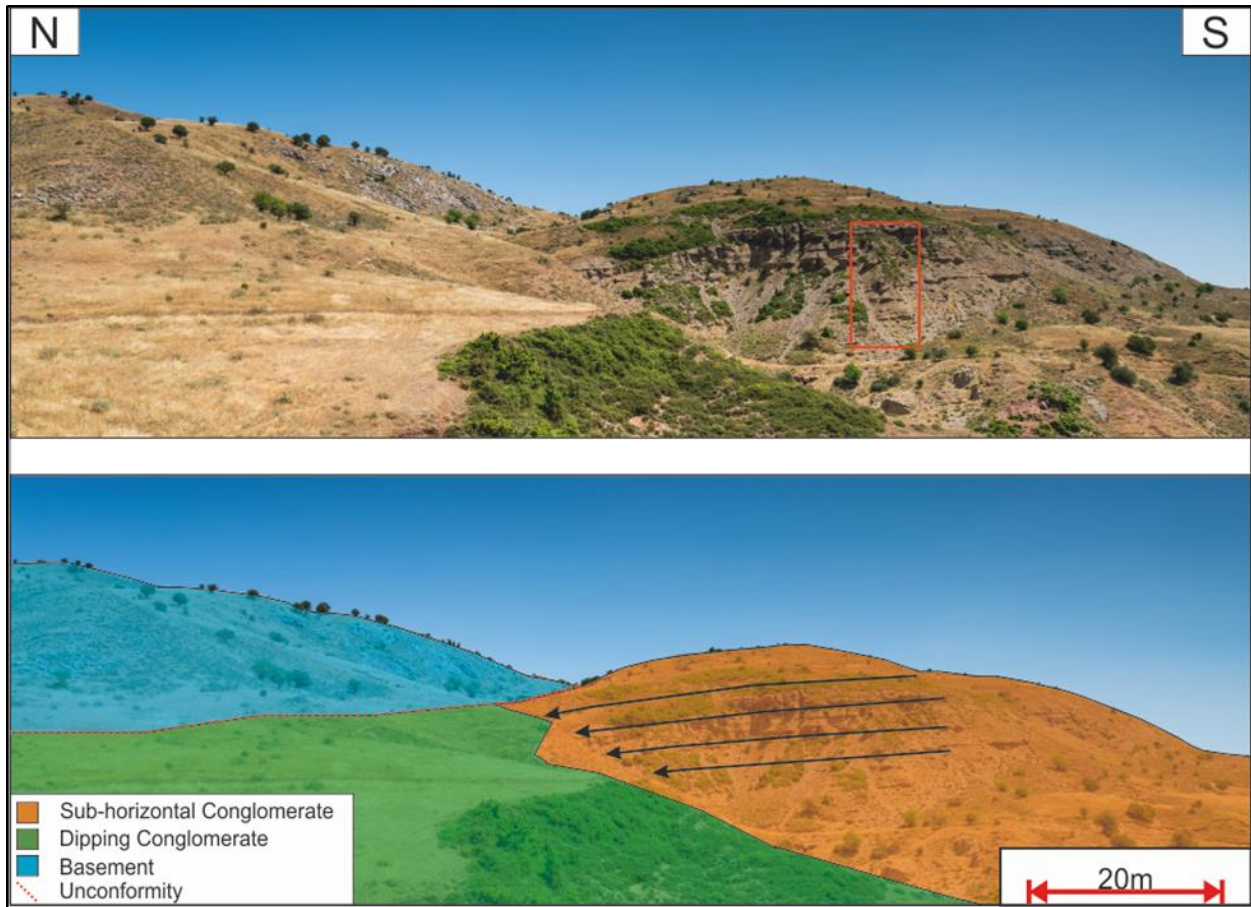


<b>Unit D</b>		
<b>Location (centre outcrop)</b>	N38°05.470' E022°5.821'	
<b>Elevation at base (approx.) [m]</b>	1260	
<b>Max preserved thickness (approx.) [m]</b>	66	
<b>Colour</b>	Light brown to grey	
<b>Clast size</b>	Pebble to Cobble (High up ~171mm) (Lower down ~127mm)	
<b>Clast type</b>	Limestone with <15% Chert, ~10% consolidated sandstone clasts.	
<b>Grain fabric with sorting</b>	Clast-supported with a poorly sorted matrix	
<b>Grain morphology</b>	<b>Limestone</b>	Sub-rounded to rounded
	<b>Chert</b>	Angular to sub-angular
	<b>Sandstone</b>	Rounded / Tabular
<b>Dip / Dip Direction [°]</b>	7/060	
<b>Paleo flow (Imbrication)</b>	E	
<b>Contact</b>	Contact between sub-horizontal and dipping sediment is not exposed. On the northern edge the outcrop clearly onlaps basement, however the direct contact is covered with recent soil.	

**Table 4-4: Summary of Unit D**

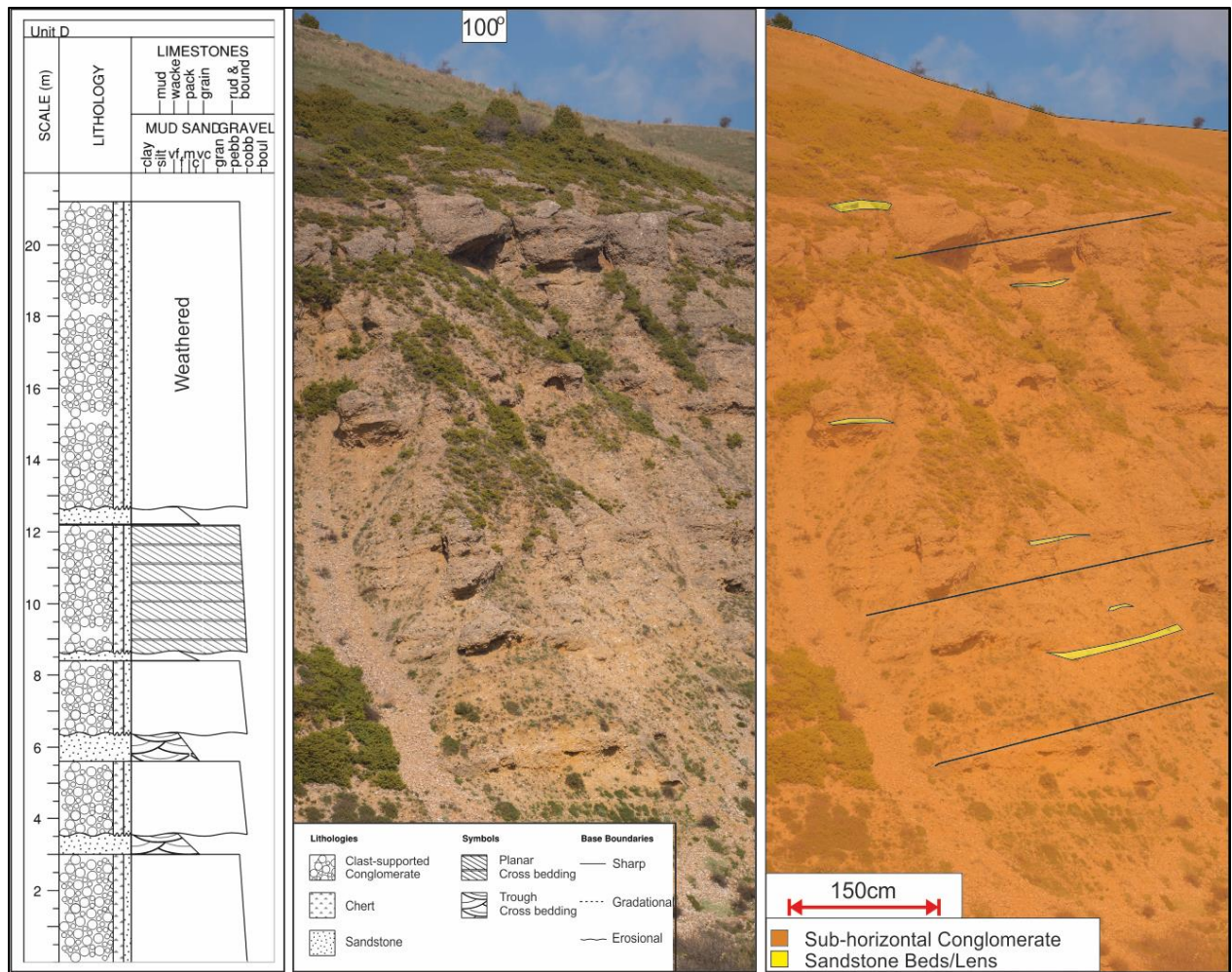
Unit D sits in the north-western region of the Kerpini Fault Block, the northern edge of the outcrop is approximately 1.5km of the Dhoumena fault. It is a large outcrop measuring 400m (east-west) and 300m (north-south). As the western and south-western sides are well exposed, they show clear indication of layering. These well exposed sides make it easier to observe the clast than the heavily weathered eastern sides. The south-eastern and eastern side appear greyer in colour, have a gentler slope, and are more consolidated, whereas the western side is light brown to grey in colour and is less consolidated.

The onlap with basement can be best viewed from the western side (Figure 4-27). This figure displays the unit as it onlaps the basement to the north. Additionally it is here on the western side of the outcrop that there is the possibility of a contact between sub-horizontal and dipping coarse conglomerate. However this contact, and the south-dipping conglomerate, is covered by recent soil making it very difficult to ascertain the exact position and nature of the contact.



**Figure 4-27: Image taken looking east at Unit D. The western side, as shown in the image, shows layering. The red outline shows Figure 4-28. The scale is applicable to base of Sub-horizontal conglomerate.**

Overall this unit is difficult to access as the surrounding sides are very steep and covered with scree. Most of the images are taken from a distance to allow for a more direct view of the outcrop. Unit D, like Units A and C, has interlayered sandstone beds that occur at irregular intervals within the outcrop. The sandstone beds within Unit D are thicker and occur more frequently than the sandstone beds observed in the dipping, coarse grained conglomerate. Furthermore Unit D contains the consolidated, rounded sandstone clasts that occur rarely in the dipping conglomerate. In general there appears to be a fining upwards trend within the layers of Unit D, which is also visible in the sandstone beds. As the log in Figure 4-28 shows, some evidence of possible planar cross bedding was found in the conglomerate layer half way up the exposed side. The cross bedding is not shown in the actual image as it was not possible to operate a camera to get a good view when climbing up the scree side; therefore it is only depicted in the log. Moving further down the side shown in Figure 4-28, the cross bedding is difficult to observe as the area is covered with loose pebbles/cobbles.



**Figure 4-28:** This image is a close up of the highlighted area in Figure 4-27. It reveals some of the layering that is visible in the unit on the western edge. The log on the left is general representation of the outcrop. Many of the areas are inaccessible and few good vantage points are available. The log is stopped at 21m, however the unit does continue for another ~45m. The upper part of the outcrop is covered with vegetation and there are very few exposed beds, but it is assumed that the conglomerate continues throughout.

#### 4.3.6 Unit E (Figure 4-16, G3)

South-east of Unit D lies the outcrop that has been named Unit E. Unit E lies approximately 1km northwest from Kerpini Village. This is another large outcrop that is well exposed along the south-eastern edge. The remaining edges are covered with recent soil and vegetation. In shear area, this unit appears to be the largest.

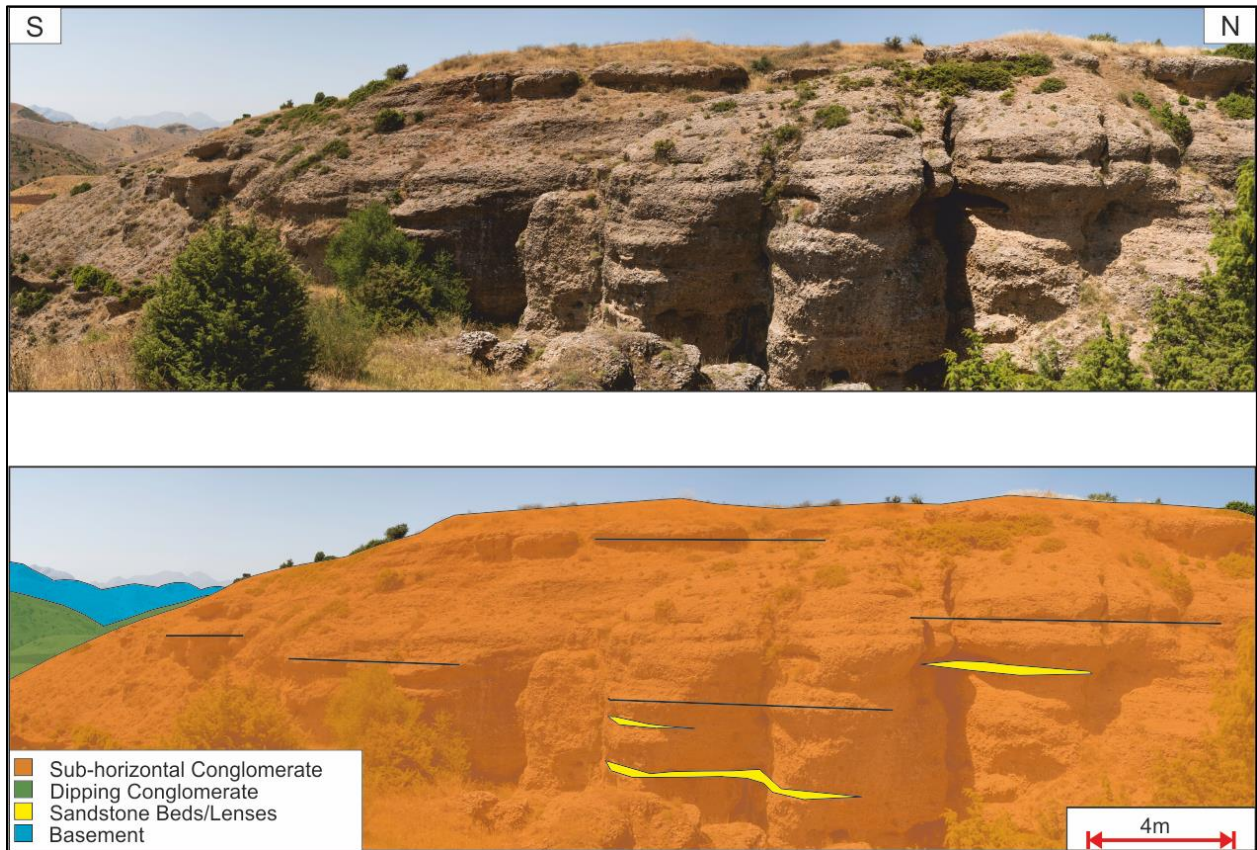
<b>Unit E</b>			
<b>Location (centre outcrop)</b>		N38°05.233' E022°6.082'	
<b>Elevation at base (approx.) [m]</b>		1190	
<b>Max preserved thickness (approx.) [m]</b>		94	
<b>Colour</b>		Light brown to grey	
<b>Clast size</b>		Pebble to Cobble (~130mm)	
<b>Clast type</b>		Limestone with <15% Chert, ~10% consolidated sandstone clasts.	
<b>Grain fabric with sorting</b>		Clast-supported with a poorly sorted matrix	
<b>Grain morphology</b>	<b>Limestone</b>	Sub-rounded to rounded	
	<b>Chert</b>	Angular to sub-angular	
	<b>Sandstone</b>	Rounded / Tabular	
<b>Dip / Dip Direction [°]</b>		<b>East</b>	14/085
		<b>West</b>	2/185
<b>Paleo flow (Imbrication)</b>		E/NE	
<b>Contact</b>		No obvious contact with basement is visible. No exposed contact with dipping conglomerate is visible, however sub-horizontal sediment assumed to overlay south dipping conglomerate.	

Table 4-5: Summary of Unit E.

Large areas of this outcrop are covered with recent soil and vegetation. Viewing Figure 4-26, only ~100m separates Unit D from E. The exposed outcrop (Figure 4-29) is very similar in both colour and texture to units A and D. Unit E contains interlayered sandstone beds that occur at irregular intervals and range from 20-70cm. The conglomerate layers show a general upward fining trend, and there are possible indications of planar cross bedding in the conglomerate. This



crossbedding is difficult to observe as it is very subtle. Similar to the other sub-horizontal units, Unit E also contains the consolidated rounded sandstone clasts.

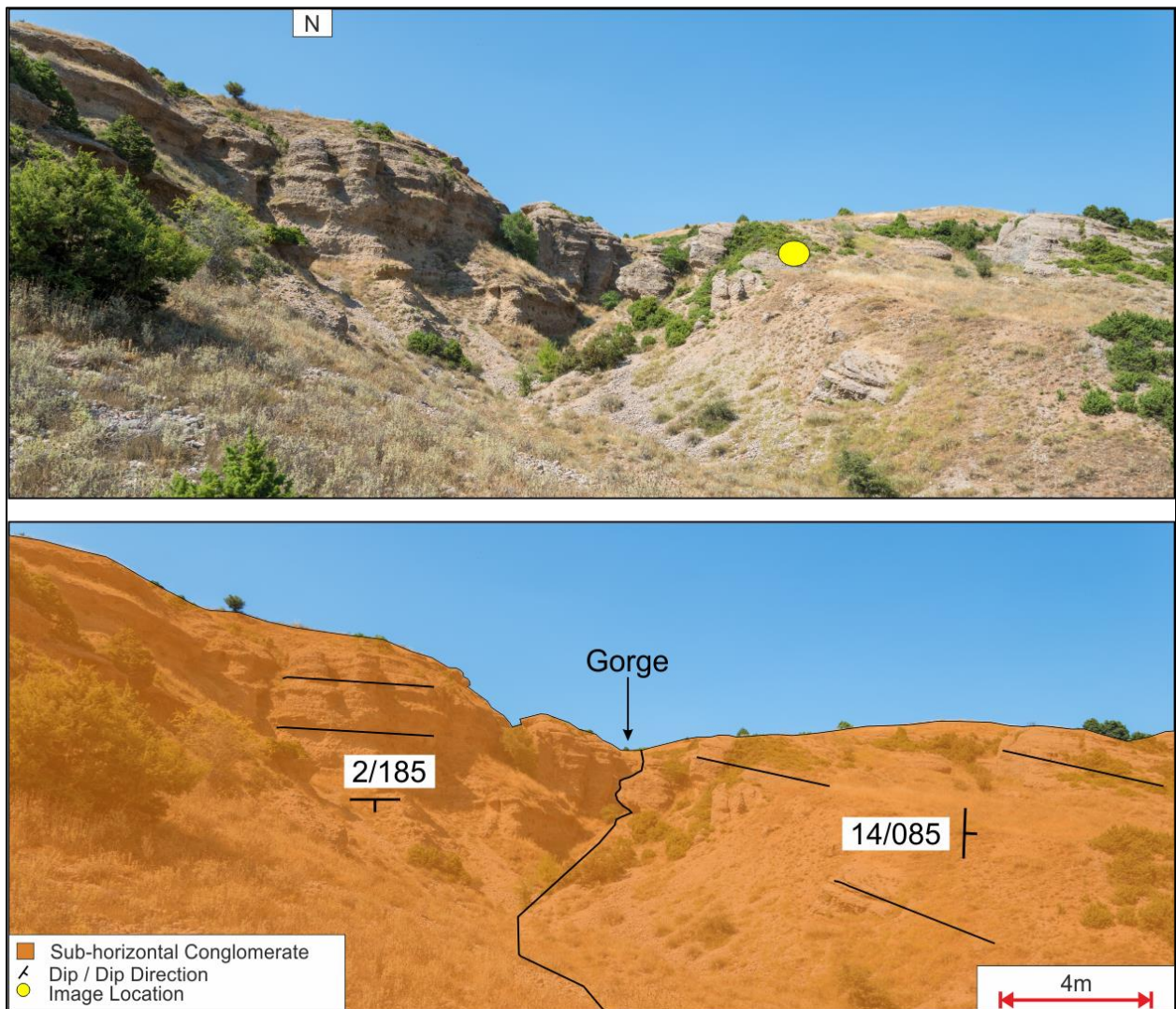


**Figure 4-29: Looking west across the gorge at the western part of Unit E. This part of the unit shows a 2° dip towards the south. Some sandstone layers/lenses are visible, however many are heavily weathered or covered with loose sediment.**

When observing Unit E from the south (Figure 4-30), there is a gorge that runs south-north dividing the unit into two separate sections (N38°5.203 E022°6.048). Following this gorge north it becomes covered with recent soil and vegetation. As a result of this gorge, Unit E displays two distinct different dip angles. The western side of the gorge shows 2° dip angle towards the south, the eastern side 14° towards the east. Attempts were made to try and identify beds that would correlate the eastern and western sides; however it proved to be difficult due to erosion.

As one walks northward along the edge of the eastern outcrop (14/085 dipping section), the dip angle remains the same until one reaches a point where the outcrop is again covered with recent soil and vegetation. Furthermore Figure 4-26 shows that immediately east (<50m) of Unit E there is a large outcrop of basement. This can also be viewed in Figure 4-3 and Figure 4-4. The

conglomerate that is depicted in these two images that lies between the basement and Unit E is very chaotic, consisting of several broken slabs and large boulders.



**Figure 4-30: Image taken from the south looking north into the gorge that separates Unit E into a western and eastern section. The different dip angle is shown on the interpretation. The yellow circle indicates the location at which Figure 4-29 was taken.**

A log was created for this outcrop. It is based on the observations made looking from the vantage point (yellow circle) shown in Figure 4-29. A full-length vertical section was not visible due to the lower section being covered with scree. Therefore the log is also based on observations made moving horizontally from the vertical section. By doing this a complete log was produced. The log, Figure 4-31, shows similar features as the log from Unit D. Each of the conglomerate beds show a subtle fining upwards and in certain layers there are indications of planar crossbedding. The sandstone beds occur at irregular intervals.



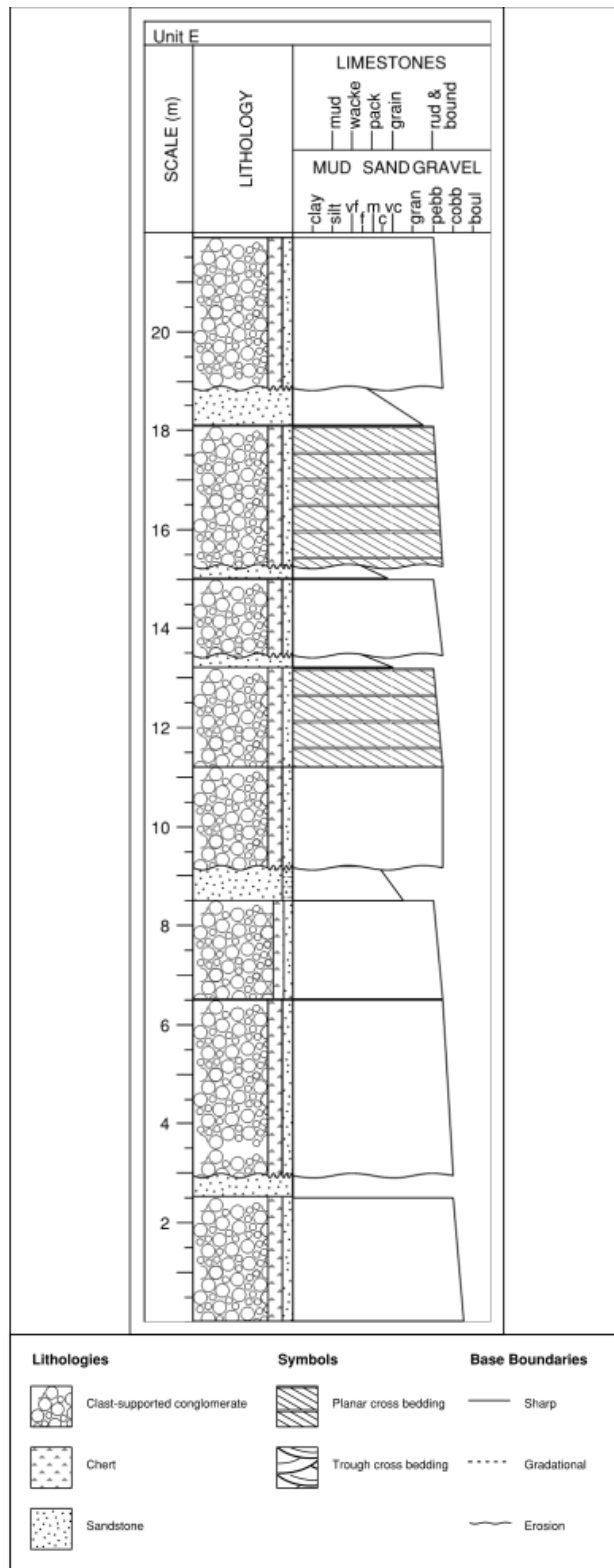
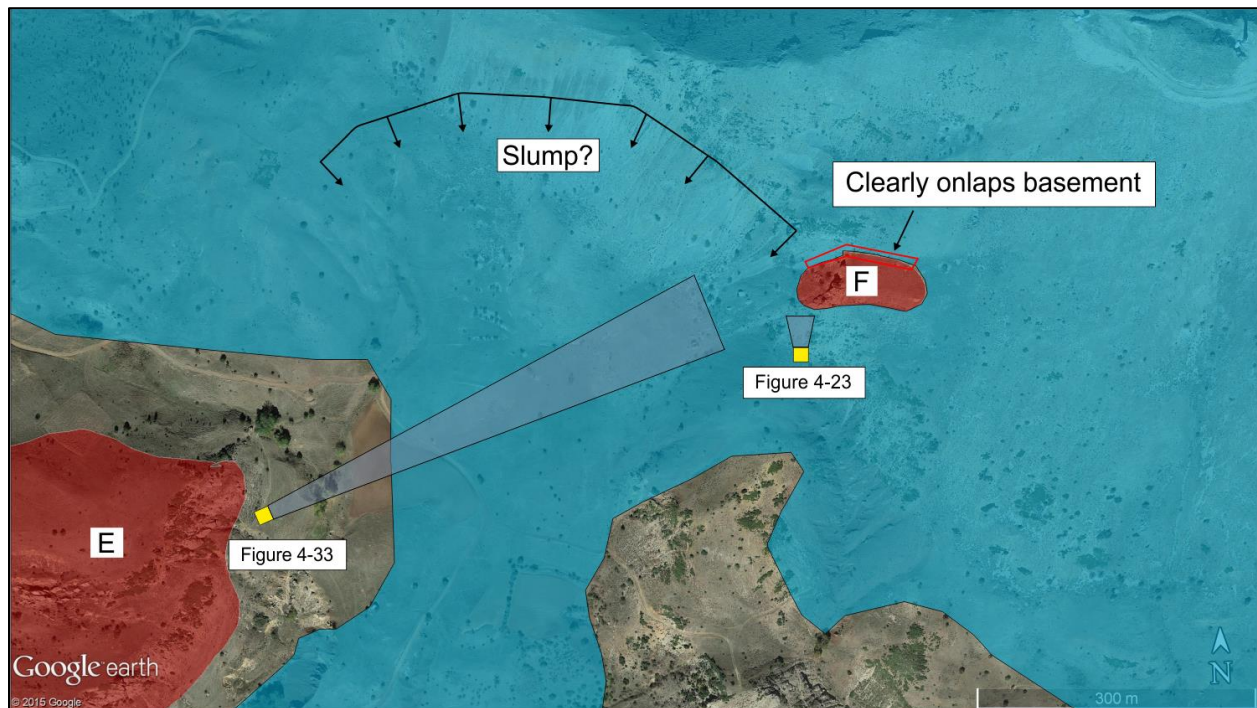


Figure 4-31: Log showing the exposed outcrop of the western part of Unit E. The lower half was extrapolated by observing horizontally as the lower section is heavily covered with scree.

### 4.3.7 Unit F (Figure 4-16, H3)

Unit F lies isolated very high up close to the Dhoumena Fault, approximately 1km from the fault. In elevation it sits ~150m higher up than the surrounding sub-horizontal sediment. It is mainly the western side that is exposed; the remaining sides are either covered with recent soil and vegetation or heavily weathered.



**Figure 4-32:** An image taken from Google Earth showing the location of Unit F relative to Unit E. Note that Unit F sits isolated on basement. The two locations of the photographs are shown. The area marked with “Slump?”, is the same area as shown in Figure 4-3.

<b>Unit F</b>		
<b>Location (centre outcrop)</b>	N38°05.433' E022°6.707'	
<b>Elevation at base (approx.) [m]</b>	1340	
<b>Max preserved thickness (approx.) [m]</b>	42	
<b>Colour</b>	Light brown to grey. The weathered sides are more greyish.	
<b>Clast size</b>	Pebble to Cobble (~128mm)	
<b>Clast type</b>	Limestone with <15% Chert, ~10% consolidated sandstone clasts.	
<b>Grain fabric with sorting</b>	Clast-supported with a poorly sorted matrix	
<b>Grain morphology</b>	<b>Limestone</b>	Sub-rounded to rounded
	<b>Chert</b>	Angular to sub-angular
	<b>Sandstone</b>	Rounded / Tabular
<b>Dip / Dip Direction [°]</b>	10/010	
<b>Paleo flow (Imbrication)</b>	E/NE	
<b>Contact</b>	Clearly onlaps basement along the northern side. Appears basement contact on the south-western side, the clasts in this area appear are very angular. No apparent contact with south dipping conglomerate.	

**Table 4-6: Summary of Unit F**

As Figure 4-33 shows, Unit F sits nestled high up the northern slope in the Kerpini Fault Block and the north-western side onlaps basement. This direct contact is however not exposed and is covered with a ~2-3m wide band of recent soil and vegetation. Following the contact eastward it becomes covered with recent soil and vegetation, however smaller outcrops of conglomerate, that are believed to be in-situ, are exposed allowing for an approximation of the extent of the unit. Along the southern edge of Unit F there is a transition to basement, this contact is also covered with soil and vegetation. However, an exposed outcrop of very angular to angular conglomerate was found along this assumed contact. This is marked by the red square in Figure 4-33.

Unit F shows similar features, such as texture and colour, as the previous sub-horizontal units. There are interlayered sandstone beds, but they do not appear as frequently as in Units D and E. It also contains the consolidated rounded sandstone clasts and the conglomerate layers

show a fining upward as well as planar crossbedding. Again, the fining upward and planar cross bedding is very subtle in Unit F.

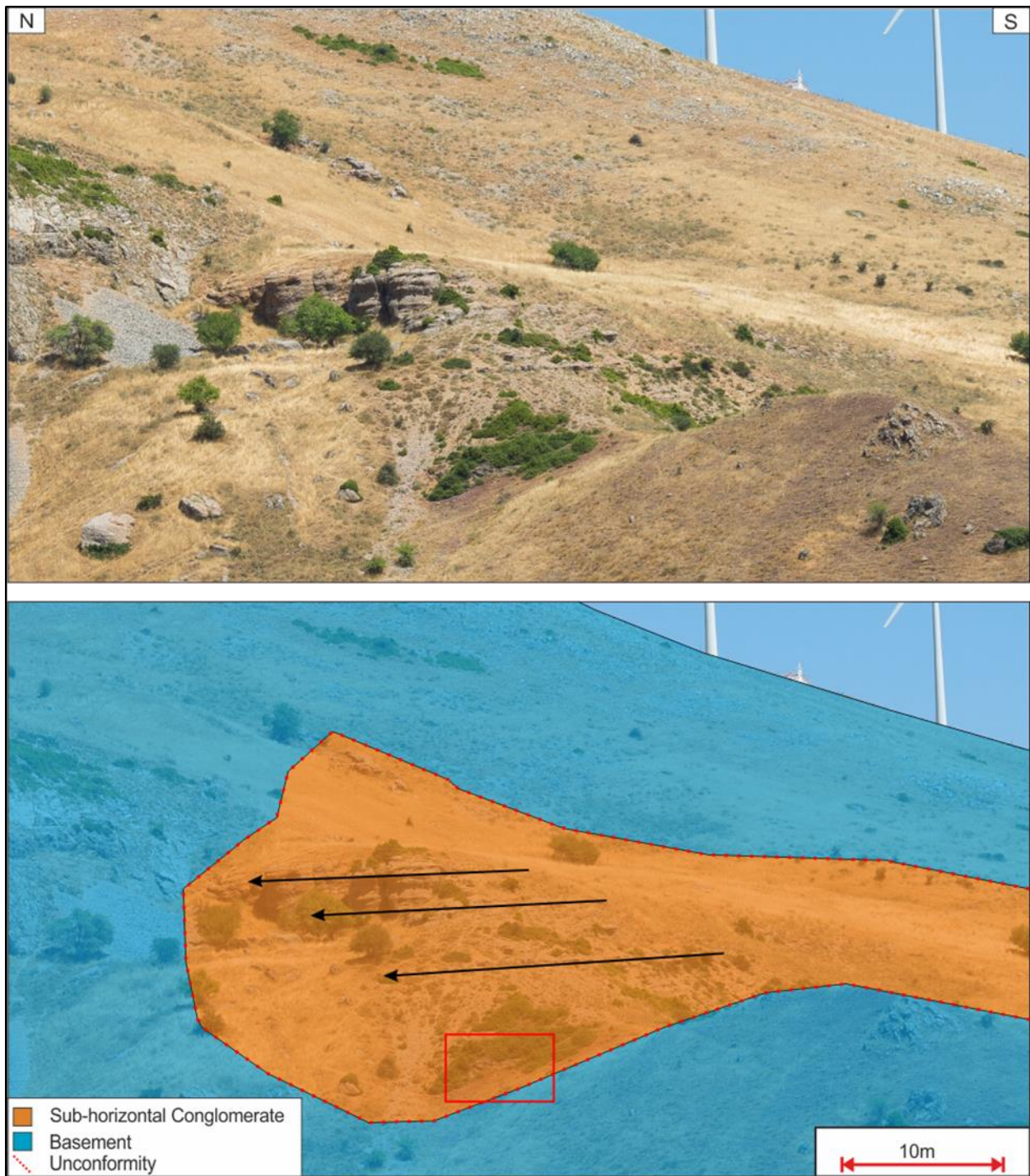
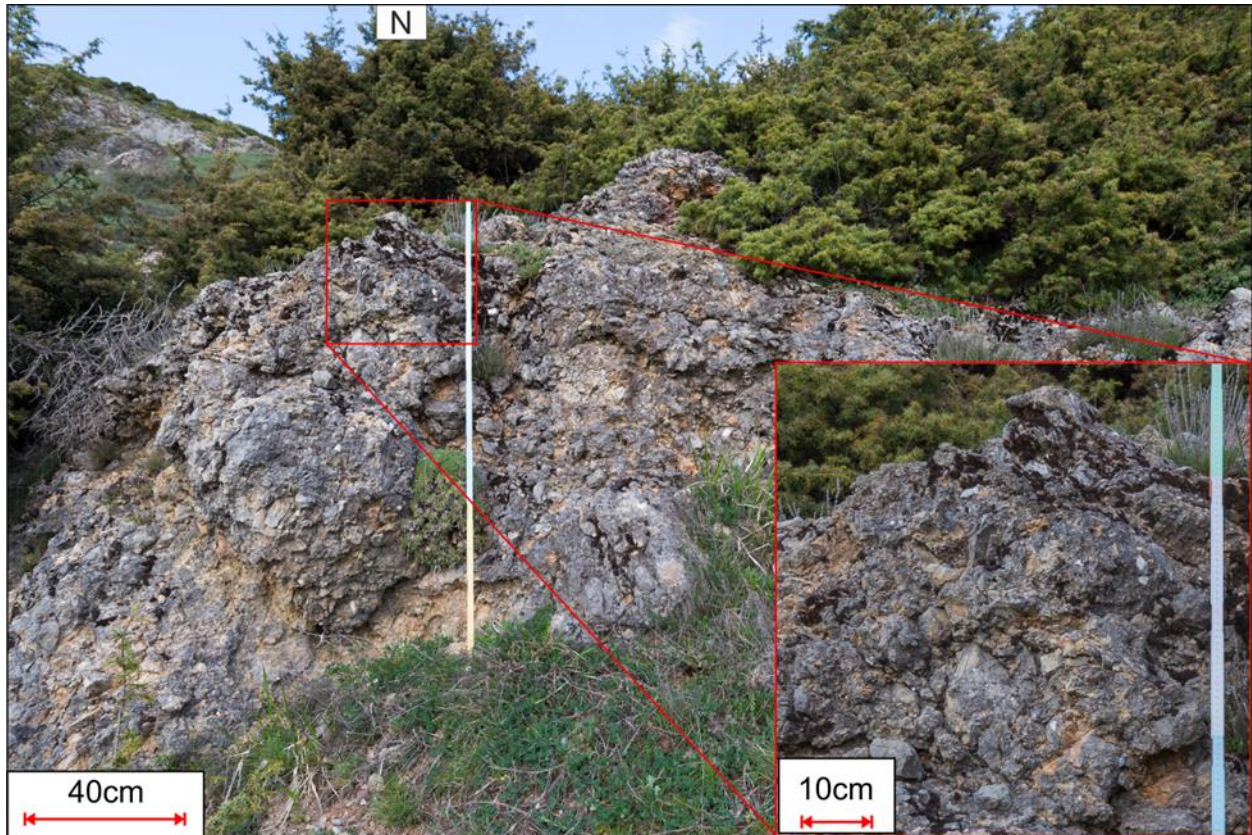


Figure 4-33: Image taken ~800m away to get a good angle. It shows the unit sits on basement, and on the northern side is onlaps basement. From the image it is visible that the eastern side of the outcrop is covered with recent soil. The red box on the interpretation is a possible contact shown in Figure 4-34.



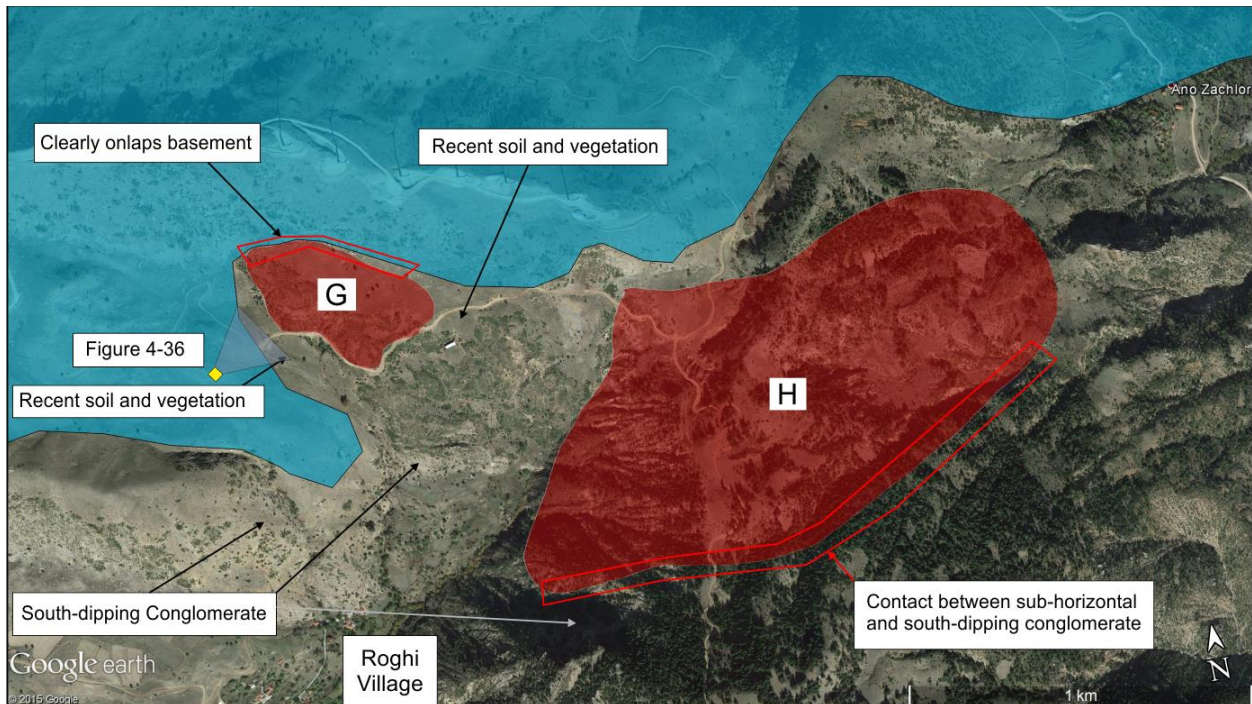


**Figure 4-34:** This is a close up of the red square shown in Figure 4-33. In the right hand corner is an enlargement of the photo. It shows the more angular clasts as they sit very close to the underlying basement. The actual contact between sediment and basement is not exposed.

Figure 4-34 shows in more detail the red square from Figure 4-33. The clasts found within this outcrop are more angular than the clasts found within the main bulk of Unit F. The actual contact between this outcrop and basement is not exposed, neither is the contact between the angular clasts shown here and the more rounded clasts of Unit F. This is the only unit that has had an outcrop with angular clasts like this exposed. No log was created for this outcrop as it is fairly small and the lower and upper boundaries are obscured by recent soil and erosion.

#### 4.3.8 Unit G (Figure 4-16, K3)

Unit G is located approximately 1.3km north from Roghi Village. It is a large outcrop that clearly onlaps basement on its northern edge. However this side is covered with recent soil and vegetation and thus the actual contact is not visible. The southern side is the best exposed side of the outcrop, and it tapers off to the east and is again covered with recent soil and vegetation. Figure 4-35 is an overview of Unit G and shows it in relation to Unit H, which is located further to the east. The image shows how Unit H is set against the northern basement and that further to the south there is south-dipping conglomerate. The area between Unit G and H is mostly recent soil and vegetation. Few good exposed outcrops are found and the ones that are there show trending dip angle of south/south-east.



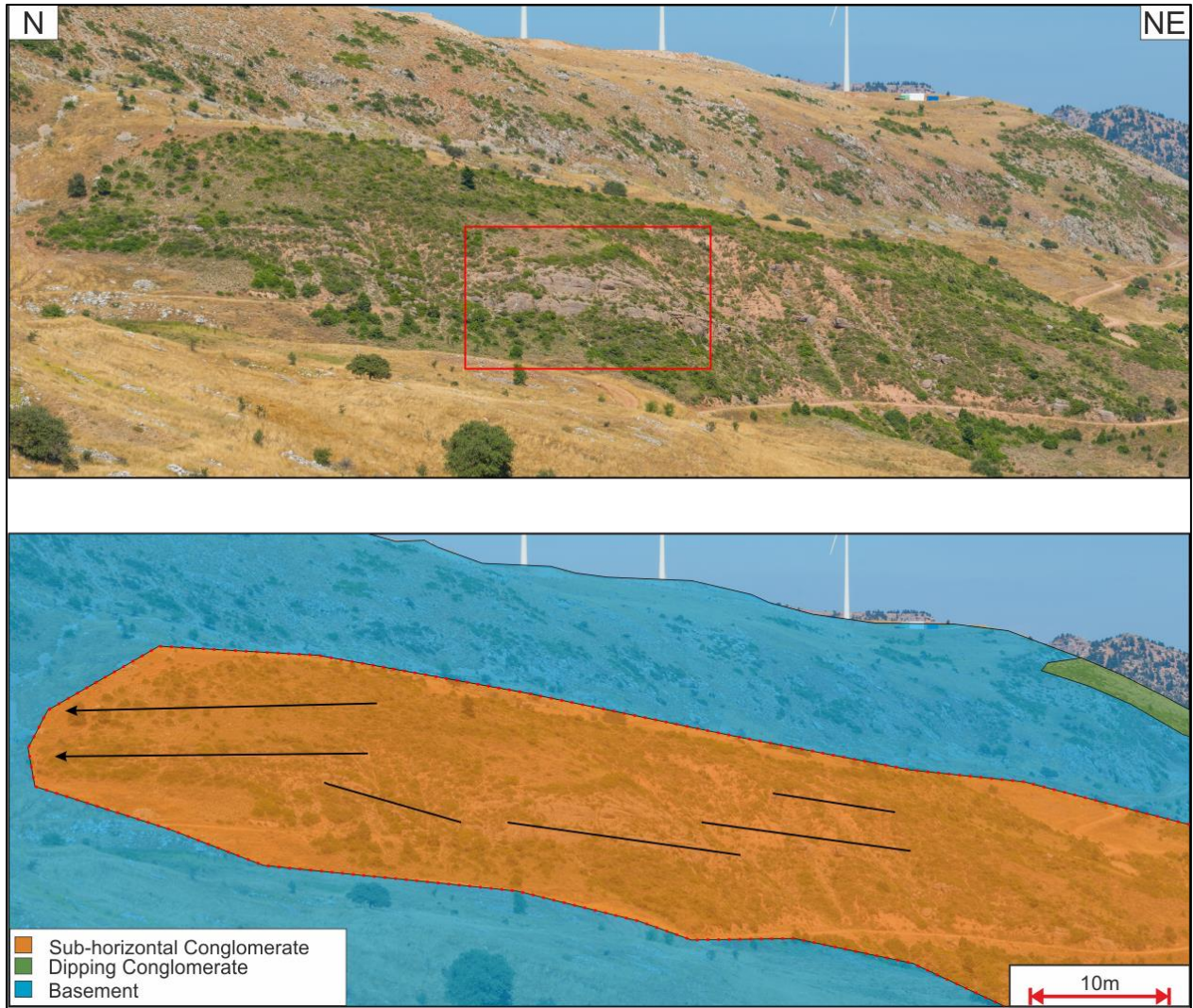
**Figure 4-35: An overview taken from Google Earth showing the location of Unit G in relation to Unit H and basement. Unit G clearly onlaps the basement along the northern edge. On the remaining sides only recent soil is found. Further south of Unit G one finds south-dipping conglomerate. Unit H sits on the northern edge of the massive conglomerate Roghi Mountain and appears to onlap basement.**

<b>Unit G</b>		
<b>Location (centre outcrop)</b>	N38°05.273' E022°8.274'	
<b>Elevation at base (approx.) [m]</b>	1195	
<b>Max preserved thickness (approx.) [m]</b>	56	
<b>Colour</b>	Light brown to grey. The weathered sides are more greyish.	
<b>Clast size</b>	Pebble to Cobble (~138mm)	
<b>Clast type</b>	Limestone with <15% Chert, <5% consolidated sandstone clasts.	
<b>Grain fabric with sorting</b>	Clast-supported with a poorly sorted matrix	
<b>Grain morphology</b>	<b>Limestone</b>	Sub-rounded to rounded
	<b>Chert</b>	Angular to sub-angular
	<b>Sandstone</b>	Rounded / Tabular
<b>Dip / Dip Direction [°]</b>	10°/130°	
<b>Paleo flow (Imbrication)</b>	N/A	
<b>Contact</b>	Clearly onlaps basement along the northern side. Along the southern side it appears to contact with basement and south dipping conglomerate, however these contacts are covered with recent soil.	

**Table 4-7: Summary of Unit G.**

From afar, the outcrop appears flat on the western part, and then it changes its dip angle to more of an eastern dip as one moves east along the beds. Figure 4-36 shows an overview of the unit and from the image the beds appear to change their dip angle. Moving closer in on the outcrop, it reveals a 10°/130° (dip/dip direction) trend. Due to the poorly exposed layers, it was difficult to get accurate measurements of the dip angle and dip direction. Many of the areas that appear on the image as good outcrops are indeed very weathered, and this makes it difficult to pinpoint any imbrication as it is hard to get a good 3-dimensional view. The unit also shows interlayered sandstone layers varying from 10-20cm in thickness. The sandstone layers do not occur as frequent as in Units A-F and are generally thinner.

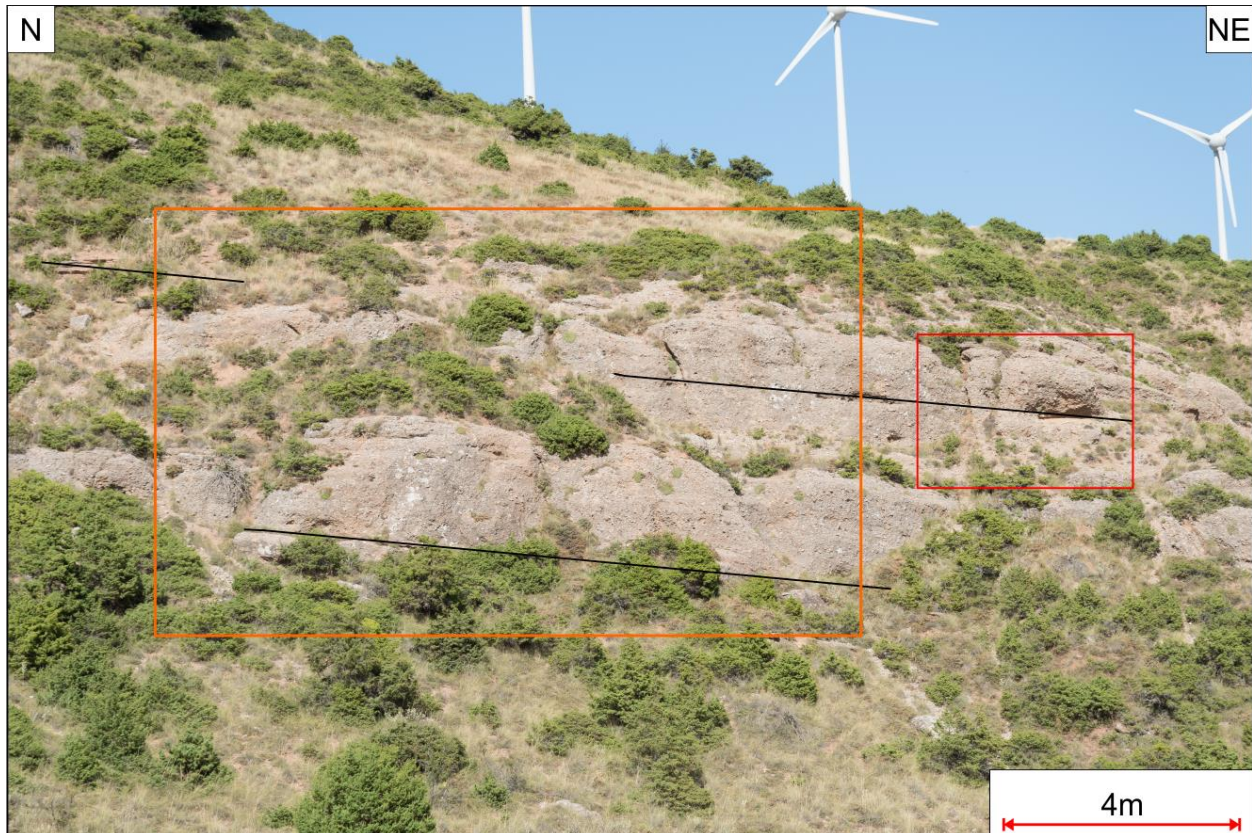




**Figure 4-36: Image of Unit G looking northwards. The unit clearly onlaps basement along the northern side, however this contact is covered with recent soil and vegetation. On the southern side, the second basement contact is also covered. Off image bottom right, there is a transition to dipping conglomerate this contact too is covered. Following the beds eastward, the angles of the beds appear to change to a more eastern dip angle.**

Figure 4-37 is a close up of the red square depicted in Figure 4-36. This close-up shows that the layers appear to be dipping gently towards the east. From a general appearance point of view, colour and clast, it appears very similar to the dipping, coarse grained, south-dipping conglomerate found abundantly throughout the Kerpini Fault Block and less like the sub-horizontal units such as Units A, D and E.

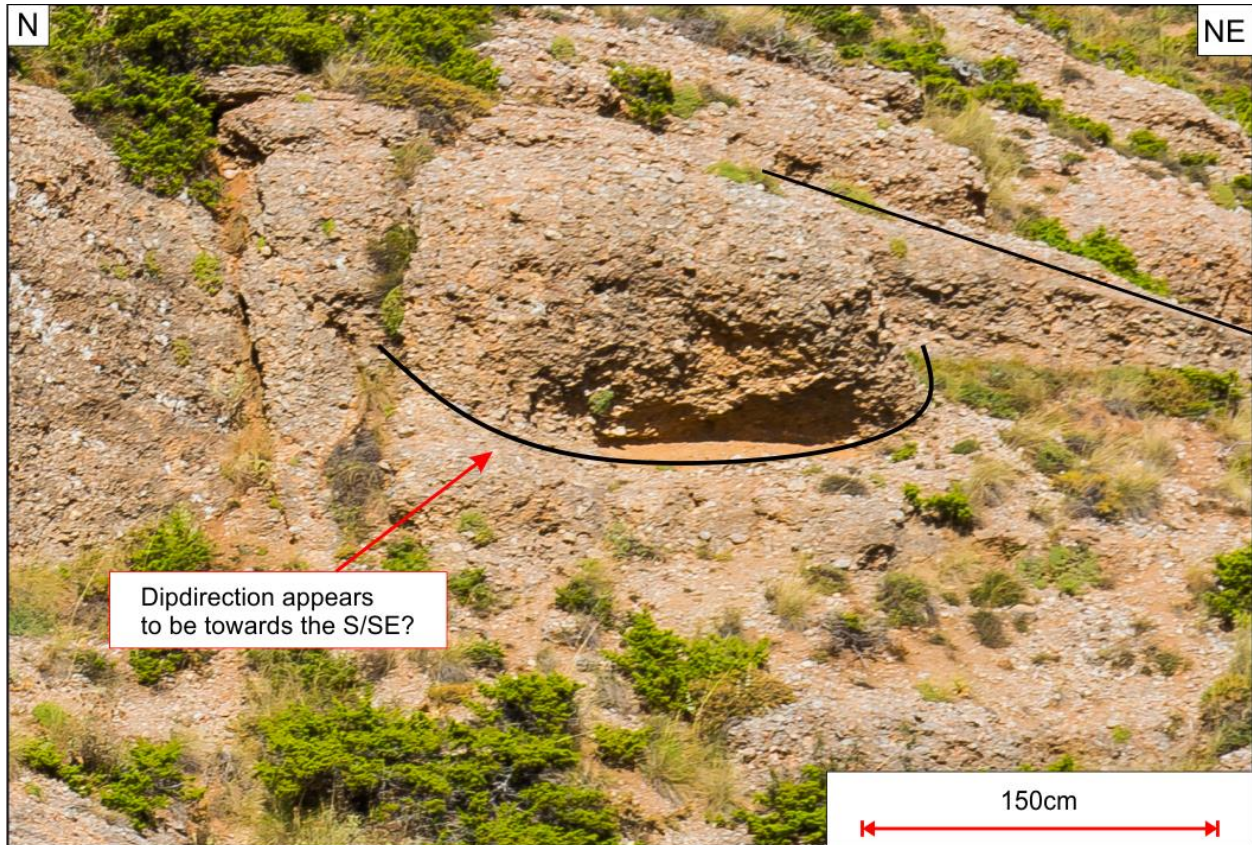




**Figure 4-37:** This is an image of the red square shown in Figure 4-36. From this angle the beds appear to be dipping slightly to the east. The appearance of the outcrop is more reminiscent of the south dipping conglomerate that is the main lithology in the Kerpini Fault Block, than the sub-horizontal sediment found in Units D, E and F.

Figure 4-38 is a crop from Figure 4-37, showing the red square. Although the image is not of optimal quality, the intention here is to show that when viewing the outcrop, it is possible that one is viewing apparent dip. It may appear that this knoll, shown in Figure 4-38, is broken off. However the gap that appears on the left hand side of the black crescent is very small and will not greatly affect the angle. The layers that appear behind and right of the knoll (marked with black line) also appear to be dipping at a steeper angle. Returning to Figure 4-37, when viewing the exposed outcrop that is within the orange square it is then entirely plausible that one is viewing into the layers. The areas shown in the last two pictures are very difficult to get access to. Even when reached it is not possible to obtain any good photographs due to the steep terrain. No log was created for this unit as the outcrops were sporadically exposed or at such a distance that guesswork would have to be done in order to depict features within the outcrop.





**Figure 4-38:** An even closer view of the red square shown in Figure 4-37. The black crescent is an attempt to follow a layer around this small knoll. When viewing the layer that the black crescent is showing, the layer appears to show a more south/south-east dip rather than a eastern dip.

#### 4.3.9 Unit H (Figure 4-16, L4)

<b>Unit H</b>		
<b>Location (centre outcrop)</b>	N38°05.063' E022°8.786'	
<b>Elevation at base (approx.) [m]</b>	1120	
<b>Max preserved thickness (approx.) [m]</b>	140	
<b>Colour</b>	Light brown to grey.	
<b>Clast size</b>	Pebble to Cobble (~117mm)	
<b>Clast type</b>	Limestone with <15% Chert, <5% consolidated sandstone clasts.	
<b>Grain fabric with sorting</b>	Clast-supported with a poorly sorted matrix	
<b>Grain morphology</b>	<b>Limestone</b>	Sub-rounded to rounded
	<b>Chert</b>	Angular to sub-angular
	<b>Sandstone</b>	Rounded / Tabular
<b>Dip / Dip Direction [°]</b>	20/170 <sup>2</sup>	
<b>Paleo flow (Imbrication)</b>	N/NNE <sup>1</sup>	
<b>Contact</b>	Clearly onlaps basement along the northern side, although the contact is not well exposed. Moving south along the outcrop the dip angles change from horizontal to south dipping, exact location is difficult to pinpoint due to vegetation. Similar on the eastern side, there is a contact between the horizontal and dipping sediment (Figure 4-40). The eastern side contact is less visible as the vegetation obscures it.	

**Table 4-8: Summary of Unit H.**

Unit H forms the northern section of the Roghi Mountain outcrop, where it sits in the eastern part of the Kerpini Fault Block. The unit was considered sub-horizontal as it exhibits beds that are not dipping in the general trend of the south-dipping conglomerate in the Kerpini Fault Block and especially immediately south on Roghi Mountain where the dip angles are ~20° southward. Figure 4-39 is an image looking at Unit H, with an underlying interpretation of the

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<sup>2</sup> This dip measurement is taken on the upper layers of Unit H and approximately 25m down, moving down the western cliff face. The same is applicable for the imbrication. The imbrication was measured on the upper and the lower lying, regardless of dip angles the imbrication stayed fairly constant trending N/NNE.

image. The image shows that there is a clear change in dip angle as one moves south along the side of Roghi Mountain. This contact between the sub-horizontal and south-dipping conglomerate is also depicted in Figure 4-35. It is unclear whether or not these beds are carried through to the other side. An attempt to view the eastern side is shown in Figure 4-40. This is an image taken from the east side of Vouraikos River looking west towards Unit H. It shows what appears to be sub-horizontal layers and an elevation marker has been placed on the lower lying beds at ~1122m. This elevation marker has also been placed on the eastern side (Figure 4-39). This shows that both markers are roughly in the vicinity of the lower layers in Unit H. However keeping in mind that Figure 4-9 showed drastic dip angles to the east, one cannot rule out the effect of apparent dips. Within the sub-horizontal layer, there are also layers that are showing a more southern dipping trend. Attempts were made to climb down to get a closer look, however the terrain is very steep, and many observations had to be made from a distance.

An important observation on this unit was the flow direction. Flow direction was attempted measured at several locations; three of these locations are shown in Figure 4-39. The upper location is shown in Figure 4-41 with a close up in Figure 4-42 (a). This shows the imbricated clasts revealing a possible northern flow direction with the beds dipping  $\sim 20^\circ$  south. These beds are overlying the more horizontal beds shown in Figure 4-39. Figure 4-42 (b) is taken looking in the opposite direction of (a) and again displays a northward flow direction. Attempts to climb down the western side of Unit H were conducted, and Figure 4-43 is an image of one of the lower lying horizontal beds. This outcrop also shows a flow direction to the north, even though the bed is sub-horizontal.

Lastly, the contact between the sub-horizontal layers and the dipping layers of Roghi Mountain can be seen in Figure 4-39. This contact is located on the southern edge of Unit H and is shown as either a fault or unconformity on the interpreted image. Attempts were made to climb down or walk on top to ascertain any further evidence of this contact. However it is covered with recent soil and thick vegetation, thus climbing down was not an option.



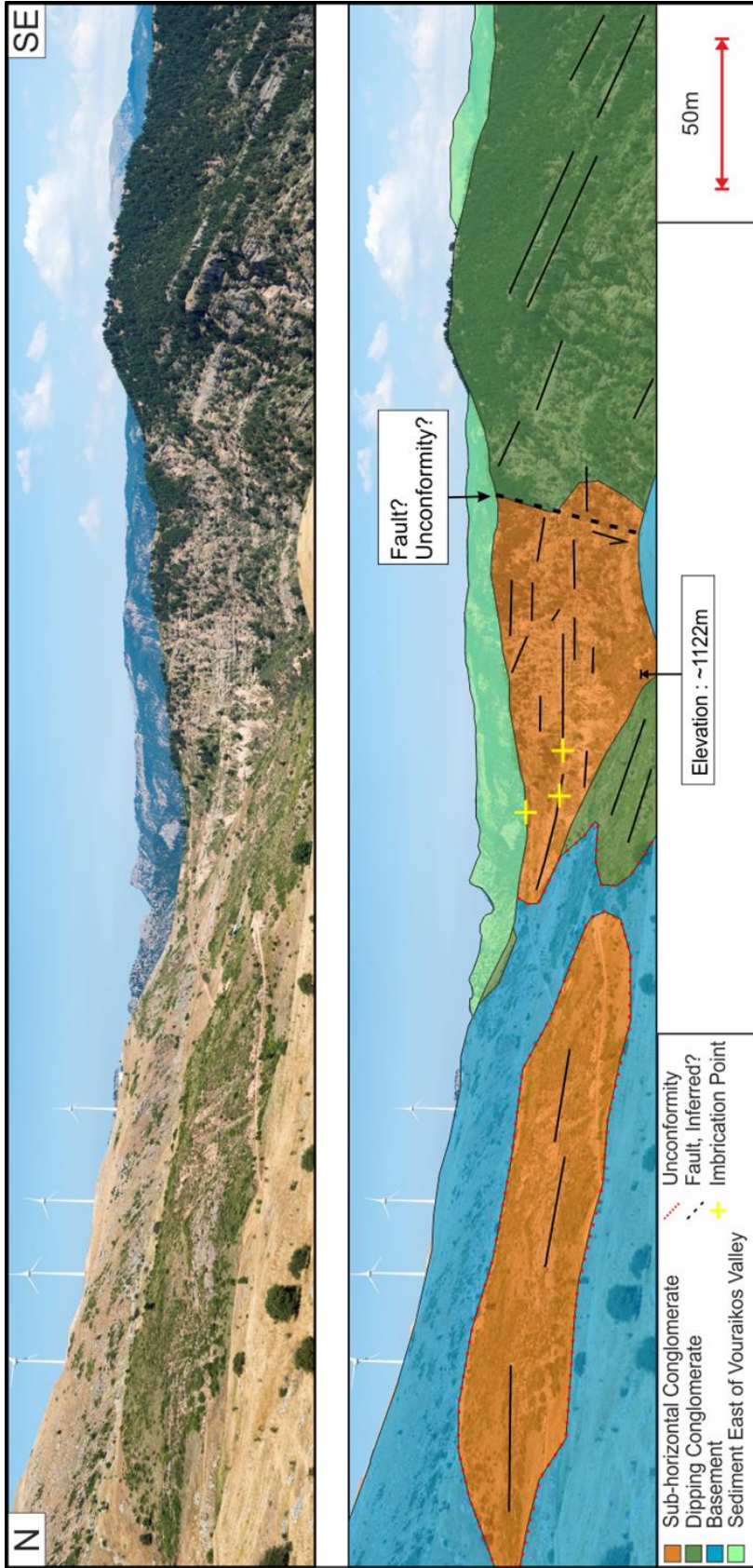


Figure 4-39 : Image looking east towards Unit H (centre of image) and Unit G (left on image). What to note here is the sharp change in dip angles from Unit H south into the thick coarse grained, south-dipping conglomerate of Roghi. However within Unit H there are also anomalous dip angles that trend more towards the south than being sub-horizontal. The elevation point showed on the interpreted image is correlated further east to Figure 4-40.

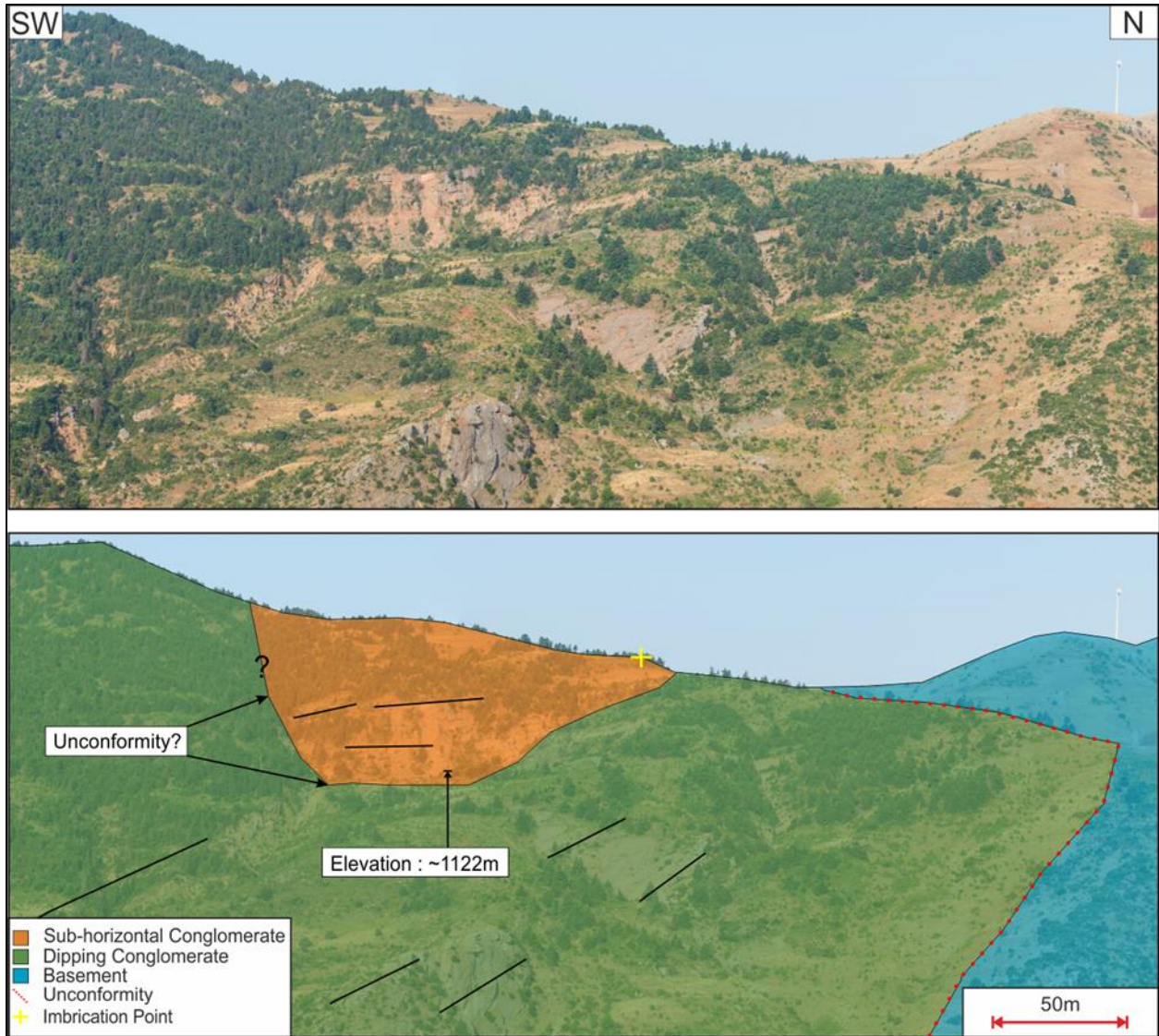


Figure 4-40: Image taken looking west from above the Monastery towards Unit H. Due to vegetation it is difficult to distinguish dipping beds from non-dipping beds, therefore the placement of the southern contact between dipping and sub-horizontal is diffuse. The inferred fault that is placed in Figure 4-39 is also hard to project through the mountain due to vegetation. The imbrication measuring point (yellow) shown here is the same location as the upper measuring point on Figure 4-39. More importantly the sub-horizontal beds are visible from this view point as well.





Figure 4-41: Image taken at the upper imbrication point shown in Figure 4-39 & Figure 4-40. The black lines show the trending beds. This location allowed the beds to be viewed in 3D. The red square shows the position of Figure 4-42.

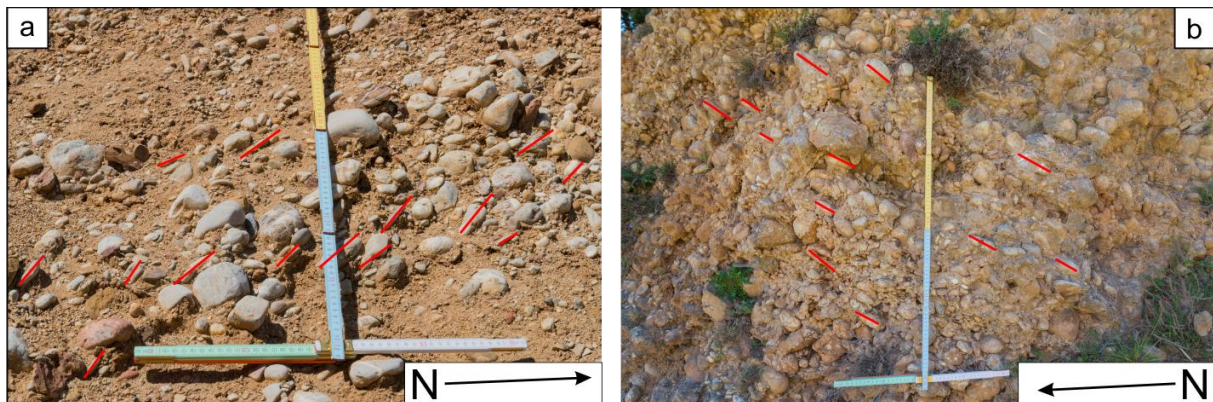
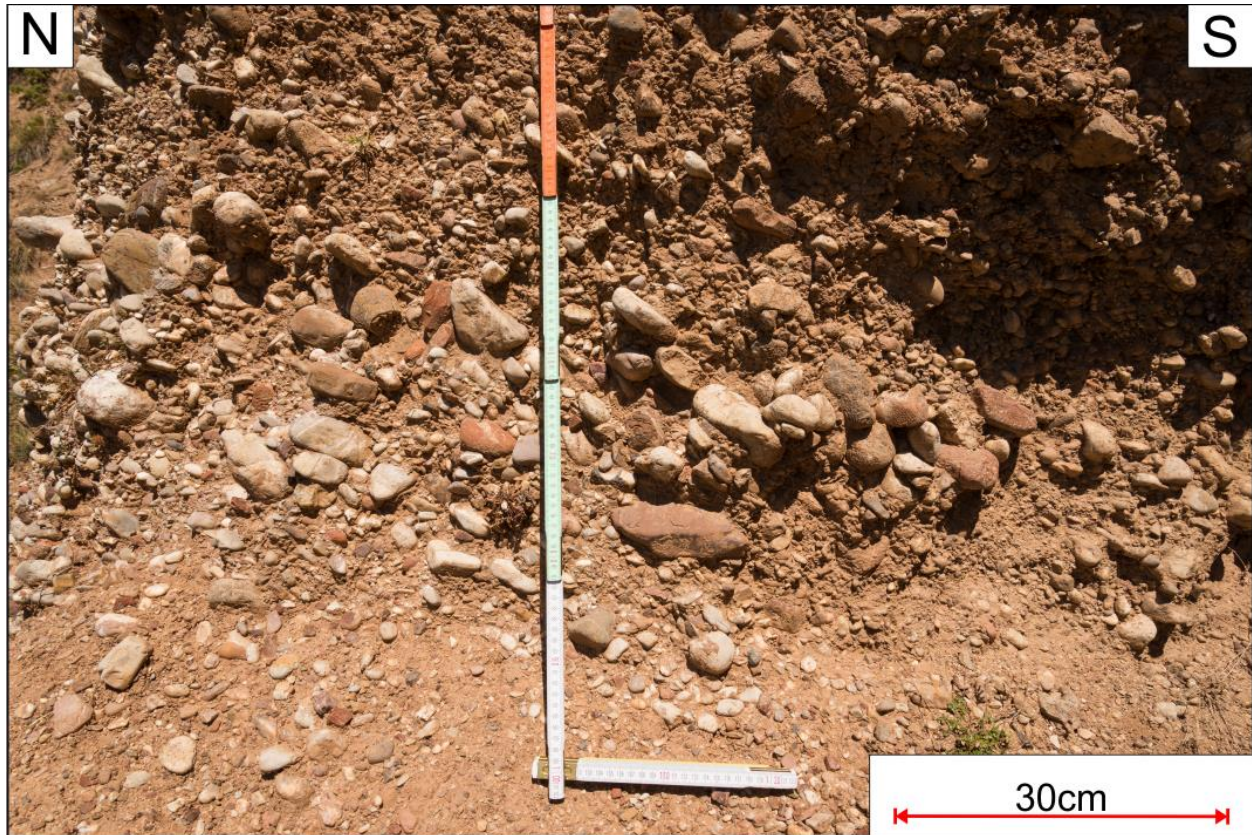


Figure 4-42: Image (a) is an enlargement from Figure 4-41, with a view towards the west. This indicates a flow in a northern direction. Image (b) is taken from the same location looking east, this side also shows a possible flow towards the north. The red dashes have been placed on a few tabular clasts to show imbrication. The horizontal part of the yard stick measures 40 cm for scale.



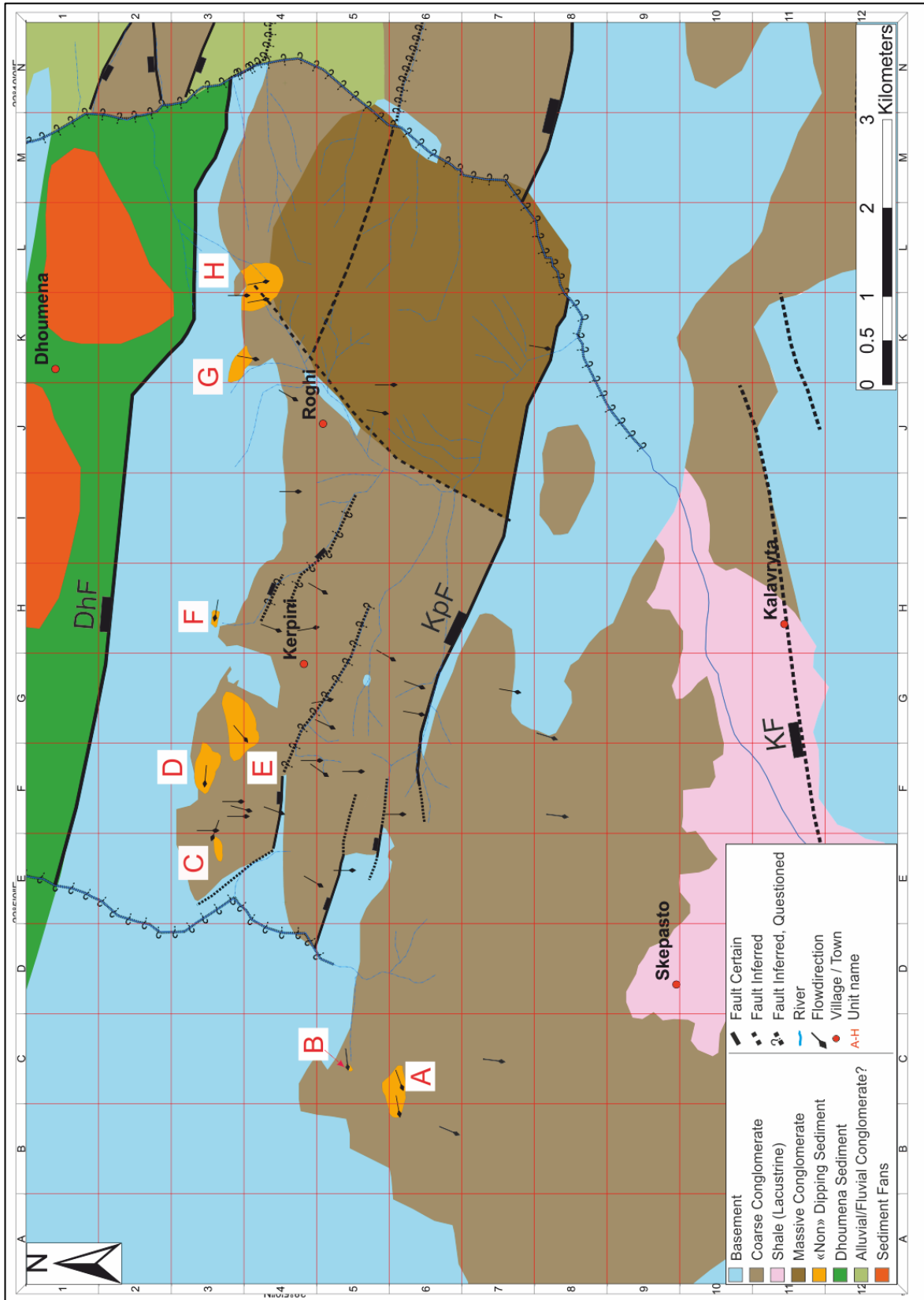


**Figure 4-43:** This image is taken on the western side of Unit H, at approximately the lower right yellow cross on Figure 4-39. The horizontal section of the yardstick is oriented north-south. The important thing to note is the orientation of the tabular clasts that indicate a flow direction towards the north; also this image is taken in a section of Unit H that shows a horizontal dip.

#### **4.4 Paleo Flow**

Within the area of interest (Kalavryta and Kerpini Fault Blocks) the main sedimentary units studied for this thesis are of a conglomeratic nature. Upon visiting an outcrop, time was spent looking for possible signs of flow direction. Many of the sub-horizontal units have what appear to be planar cross bedding, however imbrication of the tabular clasts proved to be a better indicator of flow direction. The method used is described in Chapter 3. Figure 4-55 is an overview map of the locations measured; the overall trend is an N/NNE flow direction for the coarse conglomerate and an east trending direction for the sub-horizontal. This flow direction of N/NNE within the lower-lying coarse conglomerate is supported by Ford et al. (2013) and Wood (2013).

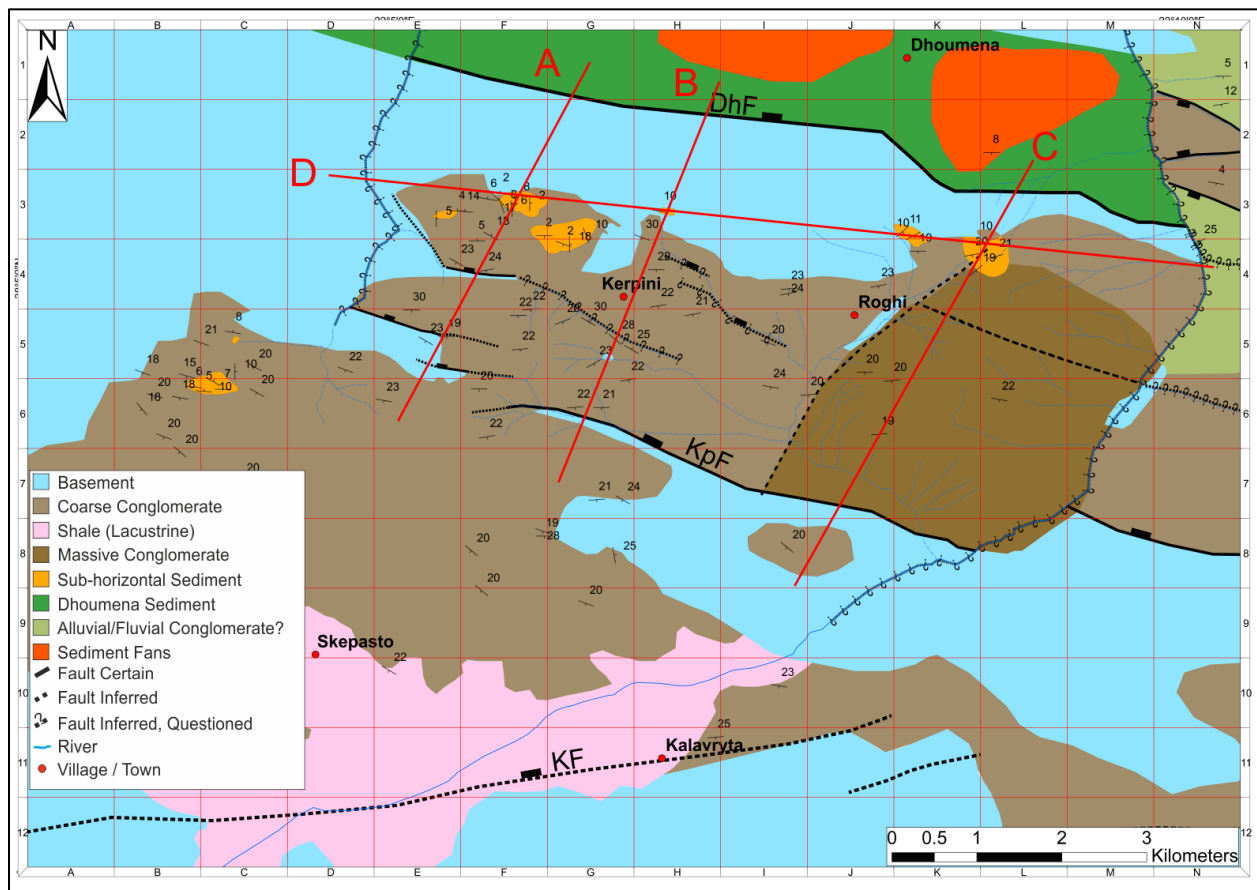




**Figure 4-44:** Map showing the distribution of main depositional units and faults. Also has the location where flow direction was determined by looking at the imbrication within the sedimentary layers. This gave an overall trend of N/NNE.

## 4.5 Structural

This section will put forward the structural observations made during the course of the field work. Initially this was not to be a major focus of this study. However a number of observations were made that merit a dedicated section to put these observations forward as they will be included in the discussion. Within this study's area of interest there are three major faults that dominate the region. From the south to north: Kalavryta Fault (KF), Kerpini Fault (KpF) and the Dhoumena Fault (DhF). These three faults are normal faults with a northward dip and striking east-west, which can be seen in Figure 4-45. This figure has also four lines representing the cross sections made for this area.



**Figure 4-45: Map of the area showing the faults in conjunction with the lithology. Lines A-D represent profiles made of the area.**

## 4.5.1 Kalavryta Fault Block

### 4.5.1.1 Kalavryta Fault

As the sedimentation within this fault block has not been the focus for this study, the Kalavryta Fault has not been studied in great detail. The Kalavryta Fault (KF) as depicted in Figure 4-45 is an observation made by the author during a graduate class field trip in April 2014. The Kalavryta Fault is the southern boundary of the Kalavryta Fault Block and is approximately 14-15km in length. There is some uncertainty as to where the fault ends in the west as it appears to be eroded. The northern boundary is the Kerpini Fault. Of the three major normal faults in this study, the Kalavryta Fault is not truncated by the two valleys, Kerinitis (west) and Vouraikos (east).

Although the Kalavryta Fault has not been mapped in this study, it was mapped in detail by Finnesand (2013) as part of her MSc Thesis. Figure 4-46 is an image from her study with the interpretation underneath. It is a southern view of the town of Kalavryta and the surrounding area. The image shows the stepping of the fault from east to west. As the fault passes through the town of Kalavryta, it appears to have been eroded and is no longer visible. Considering the two main segments of the fault, Kalavryta Fault East and West (Figure 4-46), they show dip angle of  $45^{\circ}$ N. The strike of the two segments is  $N88^{\circ}$ E and  $N85^{\circ}$ E, respectively. The displacement is, from west to east, 600-900m (Finnesand, 2013). It should be mentioned that Ford et al. (2013), estimated the Kalavryta Fault to dip  $55^{\circ}$ - $60^{\circ}$ N. The length of the fault, including the steps, is estimated to be 14-16km as there is some uncertainty to where the fault ends in the west.

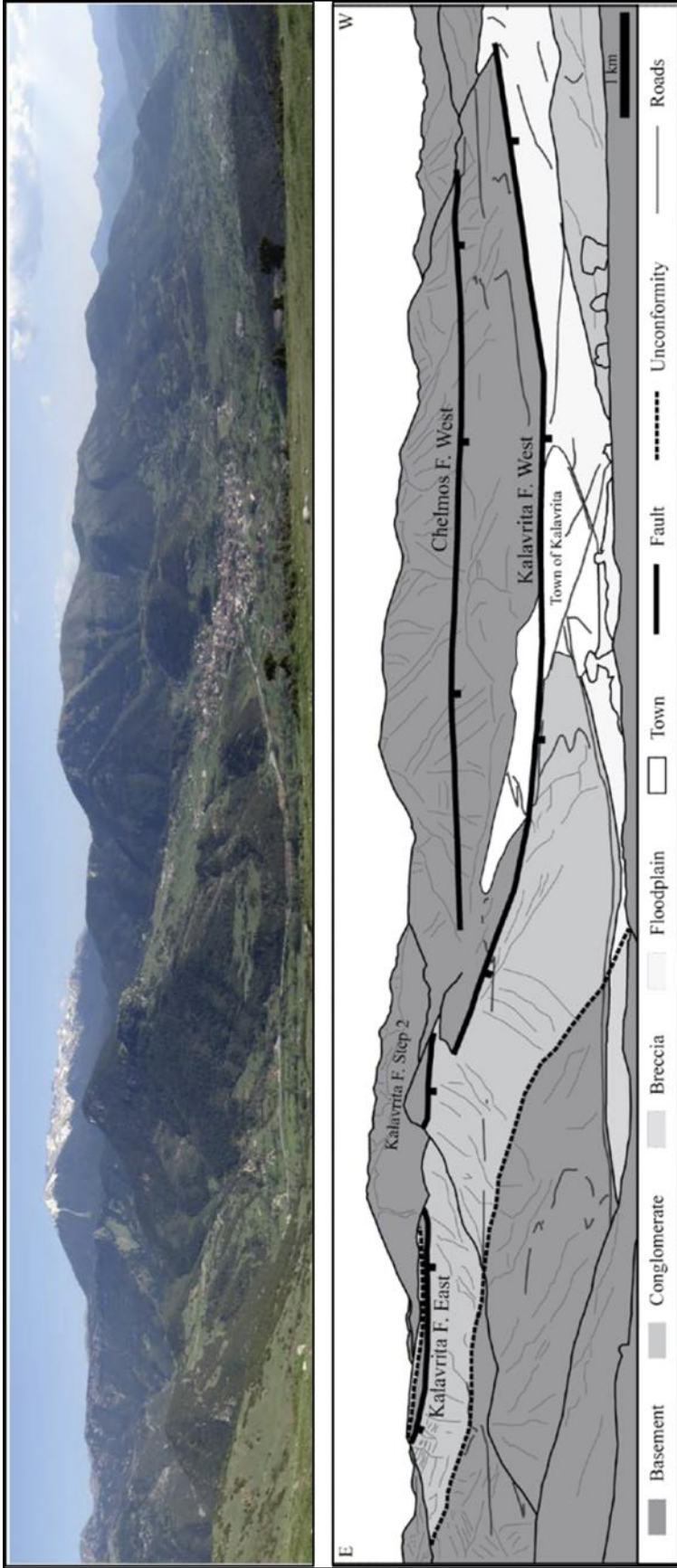


Figure 4-46: This is an image taken by Stine Finnesand in conjunction with her MSc Thesis. It shows a view from the Kerpini Fault looking south towards the town of Kalavryta. The interpretation made by Finnesand underneath depicts the Kalavryta Fault as it steps. Furthermore it shows how the Kalavryta Fault has been eroded moving westward. Behind the Kalavryta Fault, the Chelmos Fault is displayed. Chelmos Fault is considered the oldest in the region. (Finnesand, 2013)



## **4.5.2 Kerpini Fault Block**

The Kerpini Fault Block has been studied in more detail than the Kalavryta Block in this thesis, partially because this block contains more of the sub-horizontal layers. In addition to the sedimentary structures, the structural features have also been examined. The Kerpini Fault Block is bounded in the south by the Kerpini Fault and in the north by the Dhoumena Fault. In the east the fault block is bounded by the Vouraikos River valley and in the west the Kerinitis River valley. Within the fault block, several intra block faults were identified. These faults were assumed present due to the presence of exposed basement and sediment dipping into the basement. The fault block is at its widest in the east at 4.3km, and narrows towards the west where it shows a width of 2.9km. The main depocentre of the fault block is assumed to be in the south-east corner (Figure 4-45, K8).

### **4.5.2.1 Kerpini Fault**

The Kerpini Fault is the southern bounding fault in the fault block. There is no clearly exposed fault plane to derive measurements from. However sharp changes in lithology are observed as well as sediment that dips into the exposed basement. These indicators give rise to the possibility of a fault. The Kerpini Fault, being one of the major faults in the area, is a normal fault. It strikes N110°E and has a general dip trend of northeast. Due to the lack of fault plane, the dip angle cannot be directly measured. Syahrul (2014) assumed the dip angle to be 40°-45° based on the regional fault dips of the major fault in the area. Ford et al. (2013), however, estimate the dip to be 50°-60°N.

With regards to the maximum throw of the fault, it has previously been proposed by Syahrul (2014) and Ford et al. (2013) that the throw may lie between 1200m-1500m. Using the observed sediment north in Roghi Mountain (Unit H) shown in Figure 4-41, assuming that these beds continue through moving south into Roghi Mountain, it is possible to extrapolate the displacement of these sediment. The sediment found in Unit H sit very close to the unconformity, ~150m, and show a dip angle of ~20° in a southern direction (170°). By looking at these layers, the throw is estimated to be 1150m. However this does not take into account the possible erosion of the footwall. Therefore an estimate of 1200-1500m is agreeable.

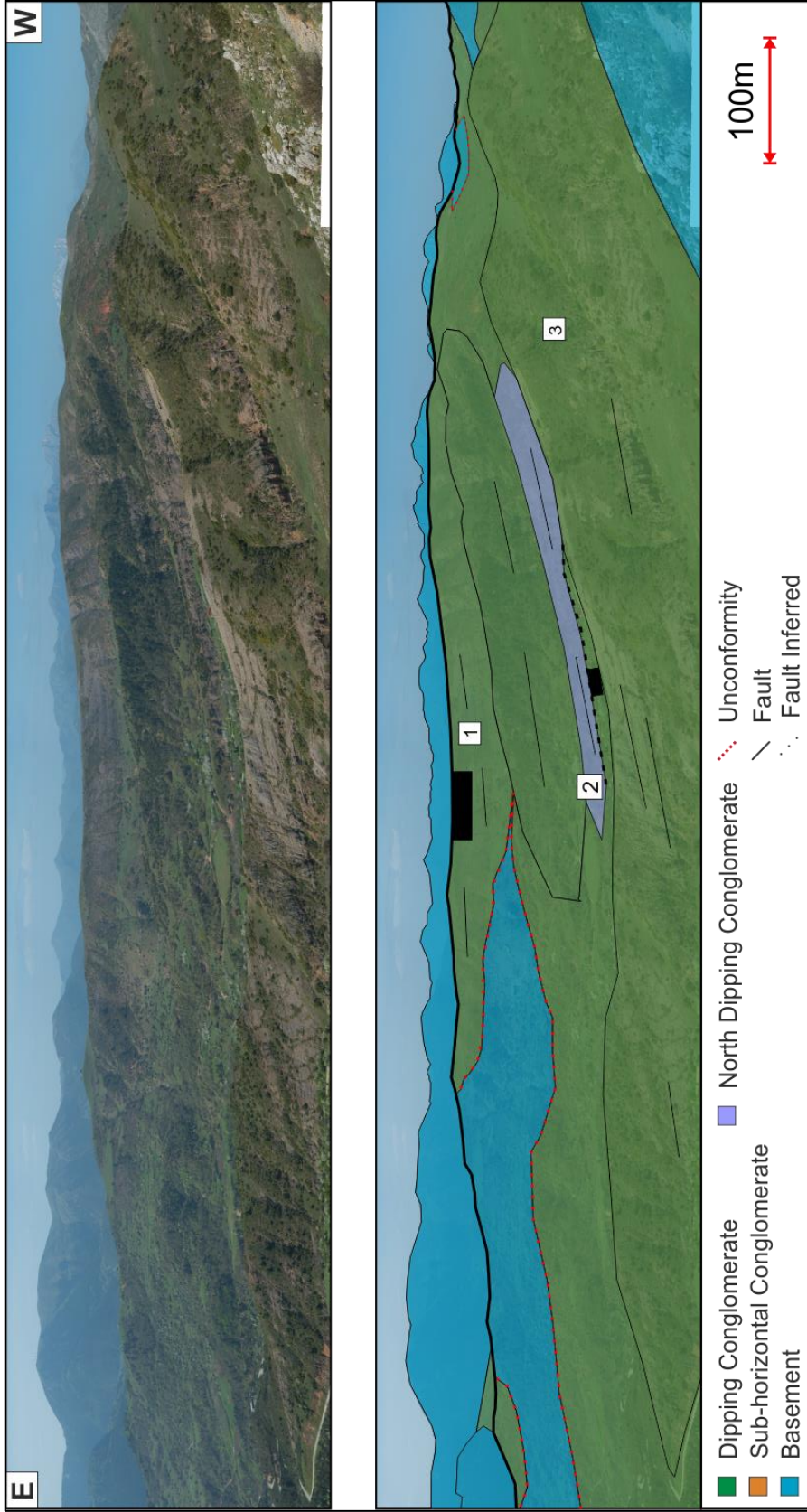
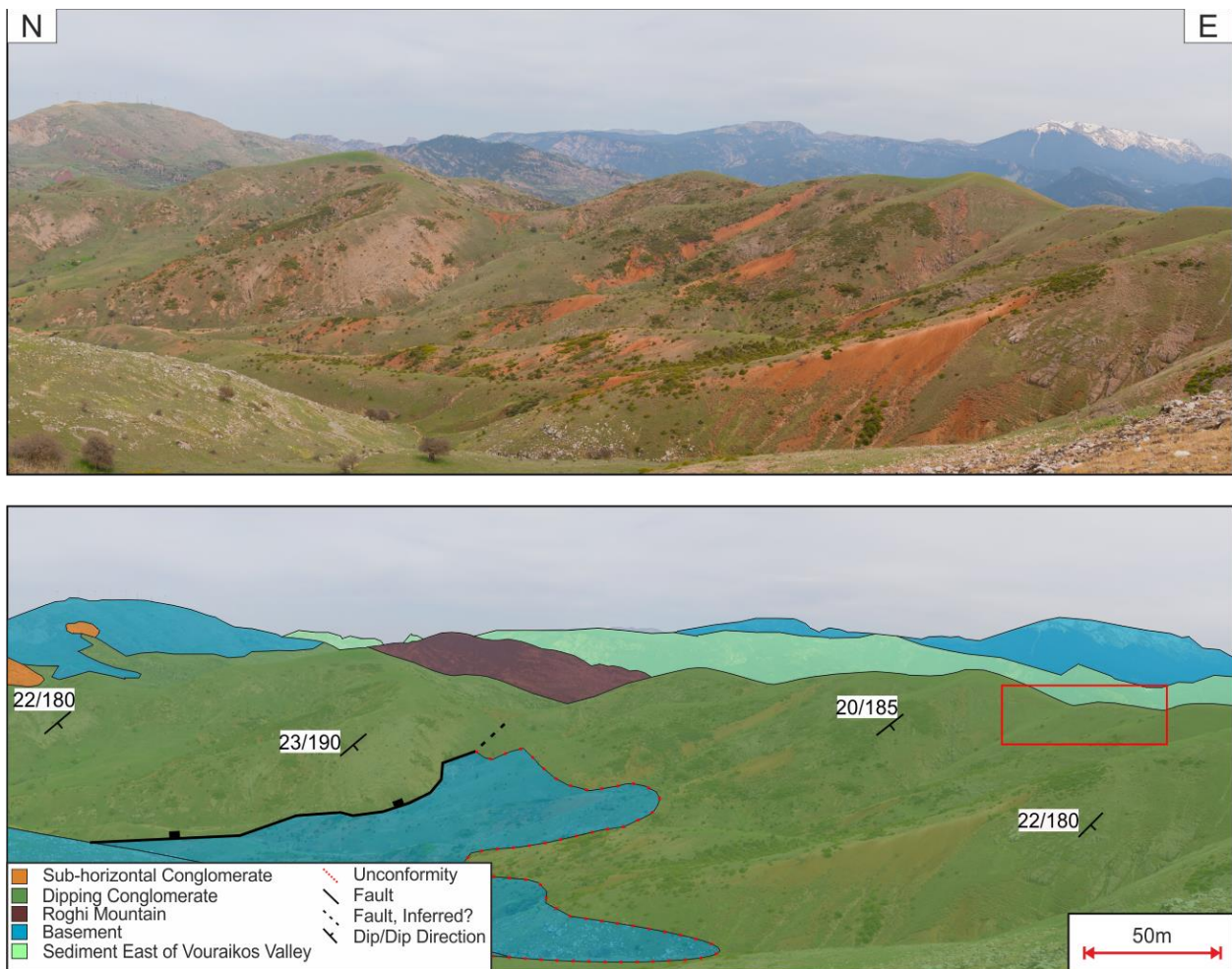


Figure 4-47: A view from north looking south into the Kerpini Fault Block. This image shows the Kerpini uplifted footwall (1), note the thick layer of coarse conglomerate that overlies the Pindos carbonate basement. This sediment (1) dips  $\sim 21^\circ$  southward. This image also shows to more features of interest (2 and 3). These two features have previously been thought to be fans (Syahrul, 2014). #2 has its apex close to the Kerpini Fault, and is believed to have a flow direction to the east. #3 has its apex close to the Dhoumena fault and is believed to have a flow direction of south-east.

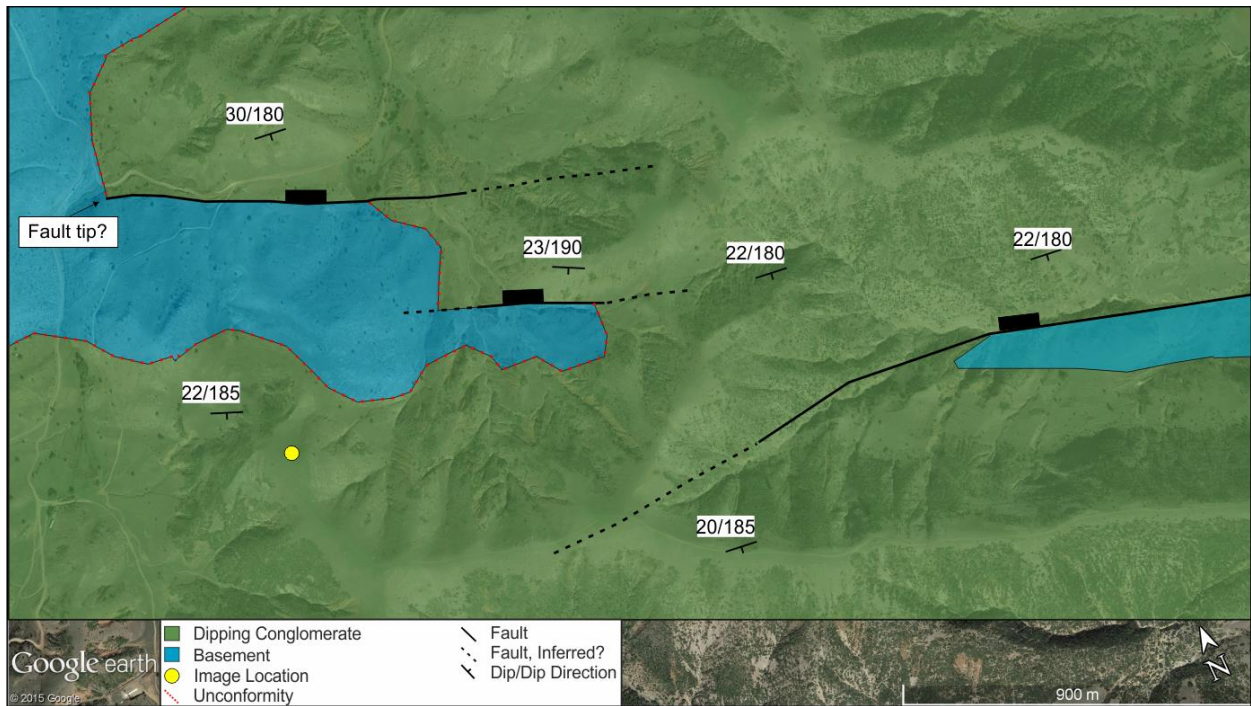
The Kerpini Fault was previously interpreted as a single fault propagating from the Vouraikos River, westward towards Kerinitis River where it was believed to truncate. New observations made in the western region of the fault block open the possibility that the Kerpini Fault right-steps two times before truncating at the Kerinitis River. These right steps are supported by the observed exposed basement. Following the Kerpini Fault from the east (Figure 4-45, K8) and eastwards, the first step is observed at Figure 4-45, F6. The following figure (Figure 4-48) shows the interpreted first step. Here basement is exposed and to the north one finds conglomerate dipping south into the exposed basement. South of the exposed basement, one then enters the Kalavryta Fault Block and the dipping conglomerate that overlays the basement is again dipping south.



**Figure 4-48: Image of the first step in the Kerpini Fault. The sediment north of the fault is dipping into the fault, and in the south dipping away from the fault. In the area of the red square is where the main Kerpini Fault is interpreted to end.**



The exposed basement shown in Figure 4-48 continues westward. This is shown in the Google Earth image (Figure 4-49). Figure 4-49 gives a closer view of the observed sediment and basement in the western region of the Kerpini Fault Block. Furthermore it shows the interpreted possible stepping of the Kerpini Fault. The first step fault has an estimated strike of N100°E and the second step N105°E. There are no exposed fault planes to measure the dip of the two faults; it has been assumed that they follow the trend of the main Kerpini Fault at 40°-45° north. On the second step the fault is at the location where it is assumed to end/truncate (marked with the “Fault Tip”). It is believed to end here as there is no evidence allowing for the fault to continue propagating westward. Moving west directly across the Kerinitis River at the fault tip is the Skepasto Mountain. Skepasto Mountain is a massive basement feature with no indication of faulting in the vicinity of the fault tip.



**Figure 4-49:** Image to show the exposed basement and proposed stepping of the fault in the western region of Kerpini Fault Block. It shows the exposed basement and the surrounding dipping sediment. The yellow circle indicates the location that Figure 4-48 was taken.



## 4.5.2.2 Intra Kerpini Fault Block

### 4.5.2.2.1 Western Kerpini Fault

Figure 4-45 (F4) is the location of an east-west oriented basement exposure that lies in-between dipping sediment. To the north and south of this exposure the sediment dips in a southern direction. Figure 4-50 shows a western view of the basement as it stretches out westward with sediment of the northern and southern side.

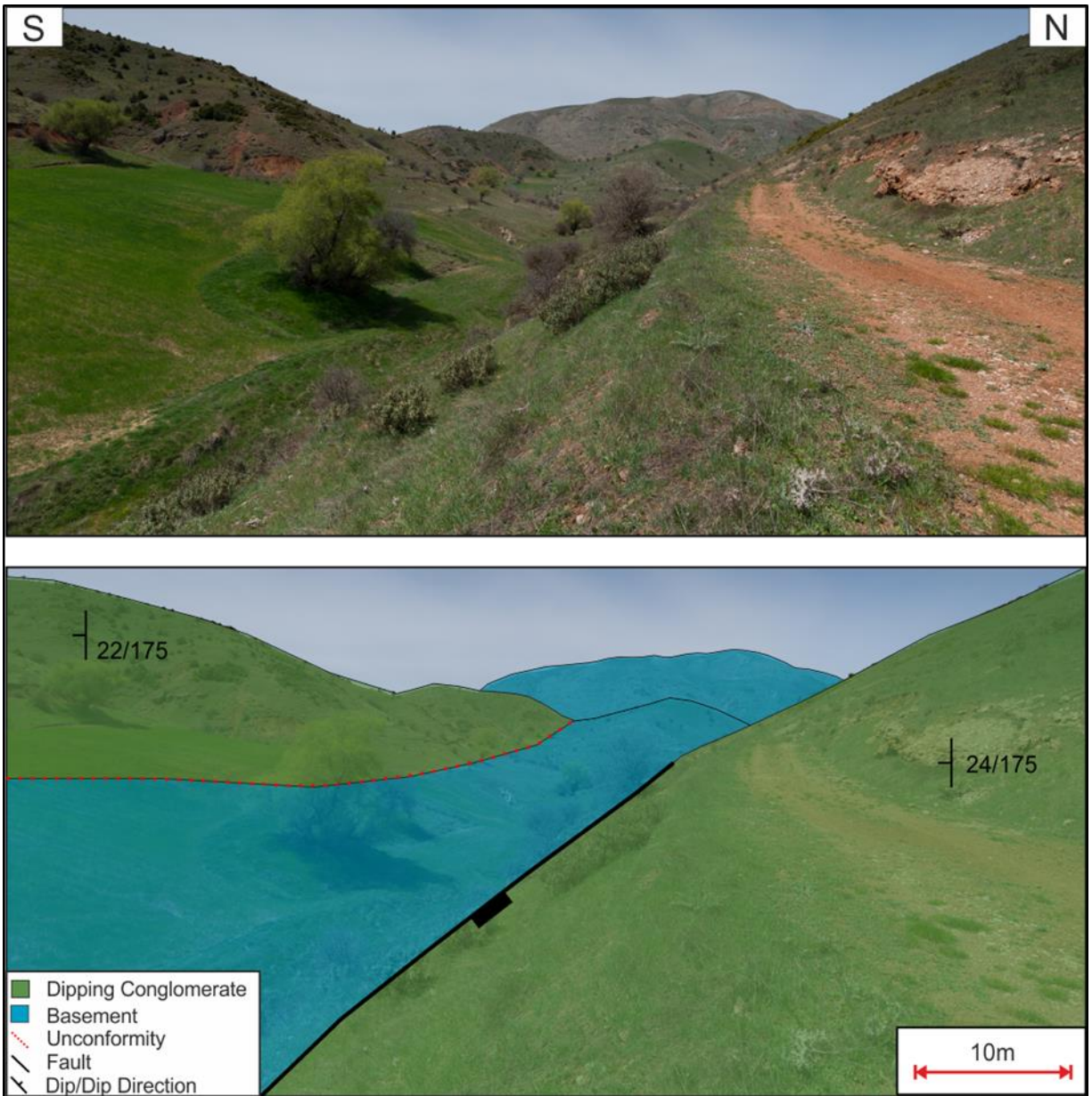


Figure 4-50: Image of the exposed basement. The basement is ~90% covered with recent soil, so is the contact between sediment and basement. Scale is applicable to the large tree in foreground.

The contact basement-sediment is obscured by recent soil and a constructed dirt road. Furthermore the basement is ~90% covered by recent soil and vegetation; however the outcrops that are visible are believed to be in-situ as they are fairly large and consolidated. The closest area for this basement to have broken off sits 1km to the west and at the same elevation. The fault shown in Figure 4-50 is proposed to continue west and then turn northwest (Figure 4-45, E4). Furthermore it has been continued further to the east, running south of Kerpini Village. Figure 4-13 shows an image of the north dipping sediment found immediately south of Kerpini Village, which is postulated that the fault continues to this location. The strike of the exposed basement fault is assumed to be N95°E, moving west it changes to N145°E. The inferred fault south of Kerpini Village is assumed to follow the same strike as the one shown in Figure 4-50, N95°E. There is no fault plane to measure dip and therefore the dip can only be speculated to follow the trend of the Kerpini Fault.

#### **4.5.2.2.2 Roghi Fault South**

This fault was interpreted by Syahrul (2014). His interpretation is that it is a normal fault striking N30°E with unknown dip, but assumed to be almost vertical. It can be identified in a river valley and its presence is due to the difference in lithology from Kerpini side (west) to the Roghi Mountain side (east) (Syahrul, 2014).

This change in lithology has not been observed during the fieldwork for this study. A section of basement has been observed (Figure 4-45, J5) to lie east of Roghi Village in the river valley and therefore the fault may exist. Figure 4-8 & Figure 4-9 show the possible location of this fault and exposed basement. These figures also show the anomalous dipping layers on the western edge of Roghi Mountain, which could provide further support the possibility of a fault.

#### **4.5.2.2.3 Intra Roghi Mountain Faults**

The intra Roghi Mountain Fault that is shown in Figure 4-45 is there as a result of the interpretation done by Syahrul (2014). Syahrul justified this fault by looking at the Pindos Basement Inlier (Figure 4-45, M6). The fault was interpreted to strike N110°E, dipping 40°-45°NE. As the Roghi Mountain has not been studied in detail, this fault has been carried over into this study. Furthermore Solheim (2002) interpreted as many as 6 major normal faults in the Roghi Mountain. Due to the massive presence of the Roghi Mountain it is difficult to ascertain if

all of these faults are present. Tracing the beds on the western side can lead to erroneous dip angles as Figure 4-9 shows. However viewing Roghi Mountain in Google Earth there are three distinct changes in elevation that are visible. Therefore the presence of Intra Roghi Mountain faults cannot be disregarded.

### 4.5.3 Dhoumena Fault Block

The Dhoumena Fault Block has not been studied in detail for this thesis. It is bounded in the south by Dhoumena Fault and in the north by the Mamousi-Pirgaki Fault. The fault block is ~6-7km wide. The most dominant feature in the fault block is the Troulos Ridge/Mound that sits on the Dhoumena hanging wall. Troulos Ridge was interpreted as a growth syncline by Ford et al. (2013).

#### 4.5.3.1 Dhoumena Fault

The Dhoumena Fault has an exposed fault plane that allows direct measurements to be made. The following table shows various studies that have been conducted.

Author	Strike / Dip (avg.)
Solheim (2002)	N096°E / 48°N
Ford et al. (2013)	N096°E / 48°N
Syahrul (2013)	N110°E / 44°NE
This study	N100°E / 45°N

**Table 4-9: Summarising various measurements on Dhoumena Fault.**

The maximum throw of the fault varies from study to study. Doutsos and Poulimenos (1992) set it at 240-650m, Flotté and Sorel (2001) at >1000m and Ford et al. (2013) at 800m. In the west the fault may truncate in the Kerinitis River valley or steps, however in the east it is believed that it steps across the Vouraikos River before continuing eastward. Figure 41 shows a panorama looking into the fault block.

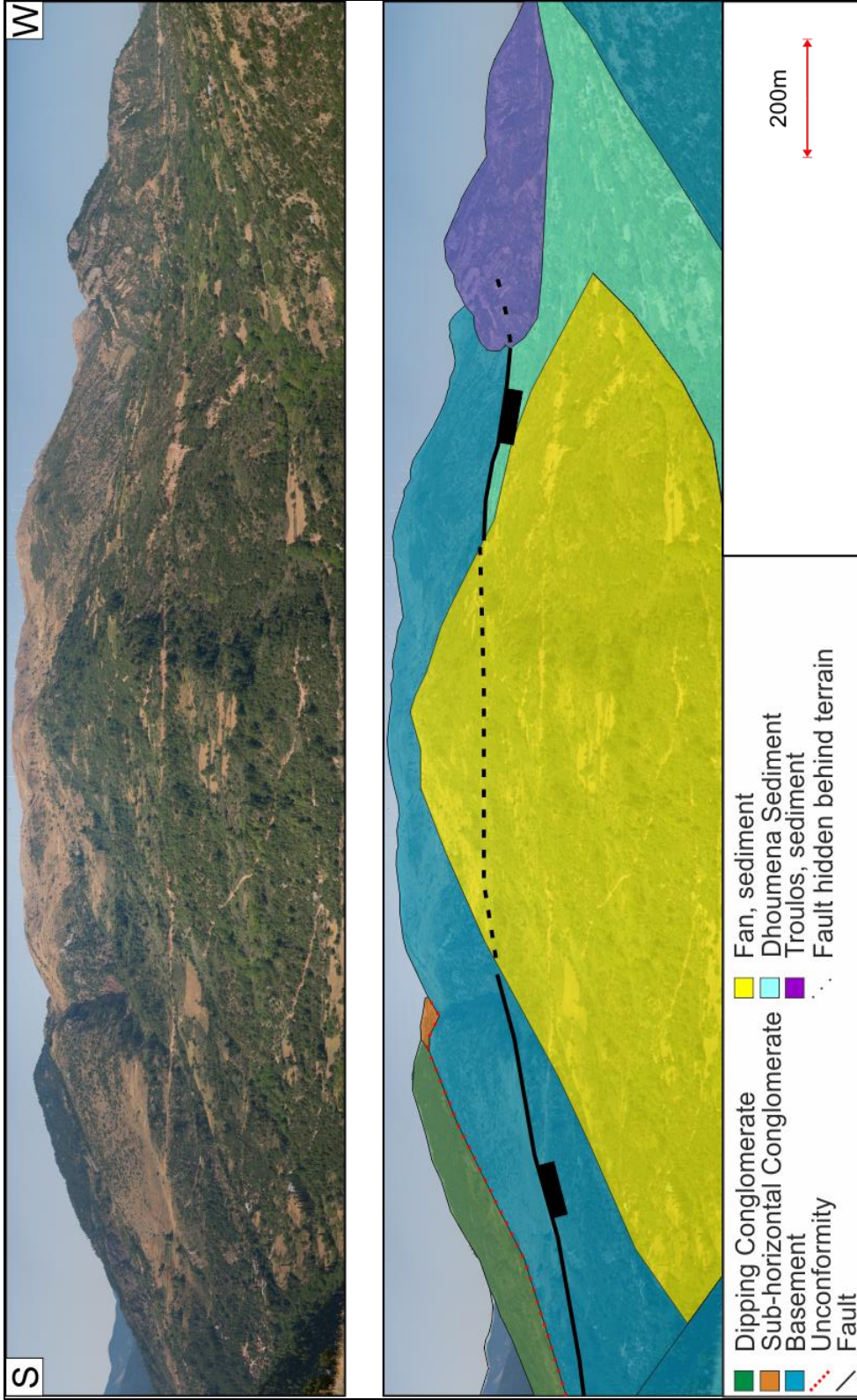


Figure 4-51: Panorama looking southwest into the Dhoumena Fault Block. The yellow shows a fan mapped by Anita Kolbeinsen (Kolbeinsen, 2013). The purple shaded is the Troulos Mound/Ridge that Ford et al. (2013) interpreted as a growth syncline. The fault as depicted passes behind the yellow shaded fan, in the west it continues towards the Kerinitis Valley.



#### **4.5.4 River Valleys**

In the area of study there are two south-north running river valleys: in the east Vouraikos River Valley and in the west the Kerinitis River Valley. Two of the main faults in the area, Kerpini and Dhoumena, either step or are truncated by these valleys.

##### **4.5.4.1 Vouraikos Fault**

Both the Dhoumena and Kerpini Fault are assumed to make a step in this river valley. With regards to the Kerpini Fault, which has its assumed maximum displacement before entering the river valley, it cannot be traced directly across the river. Figure 4-45 (L8) shows the relationship between the lithology in the Kerpini Fault Block and the lithology on the east side of the river. As the fault cannot be traced directly, from sediment to basement, it is assumed that the fault steps. The same is assumed for the Dhoumena Fault (Figure 4-45, N4) although this is questioned as there is not a clear change in lithology as with the Kerpini Fault.

There is no fault plane exposed in the valley, and therefore the dip angle is difficult to estimate. The assumption is made that it is a near vertical fault. Given that the Kerpini and possibly the Dhoumena fault make a step across, it is assumed that the Vouraikos Fault is possibly a transfer zone or fault.

##### **4.5.4.2 Kerinitis Fault**

The Kerinitis River valley is the western boundary of the Kerpini Fault block and it is assumed that the Kerpini Fault truncates at this point. Due to the abrupt change in lithology across the Kerinitis River, from conglomerate to basement, there is no evidence to support a possible step in the Kerpini Fault. Whether the Dhoumena Fault steps in unclear, but that has not been studied. Furthermore, as the observed change in lithology may be the result of paleo-topography, it is unclear if there is a fault within the Kerinitis River Valley.

## 4.5.5 Profiles

### 4.5.5.1 Profile A

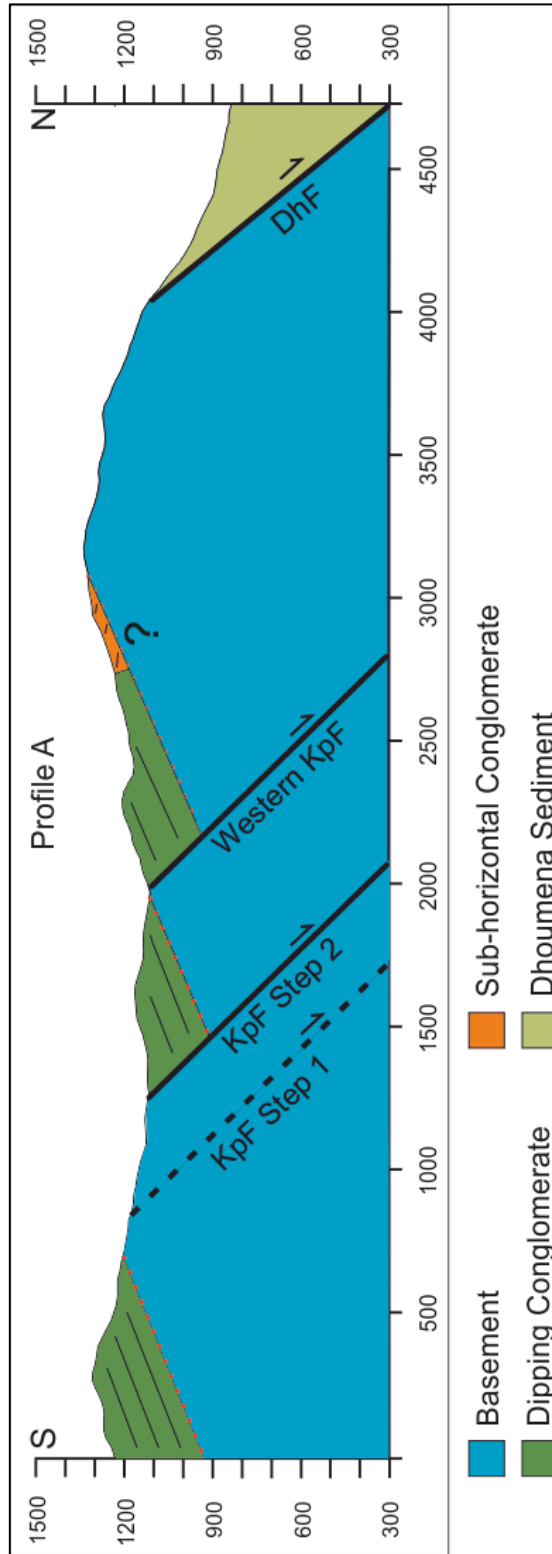


Figure 4-52: Profile A is taken from the western region of the Kerpini Fault Block (Figure 4-45). Moving from south to north, the south dipping sediment is overlying the basement. The first fault is the first step in the Kerpini Fault; it is depicted with a dashed line as it is uncertain how far it extends and in that area there is only basement. The next fault is the second step in the Kerpini Fault. At this location one finds sediment dipping into the proposed fault. The third fault is the named Western Kerpini Fault, which is proposed to extend from south of Kerpini Village and westward (Figure 4-45). North of the Western Kerpini Fault, following the dipping sediment, one reaches the sub-horizontal unit, Unit D. In this profile the contact with south dipping sediment is depicted, however in the field it is virtually impossible to distinguish due to recent soil and vegetation. The question mark under Unit D is to signify that Unit D may overlay the south dipping sediment, however it is not observed in the field.

### 4.5.5.2 Profile B

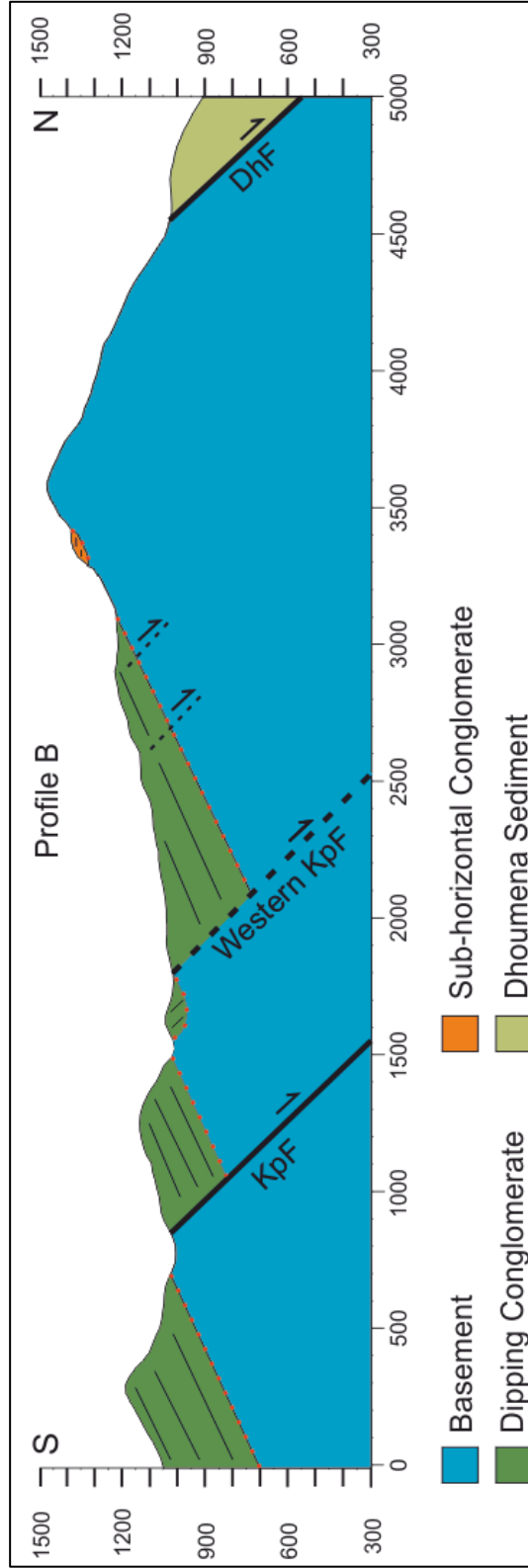
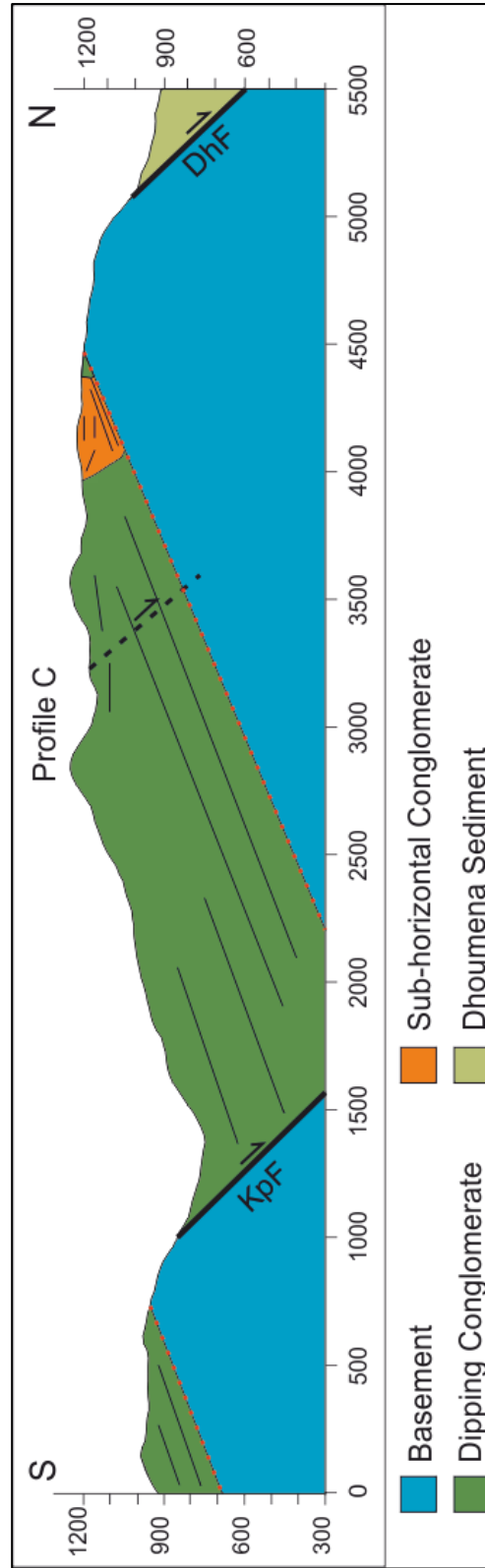


Figure 4-53: Profile B runs south-north through the central part of the Kerpini Fault Block, immediately east of Kerpini Village. Looking at the profile, in the south one can observe the dipping conglomerate in the Kalavryta Fault Block that sits directly on basement. Following this there is an area of exposed basement that is the Kerpini Fault footwall, before reaching the first fault, the Kerpini Fault. Moving northward there is another large section of south dipping conglomerate before a small section of exposed basement is revealed (~1500m). Immediately north of this section one finds the north dipping conglomerate, and the proposed Western Kerpini Fault. North of the Western Kerpini Fault is a large section of south dipping conglomerate. The two small inferred faults (~2800-3100m), are placed to show the approximate location of these, it is uncertain if they extend this far. Finally Unit F is displayed, sitting high up towards the Dhoumena Fault.

### 4.5.5.3 Profile C



**Figure 4-54: Profile C** runs along the western section of Roghi Mountain. On the southern part of the profile the dipping conglomerate in the Kalavryta Fault Block is shown. Similar to Profile B, a section of basement is exposed before the Kerpini Fault is displayed. Following the Kerpini Fault one enters the massive conglomerate of Roghi Mountain that reveals a dip angle and directions into the Kerpini Fault. Within the Roghi Mountain a single inferred fault is displayed, this fault is the possible Intra Roghi Mountain Faults. In the northern section of Roghi Mountain is where Unit H is located, displayed here with the observed varying bed dip angles. Finally one reaches the Dhoumena Fault.



#### 4.5.5.4 Profile D

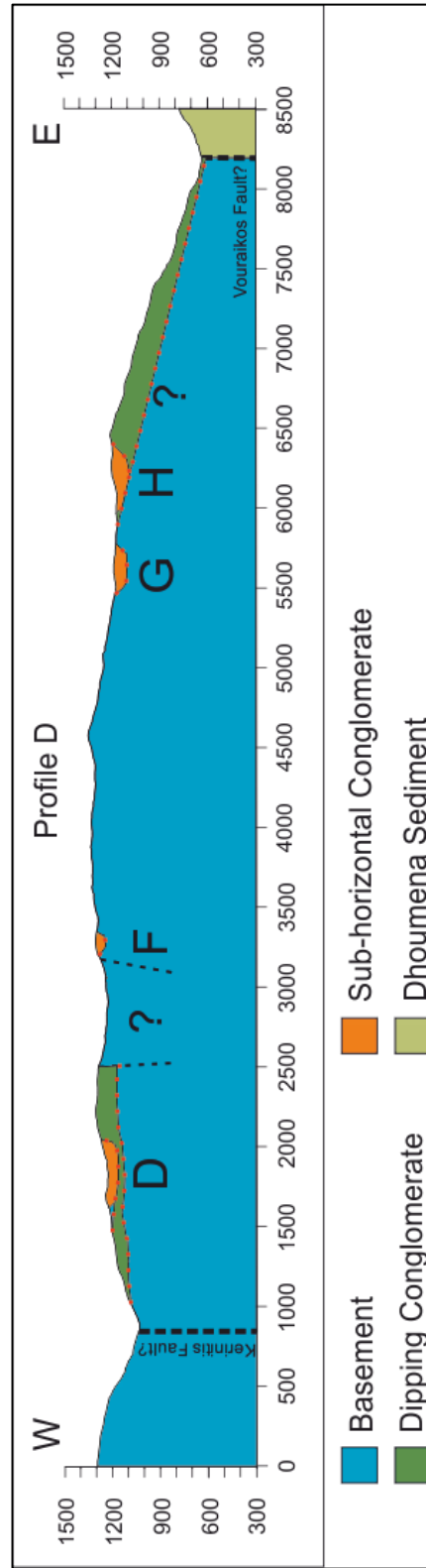


Figure 4-55: The final profile is Profile D. This profile stretches from the Vouraikos Valley in the east to the Kerinitis Valley in the west. This profile is the one with the most questions attached to it. Moving from west to east; firstly the proposed Kerinitis Fault that runs along the Kerinitis Valley is displayed. East of the Kerinitis Fault one enters the Kerpini Fault Block and the first section of dipping conglomerate is found, overlying this dipping conglomerate is Unit D. Unit D is here shown overlying the dipping conglomerate, however the actual contact was not able to be observed in the field as it is covered with recent soil and vegetation. Moving east from Unit D lies the first anomaly, there is no conglomerate, dipping or otherwise, to link it across the section of basement. Figure 4-3 has this displayed as a possible slump. Following the basement section Unit F is located. At ~5500m one reaches Unit G, followed by Unit H. This is the second question, which is the angle at which the unconformity dips to the east towards the Vouraikos Valley.

## 4.6 Summary

Below is a table (Table 4-10) summarising the observations made for the sub-horizontal sedimentary layers. The general trend among the sub-horizontal sedimentary layers is a north to east trending dip direction and a  $<10^\circ$  dip angle. The observed flow direction, based on imbrication, shows a trend to the east/north-east. The elevations displayed below show that the general trend lays  $\sim 1200\text{m} \pm 80\text{m}$ ; this does not include Unit F that is found at 1340m.

Item	Location <sup>3</sup>	Dip / Dip Dir. [°]	Flow	Elevation [m]	Additional
Unit A	K	8/030	E/NE	1204	The only large obvious sub-horizontal outcrop found in Kalavryta Fault Block.
Unit B	K	10/060	E	1281	Very small, poorly exposed outcrop.
Unit C	Kp	4/040?	E/SE	1189	
Unit D	Kp	7/060	E	1260	Large outcrop, separated by $\sim 100\text{m}$ of recent soil from Unit E.
Unit E	Kp	14/085 & 2/185	E/NE	1190	In the eastern area the outcrop appears to be divided by a gorge causing the two different dip angle and direction.
Unit F	Kp	10/010	E/NE	1340	Located isolated high up close to Dhoumena Fault.
Unit G	Kp	10/130	n/a	1195	Less consolidated sandstone compared to units A-F. Unable to ascertain flow direction. Dip direction believed to be more reminiscent of south-dipping coarse conglomerate.
Unit H	Kp	20/170	N/NNE	1120	Less consolidated sandstone compared to units A-F. Flow and dip direction more consistent with south-dipping coarse conglomerate.

**Table 4-10: Table summarising key observations.**

<sup>3</sup> K – Kalavryta Fault Block, Kp – Kerpini Fault Block

<b>Item</b>	<b>Contact with Basement</b>	<b>Contact with Dipping Coarse Conglomerate</b>
Unit A	No contact with basement visible or assumed.	Appears to onlap dipping coarse conglomerate along the northern edge, however is not exposed.
Unit B	No contact with basement visible or assumed.	Very little is exposed on this outcrop. Assumed on onlap dipping coarse conglomerate.
Unit C	No contact with basement visible or assumed.	No apparent contact with south-dipping coarse conglomerate. Clear contact with north-dipping sediment on the north-eastern edge.
Unit D	Clearly onlaps basement along the northern edge of the outcrop.	Assumed contact on the western edge, not exposed.
Unit E	No exposed contact visible, however assumed contact in the east with basement “scar”.	No exposed contact visible.
Unit F	Clearly onlaps basement along the northern edge. Appears to overlay basement.	No contact with dipping conglomerate visible or assumed.
Unit G	Clearly onlaps basement along the northern edge.	No exposed contact visible.
Unit H	Clearly onlaps basement in the northern region of the outcrop.	Clear contact between sub-horizontal and dipping sediment in the southern edge of the contact. This contact is best viewed on the western side of the outcrop. The eastern side is obscured by vegetation.

**Table 4-11: Table summarising the contacts between sub-horizontal sediment and basement/dipping conglomerate.**

The above table summarises the various contacts observed between the sub-horizontal sedimentary units with basement and dipping coarse-conglomerate. Many of the contacts, especially those with sediment surrounding the sub-horizontal units, are obscured by recent soil and vegetation.

## **Chapter 5: Discussion**

### **5.1 Introduction**

This chapter will analyse the observations made in the field and attempt to answer the initial questions of the nature and correlation of the sub-horizontal sedimentary layers (Unit A-H) found in the Kalavryta and Kerpini Fault Block. In order to understand these layers, it is crucial to understand the sediment and depositional environment within the two fault blocks. Therefore, the assumed underlying sediment will be addressed first followed by the sub-horizontal sediment. Initially this study was continuing the work from a previous thesis (Syahrul, 2014), however observations made during the current field work seemed to disagree with the evolutionary model presented in Syahrul (2014). Therefore a new evolutionary model will be presented based on the observations made here.

### **5.2 Sediment**

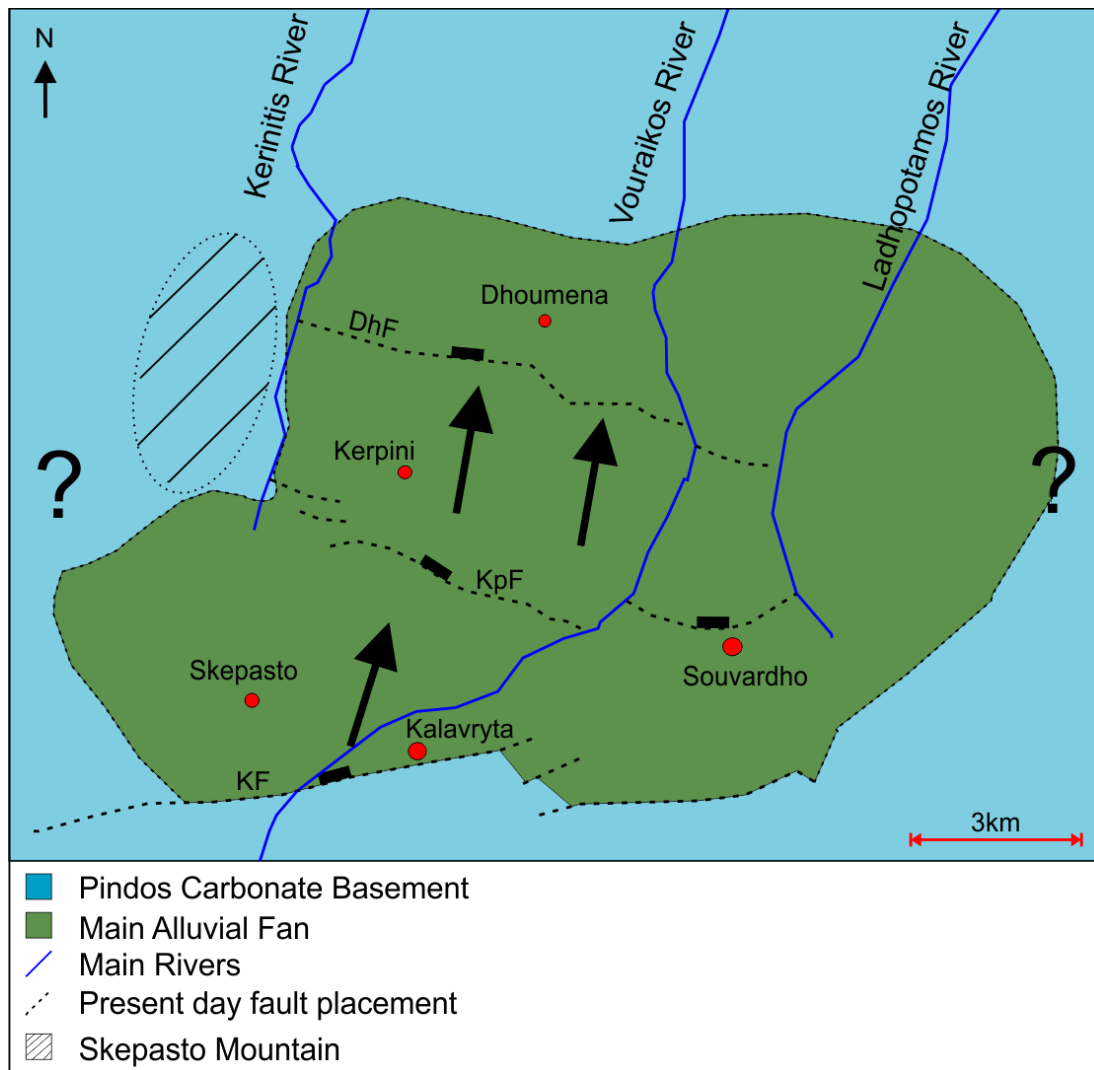
#### **5.2.1 Coarse Grained Conglomerate – Alluvial Conglomerate**

Based on the observations made in the Kalavryta and Kerpini Fault block, the south dipping conglomerate is considered the oldest sediment (disregarding the Pindos Carbonate Basement) in the two fault blocks. When viewing the Kerpini Fault (Figure 4-47), the south-dipping conglomerate is lying directly on the exposed basement. This reveals that the conglomerate is the lower-lying sediment found, at least in Kerpini Fault Block, and there is very high probability that it is the lower-lying sediment in the Kalavryta Fault Block. This, combined with the observed flow directions found in both fault blocks, aids in the timing of the south-dipping conglomerate in relation with the faults.

In the MSc thesis by Syahrul (2014), the sedimentary rocks found in the Kerpini Fault Block were interpreted as syn-fault. However based on the observations made during this study it is more accurate to describe them as syn-rift (Gulf of Corinth rifting). Describing them as syn-fault would classify them as syn-deposits, and one would expect to see growth strata within the sedimentary layering. However, this is not visible within the Kerpini south-dipping conglomerate sediment. Furthermore the flow directions observed suggest that the conglomerate (lower-lying) is part of a pre-Kerpini faulting alluvial fan that covered the pre-rift Pindos Carbonate Basement.



Additionally when viewing the dip angles and dip direction of the main conglomerate in the Kerpini Block, the trend is  $21^\circ$  towards  $\sim 175^\circ$ . Assuming that the sediment is pre-Kerpini faulting, one would expect the dip of the Kerpini Fault Block sediment to be towards the Kerpini footwall, which is observed in the field. Similar observations were made in the Kalavryta Fault Block where the assumed lower-lying conglomerate revealed a SSE trending dip direction with a dip angle of  $\sim 21^\circ$ . Figure 5-1 is a sketch to show how the lower-lying conglomerate was deposited. South of the Kalavryta Fault there is basement, therefore it is assumed that the Kalavryta Fault may be one of the sources for the alluvial fan.



**Figure 5-1:** This sketch shows the proposed alluvial fan as it has prograded from the south, assuming the eroded Kalavryta fault is the source. This fan provides the most likely scenario to fit with the alluvial conglomerate found in the two fault blocks. The two question marks indicate that the true extent of this fan has not been mapped out in this study. The shaded area in the left of the image is Skepasto Mountain. No sediment has been seen on this mountain, and it is believed that it has caused the fan to avoid it creating the odd shape.

Therefore, assuming this alluvial fan is pre-Kerpini Fault, it is thus also pre-Dhoumena Fault based on the assumption that the faults northward are younger. How far north this large alluvial fan extends has not been assessed in this study. However viewing the eastern side of Vouraikos River, it is plausible that the fan has continued for several kilometres, possibly up towards the Mamousia-Pirgaki Fault. The theory of this large scale fan with origin in the south, prograding north into the Kalavryta/Kerpini area, is supported by Ford et al. (2013) and Wood (2013). Ford et al. (2013) described the main conglomerate unit lying south in the Kerpini Fault Block as fluvial sandstones and conglomerate. However, based on observations made during this study it would be more accurate to define these south dipping, coarse grained conglomerate as alluvial, originating from the south with a flow direction northward. The south dipping conglomerate shows a coarsening upwards trend, which is commonly found in alluvial environments, whereas in fluvial one would expect to find a fining upwards trend.

With regards to clast size distribution within the alluvial conglomerate found in both Kalavryta and Kerpini, it was difficult to draw any conclusion. The assumption is that as the fan is prograding from south to north, one would expect to see a fining northward. However that assumes that the same bed is followed through either one fault block or both. This proved very challenging as the thickness of the conglomerate, both in total and in each bed, varies. That combined with possible intra block faulting and erosion, meant that it was not completed. However, it has previously been interpreted that the lower-lying conglomerate shows a fining north and eastward (Ford et al., 2013).

### **5.2.2 Local Correlation of Sub-Horizontal Sedimentary Layers**

This initial section of correlation will try to correlate the various sub-horizontal units locally. They will therefore be divided into the following groups based on locality:

- Group 1 – Units A and B
- Group 2 – Units C, D, E and F
- Group 3 – Units G and H

Following a local correlation (intra-group), the groups will be correlated between themselves, i.e. Group 1 with Group 2.

### **5.2.2.1 Group 1 – Units A & B**

These are the two units of sub-horizontal layers found in the Kalavryta Fault Block. Unit A is substantially larger than B, and A shows more clear features of being sub-horizontal. Unit B is much smaller, and although it exhibits features of possibly being sub-horizontal it cannot be disregarded as being a slump or landslide. Based on the observations made at Unit A, it is believed that this sediment is a more fluvial dominated conglomerate compared to the dipping alluvial conglomerate found in the Kalavryta Fault Block. This is based on the thicker, more sand rich layers found in Unit A. Also there is a slight fining upward trend seen within the beds, while in an alluvial setting one would expect a coarsening upward. This fining upward trend is very subtle and thus it is difficult to call this a “strict” fluvial conglomerate. Furthermore planar cross-bedding has been seen in certain areas of Unit A, which also points towards a fluvial influence.

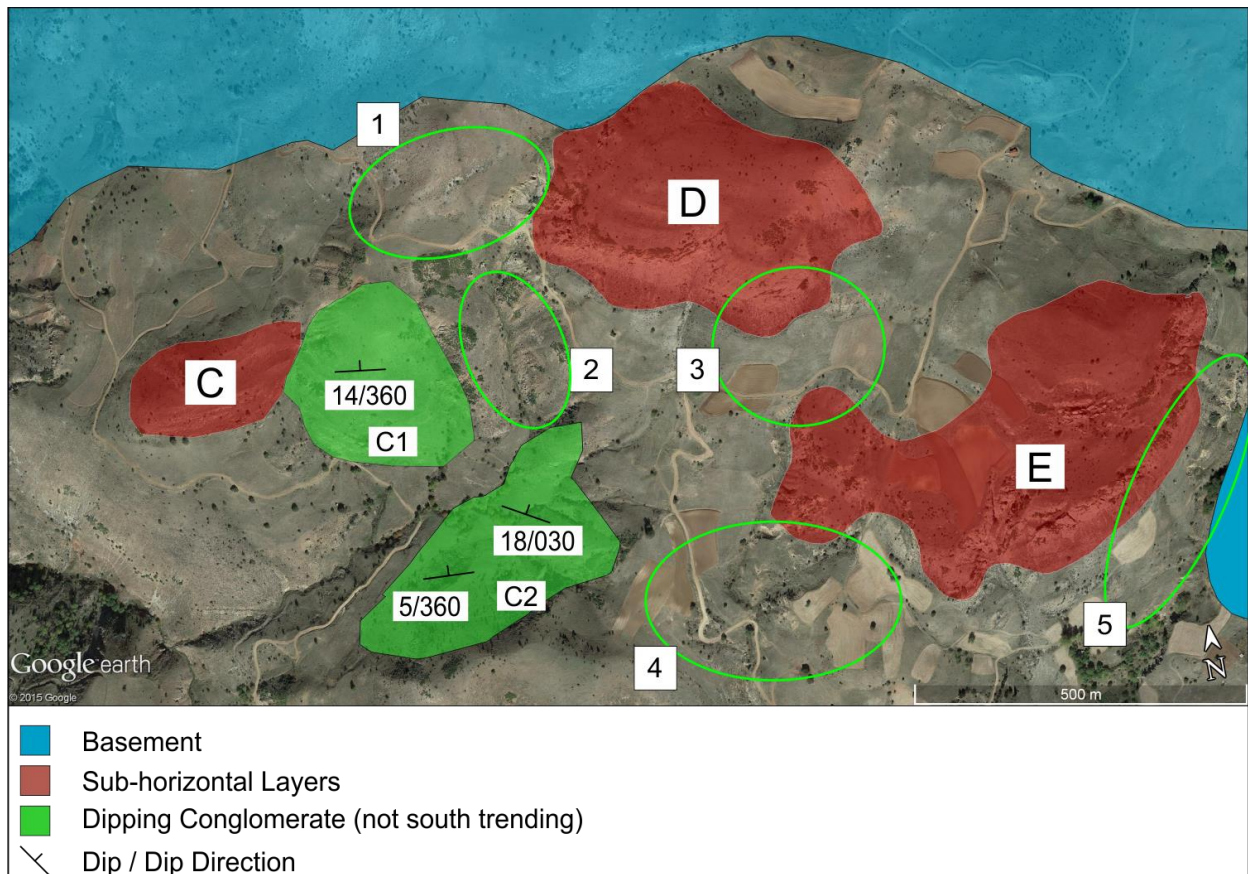
Between Units A and B there is sediment at higher elevation, which is dipping SW following the trend of the alluvial conglomerate found in Kalavryta Fault Block. Therefore there is no direct path between them. Even though there is an obstruction directly between the two units, it is believed that these two outcrops are the same rock unit.

### **5.2.2.2 Group 2 – Units C, D, E & F**

Firstly Units D and E will be examined. Units D and E are among the two largest sub-horizontal outcrops found in the Kerpini Fault Block. Additionally, as has been presented in Chapter 4, they are only separated by ~100m of recent soil. This is shown again here in Figure 5-2 as green circle #3. The image has been expanded to also include Unit C.

When comparing Units D and E, based on the observation on clast size and composition, they appear similar. However comparing the clast size within these two units may not be adequate for correlation as they highly likely have been measured in different beds. Yet, in Unit D the clast size was measured to 171mm and 127mm (Table 4-4) and in Unit E to 130mm (Table 4-5), which places them within a pebble/cobble range. Conversely both contain the consolidated sandstone clasts, have thicker sandstone layers than found in the dipping alluvial conglomerate in the Kerpini Fault Block, and show a flow direction with an eastward trend. They are, however, separated by recent soil (#3, Figure 5-2). Even so, it is with high confidence that Units D and E

are the same sediment, albeit at a slightly different elevation. However this elevation difference may be the result of erosion.



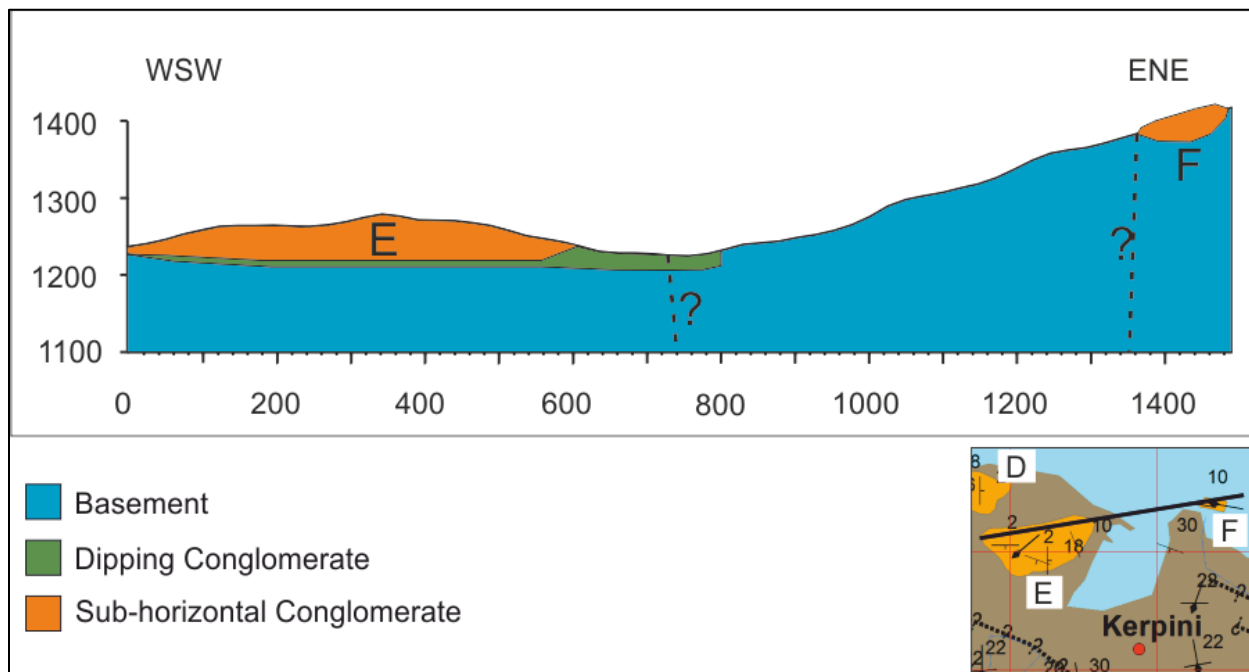
**Figure 5-2: An expanded image from Google Earth to show the possible connection between the three units C, D and E. The green circles are areas that were difficult to obtain good measurements. However due to their location in regards to the sub-horizontal, it is feasible that these are part of the sub-horizontal units.**

Unit C (Figure 5-2) sits 400m WSW from Unit D, and as described in Chapter 4, has a larger mound/ridge of 14° north dipping sediment (C1) to its immediate east. Based on the thick layer of sandstone that was found on either side of the gully separating Unit C from the mound (Figure 4-25), it is then assumed that C1 is possibly a section of Unit C that has slumped down creating the 10° difference in dip angle between the two. The second area, shaded in green on Figure 5-2 (C2), reveals very similar dip angles and direction as Unit C and C1. However C2 is not very well exposed and the dip measurements differ, given that this area is also assumed to be part of Unit C and has been possibly slumped or faulted<sup>4</sup>.

<sup>4</sup> No faulting was observed. However one cannot rule out a fault that is sediment/sediment contact, as it will be more difficult to identify in the field than a sediment/basement contact.



With regards to the green circles (Figure 5-2), #3 was discussed earlier in this section in the possible connection between Units D and E. None of the circles (#1, #2 and #4) show indications of south dipping sediment. However neither do they fall within the range that has been used to define sub-horizontal layers. Given their vicinity to the sub-horizontal, it is a fair assumption that these may be part of the three (C, D and E) units. The final green circle, #5, lays in-between Unit E and the blue shaded basement that is described in 4.2.1 (Figure 4-3, Figure 4-4). This thin section of sediment has few exposed outcrops to indicate whether it is dipping or sub-horizontal, but again given the proximity to Unit E and the basement to the immediate east, it is believed that this too is part of this larger sub-horizontal unit.



**Figure 5-3: Profile from Unit E in the west to Unit F in the east. Note the basement “tongue” that is separating these two units, also the exposed strip of basement that is found west of Kerpin Village. This image shows dipping sediment on the eastern side of Unit E; however it is possible that this sediment is part of the unit. The sediment found beneath, is believed to be dipping.**

The final unit in this section is Unit F. Unit F differs from the three others described here as it is separated, not by recent soil, but by basement (from Unit E east to Unit F). It is also located at a higher elevation than the Units C, D and E, and there are no indications of in-situ consolidated conglomerate, alluvial or fluvial, between the two units. Figure 5-3 is a profile from Unit E to Unit F; this image shows the aforementioned basement that separates the two units. This basement found between the units is believed to be a slump from the uplifted Dhoumena

Fault (Figure 4-3) that has slid south and thus removed any traces of sediment that could possibly link Unit E and F. The reason for this argument is that the red basement (Figure 4-4) appears in-situ, i.e. the bedding/layering in the radiolarite is still intact. Furthermore, conglomerate is found both underlying and overlying this basement on the western side (Figure 4-3). This conglomerate, found on the western edge, exhibits very erratic dip angles. In addition, on top of this basement “tongue” there are very large (>4x4m) conglomerate boulders scattered around, which appear to have broken off a larger structure. However, if this were an erosional feature, one would expect the sides of the larger conglomerate outcrops to be more scoured than jagged edged, as found here. Further evidence that may support the theory of a slump, and that can link the two units (E & F) across the basement “tongue” is seen in Figure 4-34. This image shows the assumed contact point where the conglomerate has interacted with the underlying basement. The argument to support this is that the clasts are angular to sub-angular in this outcrop, compared to the rounded to sub-rounded found in the overlying Unit F. Assuming that this is the contact point, the conglomerate must have flowed towards this point across the basement “tongue”, from Unit E, and interacted with the basement causing the angular clasts. Then as the flow of sediment continued from the west, the more rounded clasts were deposited on top of these lower-lying angular clasts.

Unit F also shows the same flow direction as that seen in Units D and E. When comparing the texture and appearance of Unit F, it shares more traits with Units D and E than it does with the dipping alluvial conglomerate. Additionally, the presence of a possible slump or landslide that has divided Unit F from Unit E is highly likely. Therefore it is believed that Unit F is part of the same sub-horizontal unit that is Units C, D & E.

### **5.2.2.3 Group 3 – Units G & H**

The final two sub-horizontal layers identified in the Kerpini Fault Block are found 2km further east from Unit F. In between there is only basement, with no indication of sediment as Profile D shows (Figure 4-55). Unit G (Sec. 4.3.8) from afar does appear sub-horizontal, but as described in Sec. 4.3.8, the outcrop is only properly exposed on the southern side. Therefore it is difficult to ascertain whether it is dipping towards the south as only one side is viewed. There is also a lack of consolidated sandstone clasts within the outcrop, or at least they occur at a lower frequency than in the other sub-horizontal outcrops. The thick sandstone beds that are visible in

Units A to E are not as prolific in Unit G, and are much thinner than in previous units. With regards to flow direction, it was difficult to find a trend in this unit. This could be attributed to not being able to view individual outcrops from several angles.

The dip angles that were measured on Unit G gave a trend angle of  $10^{\circ}$  towards the south-east. However, immediately south of Unit G one enters the Kerpini Fault Block alluvial conglomerate that was measured to be  $19^{\circ}$  south. As the measurements made on Unit G are in the higher spectre of what is considered sub-horizontal, and immediately south there are dipping conglomerate, it raises the question whether these are part of the sub-horizontal layers. Furthermore, as Figure 4-38 is trying to show, it is possible that the dip angles are more towards the south-east due to the poorly exposed layering. There was also no clear contact between Unit G and the dipping alluvial conglomerate found immediately to the south as it is covered with recent soil and vegetation. In addition the basement that separates Unit F from Unit G is found at a higher elevation (Figure 4-55), approximately 50m higher, i.e. the line of sight (flow path) between them is obstructed and any sediment found between the two is located at a much lower elevation and shows clear south/southwest dip angles (Figure 4-2). Based on this, it is hard to argue that Unit G is part of the sub-horizontal layering (Units A-F) and is more likely part of the Kerpini alluvial dipping conglomerate that has undergone movement in the form of a slump or landslide. Although during this study no evidence for a fault could be found, Ford et al. (2013) had interpreted an antithetic fault north of Unit G. Therefore the presence of a fault cannot be dismissed to be the cause of the shallower dip angle of Unit G compared to the Kerpini alluvial conglomerate.

Unit H is located on the northern section of Roghi Mountain and has long been considered to be part of the sub-horizontal layering found in the Kerpini Fault Block. This section has previously been interpreted as an incision by a fluvial system flowing west to east (Syahrul, 2014). This interpretation can be justified when viewing this unit solely from across the valley, north of Roghi Village looking eastward (Figure 4-39). When viewing from this angle, the beds appear horizontal in contrast to the dipping beds found further south along the western side of Roghi Mountain. However, when climbing down to view these horizontal beds, the flow direction within the imbricated clasts indicate a flow towards the north. This can be seen in the Figure 4-43. Figure 4-42, which is taken higher up, also shows a north trending flow. The trend

seen in the sub-horizontal units, A-F, has been that of an eastward direction for the flow. What is interesting is that the beds measured in Figure 4-42 show a dip angle of 20° southward (Figure 4-41). If one follows the train of thought that the horizontal layers seen in Unit H are indeed caused by a fluvial system flowing from west to east, one would expect to see an eastward trending flow direction, which is not the case. Secondly, the beds shown in Figure 4-41 are overlying the horizontal layers seen in Unit H and the flow directions measured within Unit H seem to be consistent with directions measured in other locations on Roghi Mountain within the main package of alluvial dipping conglomerate.

Based on these assessments, it appears more likely that the previously interpreted incision (Syahrul, 2014) (Unit H) is actually a part of the Roghi Mountain structure and that the appearance of the sub-horizontal layers is a result of either faulting or late slumping, or perhaps both. The largest piece of evidence to support this is the flow direction observed in the dipping layers of Roghi Mountain and in the sub-horizontal layers. The possible fault that is shown in Figure 4-39 is also supported by Solheim (2002). However one cannot rule out the possibility of other faults within Unit H that may have caused the shift in the layering making these appear more horizontal. Looking at Figure 4-8 and Figure 4-9, these two images show that viewing the dipping layers on the western side of Roghi Mountain, the dip angle changes based on the view angle. This indicates that the layers have most likely slumped/slid down the western side causing the change in angle. Therefore it is possible that a similar event has occurred at Unit H, causing the outer lying layers to have slumped or slid making them appear horizontal. This may or may not have been caused by faulting. Thus Units G and H are considered to be part of the same rock unit.

### **5.2.3 Correlation of Sub-horizontal Groups**

This section will look at the correlation between the various groups. Instead of starting with Group 1, Group 3 shall be addressed first. The reason for starting with Group 3 is the belief that these two units are not part of the sub-horizontal layers found in the remainder of the Kerpini Fault Block and in the Kalavryta Fault Block. This is based largely based on the flow direction observed in Unit H, in which the flow is consistent with the dipping older alluvial conglomerate found in both fault blocks. Also, Unit H has dipping conglomerate layers (Figure 4-41) that overlay “sub-horizontal” layers. The presence of these dipping layers poses a problem



for the theory of Unit H being sub-horizontal. Based on the direction of flow, it is then believed with a high degree of certainty, that it is the sub-horizontal layers in Unit H that actually are slumped or faulted dipping alluvial layers. As for the second unit in Group 3, G, it is a “poorly” exposed outcrop that makes it difficult to ascertain flow. Additionally there is a possibility that the dip angles seen in Unit G are apparent and that the unit is part of the dipping alluvial conglomerates. This is may have been caused by a slumping or faulting. Finally there is the distance and topography that separates Unit F from Group 3, and the lack of any other sub-horizontal sediment in this gap. Therefore, with a high degree of confidence, Group 3 cannot be correlated with the other groups further to the east (Group 1 & 2).

Explained in Sec. 5.2.2.1, Unit B is a rather small, poorly exposed outcrop. Nevertheless it is not ruled out as being part of a larger sub-horizontal sediment system. The units found in Group 2 have been discussed in Sec. 5.2.2.2, where it is believed that Units C, D, E and F can be considered to be one large unit. Unit F was separated from the others after a possible slump or landslide created a void between them.

When comparing Groups 1 and 2, three data points have been averaged and displayed in Table 5-1.

	<b>Avg. Dip / Dip Dir. [°]</b>	<b>Avg. Clast size [mm]</b>	<b>Flow</b>
<b>Group 1</b>	9/045	125	E/NE
<b>Group 2</b>	9/049	144	E/NE

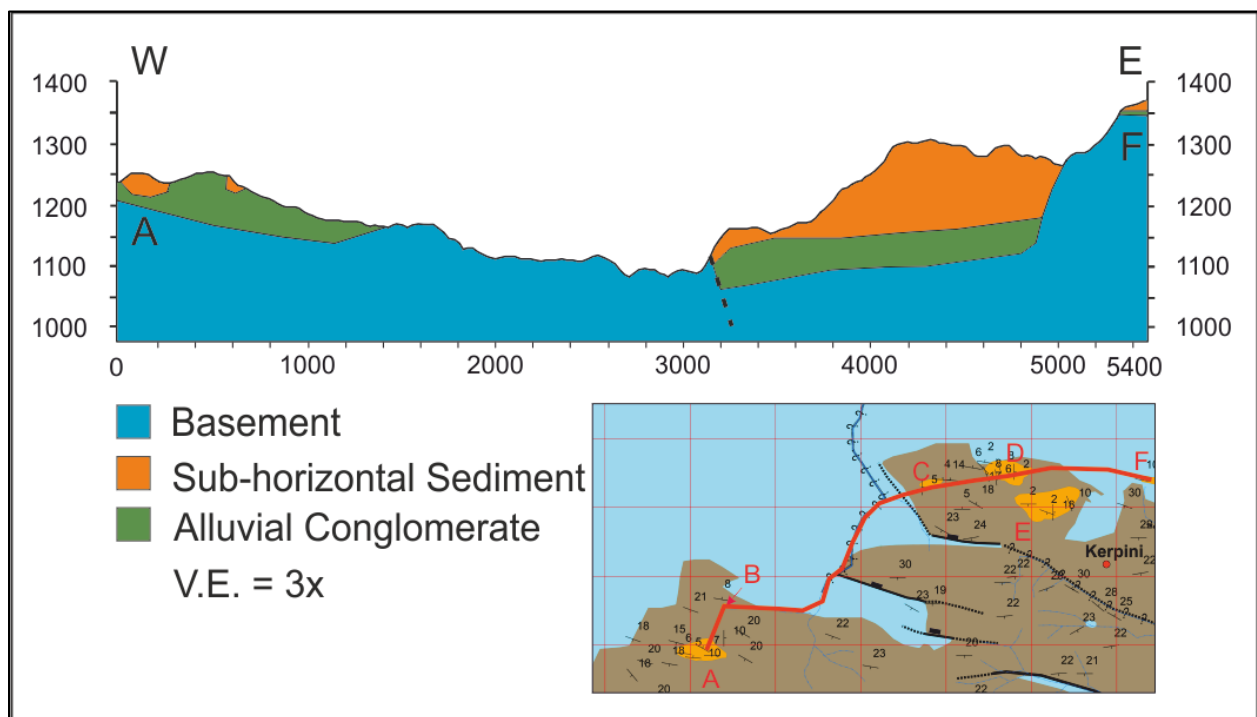
**Table 5-1: Comparison of three data points for Groups 1 and 2.**

The dip angle and dip direction are remarkably similar, especially as Group 2 is an average of four units. Bearing in mind that some of these measurement have been taken from a distance, they do show a consistent trend within the two groups. However the average clast size is, in this case, showing the opposite of what one would expect. As the clasts have been transported further, it is expected that the clast size would become smaller, whereas the averages in Table 5-1 show the opposite. However this is given that the possibility that the clast measurements were conducted at different elevation is very high and the likelihood that they were taken from

the same bed is small. Therefore accepting that there are inherent uncertainties in the measurements of the clasts, it is plausible then that the averages fall within the margin of error. Accepting a  $\pm 10\%$  error margin results in:

- Group 1 –  $125.0 \pm 12.5\text{mm}$
- Group 2 –  $144.0 \pm 14.4\text{mm}$

The upper boundary of Group 1 is then 137.5mm and the lower boundary of Group 2 is 129.6mm. Thus it is possible, granted the extremes of the uncertainty, that there is a fining of clast size in the direction of flow.



**Figure 5-4: Profile following possible flow path between Groups 1 and 2. This is based on the current topography, and shows a likely flow path for sediment. This figure has indicated Group 2 as a single unit as per Sec. 5.2.2.2. The profile has a vertical exaggeration of 3x.**

Lastly, elevation and topography will be analysed in order to correlate Groups 1 and 2. When using simple line of sight between Group 1 (centre Unit A) to Group 2 (centre Unit D) there are no obstructions as Group 1 sits at  $\sim 1200\text{m}$  and Group 2 at  $\sim 1280\text{m}$ . However this would not be an accurate path that sediment would travel and it does not take into account the lower-lying sediment in Group 2 (Unit C). Therefore a profile has been created to show a likely path of sediment transport, which is based on present day topography and the path of the Kerinitis River. The profile starts at Group 1 (Unit A) and ends at Group 2 (Unit F). The

intention here is to show that a flow path between the groups is plausible (Figure 5-4) and that no obstacles are present. The profile has taken into account the previous combining of the Group 2 units into a single one.

Within Group 1 (in between Unit A and B) there is a slight elevation of interpreted dipping conglomerate. This area is covered with recent soil and vegetation and does not indicate either sub-horizontal or south dipping alluvial conglomerate. Additionally as this is an attempt of a “most likely” path that a fluid may flow, the path may be slightly off.

#### **5.2.4 Timing of Sub-Horizontal Layers**

The timing of the sub-horizontal layers has been placed in the late-syn or post-Kerpini Fault period. This interpretation is based on the dip angle that all the units show. Secondly, none of the units identified show any indications of having south dipping alluvial conglomerate overlying or onlapping. Additionally, as no direct contact between the sub-horizontal and dipping conglomerate has been identified<sup>5</sup>, it is assumed that the sub-horizontal layers are overlying the older south dipping alluvial conglomerate.

### **5.3 Structural**

During the course of the field work observations were made that may indicate the presence of new faults found within the Kerpini Fault Block. The previously known main faults will not be further interpreted in this section with the exception of Kerpini Fault which is now assumed to right-step twice. This is a change in the interpretation of the Kerpini Fault based on Syahrul’s (2014) thesis.

#### **5.3.1 Kerpini Fault**

The Kerpini Fault is believed to have its maximum displacement in the east, close to the Vouraikos River (4.5.2.1), and the displacement decreases as one moves west along the proposed fault path. Previously this has been interpreted as a uninterrupted fault (Ford et al., 2013), however the observations made in the field support the possibility of the Kerpini Fault right stepping. There are two instances where there is sediment dipping into exposed basement (Figure

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<sup>5</sup> The one exception is Unit H (Roghi Mountain). However this unit has been interpreted as not belonging to the sub-horizontal layers found in the western region of the Kerpini Fault Block and the ones in Kalavryta Fault Block.

4-48 and Figure 4-49). This is also shown in the Profile A (Figure 4-52), where the second step is shown. Not placing a fault at these two locations and instead placing an unconformity would not explain the sediment dipping into exposed basement. The right stepping of the Kerpini Fault is supported by Wood (2013).

### **5.3.2 Western Kerpini Fault**

The possibility of this fault is again based on the presence of dipping sediment into exposed in-situ basement (Figure 4-50). The western section of this fault has also been proposed by Wood (2013). However during the course of this study it is believed that this fault may continue further eastward into the Kerpini Fault Block. On the overview map (Figure 4-2, G5) there is a small section of exposed basement. It was initially thought that this small basement outcrop may be topographical. However, immediately north of this exposed basement there is north-dipping sediment and immediately south there is south-dipping sediment. This can be seen in Profile B (Figure 4-53) at approximately 1500m. These two large outcrops of north and south-dipping sediment can also be seen in Figure 4-47. It should be noted that these two sections of outcrop were interpreted to be fans by Syahrul (2014), flowing in an eastern direction. However, based on the observations done during this study, the flow directions on both of these sections have been found to be in a northern direction.

The possibility of having the fault further east is based on the presence of the exposed basement and the north dipping sediment. The north dipping sediment is dipping at  $\sim 30^\circ$ , which could be considered very steep if it were a fan. Also this sediment shows the same characteristics of the more prolific alluvial conglomerate found in the Kerpini Block. Therefore it is not believed to be a fan with origin off the interpreted Western Kerpini Fault, but rather part of the alluvial conglomerate. The radical dip angle is believed to be caused by a large section that has broken off after having been eroded by a fluvial system. As the Kerpini Fault has its maximum displacement in the south-east corner, the drainage pattern within the fault block will be from northwest to south-east. A river would then interact with the exposed sediment that is uplifted as a result of the Western Kerpini Fault. Figure 5-5 shows a simple series of diagrams to explain the proposed events that expose this basement and cause the north dipping sediment.



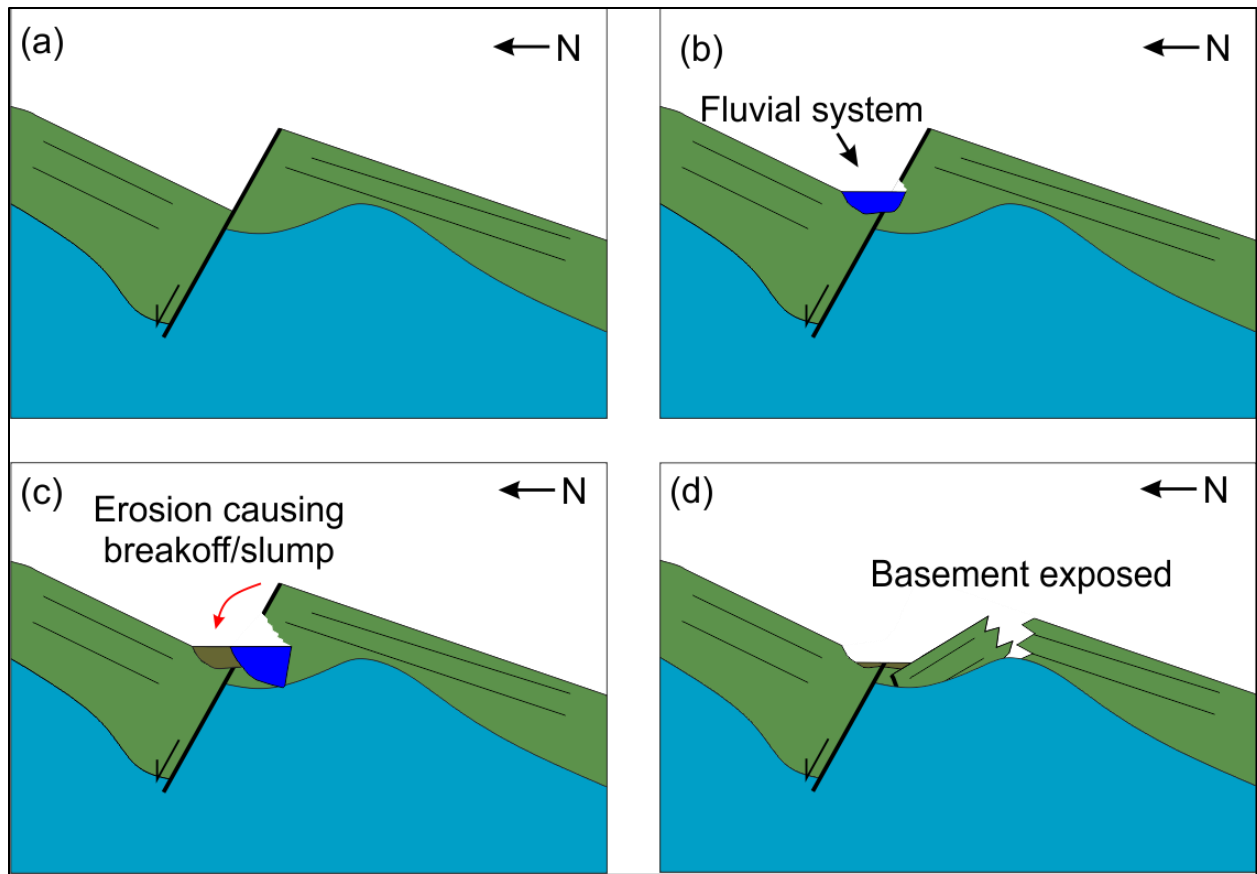
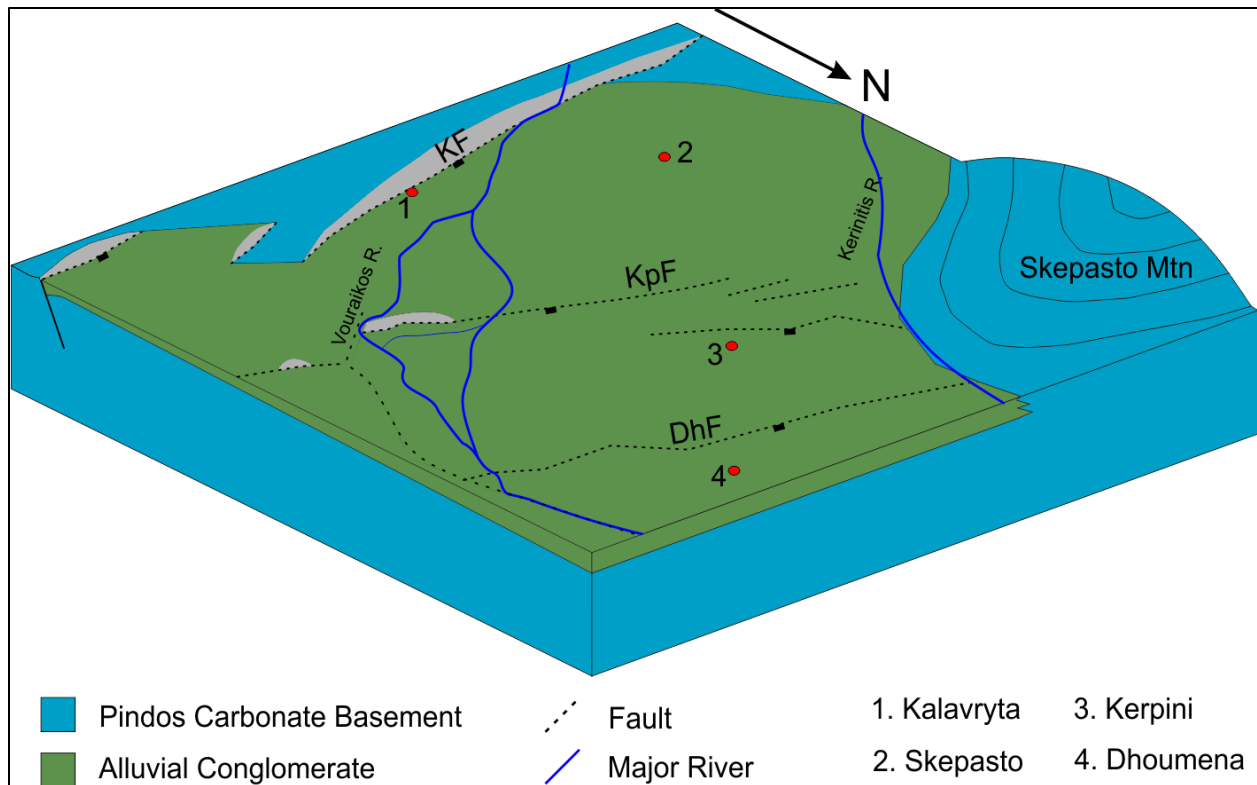


Figure 5-5: This series of diagrams show a possible explanation for the smaller exposed basement found lying between the north and south dipping sediment. Box (a) shows the initial status; in (b) the fluvial system coming from the northwest is then flowing south-east and interacts with the exposed footwall; (c) the footwall becomes eroded and an overhang is developing; (d) at a certain point the overhang will break off, this will then expose the basement. It is possible that the basement is not completely exposed at this point and that a new fluvial system erodes down to the basement. (Not to scale.)

## 5.4 Evolutionary Model

### 5.4.1 Initial Stage – Pre- to Early-Syn Kerpini Fault



**Figure 5-6:** This block diagram is a representation of the area of interest showing Kalavryta, Kerpini and parts of the Dhoumena Fault Block. This is in the initial stage of the Kerpini Fault. The Vouraikos River is here interpreted to possibly divide in two, with one branch going on either side of the initial movements of Kerpini. (Not to scale.)

The initial stage portrayed here is at the point where the pre-rift basement has been covered with the syn-rift alluvial fan with assumed origin Kalavryta Fault. The Kerpini Fault movement has started in the east at the Vouraikos River, where the maximum displacement is believed to be, and is propagating slowly to the west. As the figure shows, it is believed that the Vouraikos River has split into two, perhaps more branches. One of these branches is then thought to flow over what is today Roghi Mountain and be the cause of the likely fluvial erosional patterns seen in Figure 4-10. This erosion of Roghi Mountain would have had to occur prior to any large displacement of the Kerpini Fault, as Roghi Mountain will be rotated. Additionally it is also likely that the Kerinitis River in the west has been divided into one or more branches. At this stage it is believed that the Dhoumena Fault has not moved.

### 5.4.2 Intermediate Stage 1 – Mid- to Late-Syn Kerpini Fault

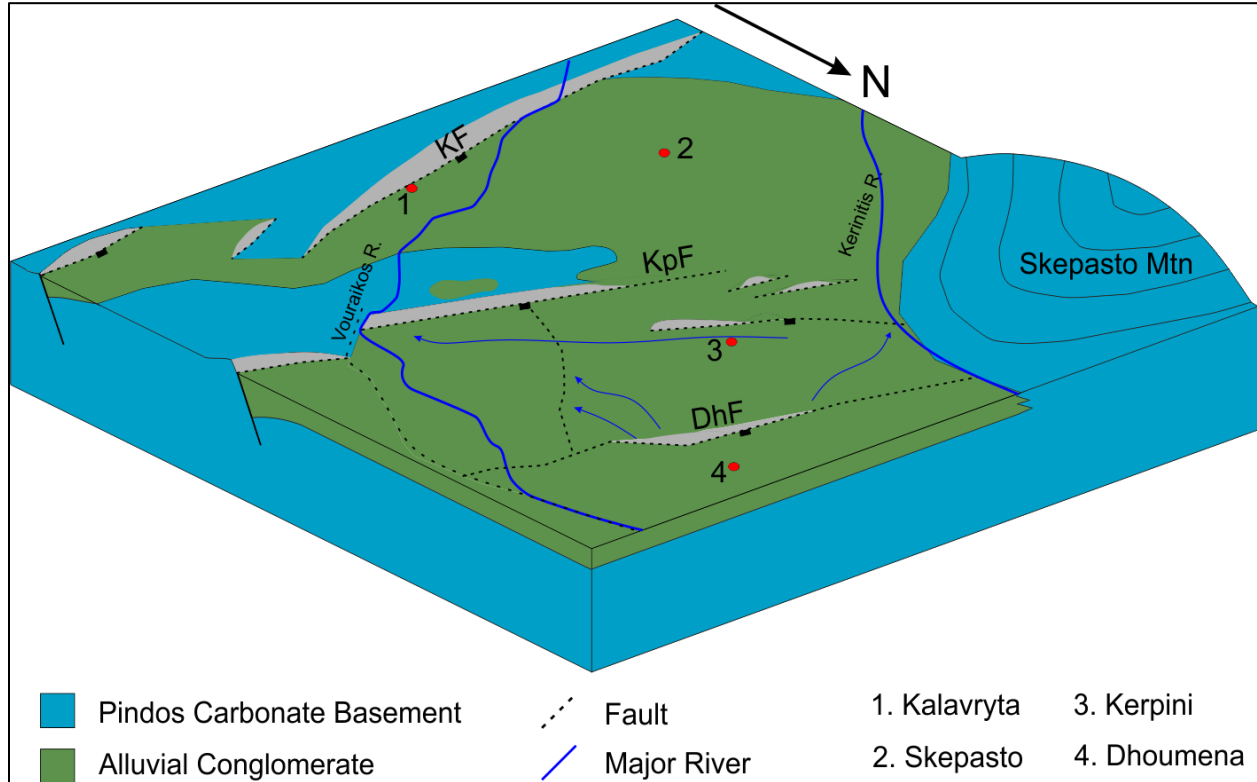


Figure 5-7: This block diagram is placed mid- to late-syn Kerpini Fault. The Kerpini Fault has propagated to the west and has right stepped. The Dhoumena Fault may have started some displacement. As the Kerpini Fault as propagated, one the branches of the Vouraikos River will no longer be able to flow over the uplifted footwall and re-joins the trunk of the Vouraikos River. (Not to scale.)

At this point the Kerpini Fault has propagated further to the west and has performed the aforementioned right stepping (Figure 5-7). The extent of movement on the Western Kerpini Fault is uncertain. As the Kalavryta Fault Block has rotated, both sides of the Vouraikos River have experienced erosion due to the uplift of the footwall and exposing basement. This sediment is then believed to be transported to the coast by the Vouraikos River. Smaller streams and rivers will have formed within the Kerpini Fault Block, bringing sediment south-east to the depocentre. The Vouraikos River is thought to have merged into fewer branches, and as the Kerpini Fault Block rotates, the river migrates further to the east. During this period it is likely that the Roghi Fault South started propagating. This fault may then have created a paleo barrier to which smaller streams would flow against, causing erosion and setting the conditions for the western side of Roghi Mountain to later slump. On the eastern side of Roghi Mountain, the Vouraikos River has most likely already eroded the sediment creating a river valley.

### 5.4.3 Intermediate Stage 2 – Late-Syn to Post Kerpini Fault

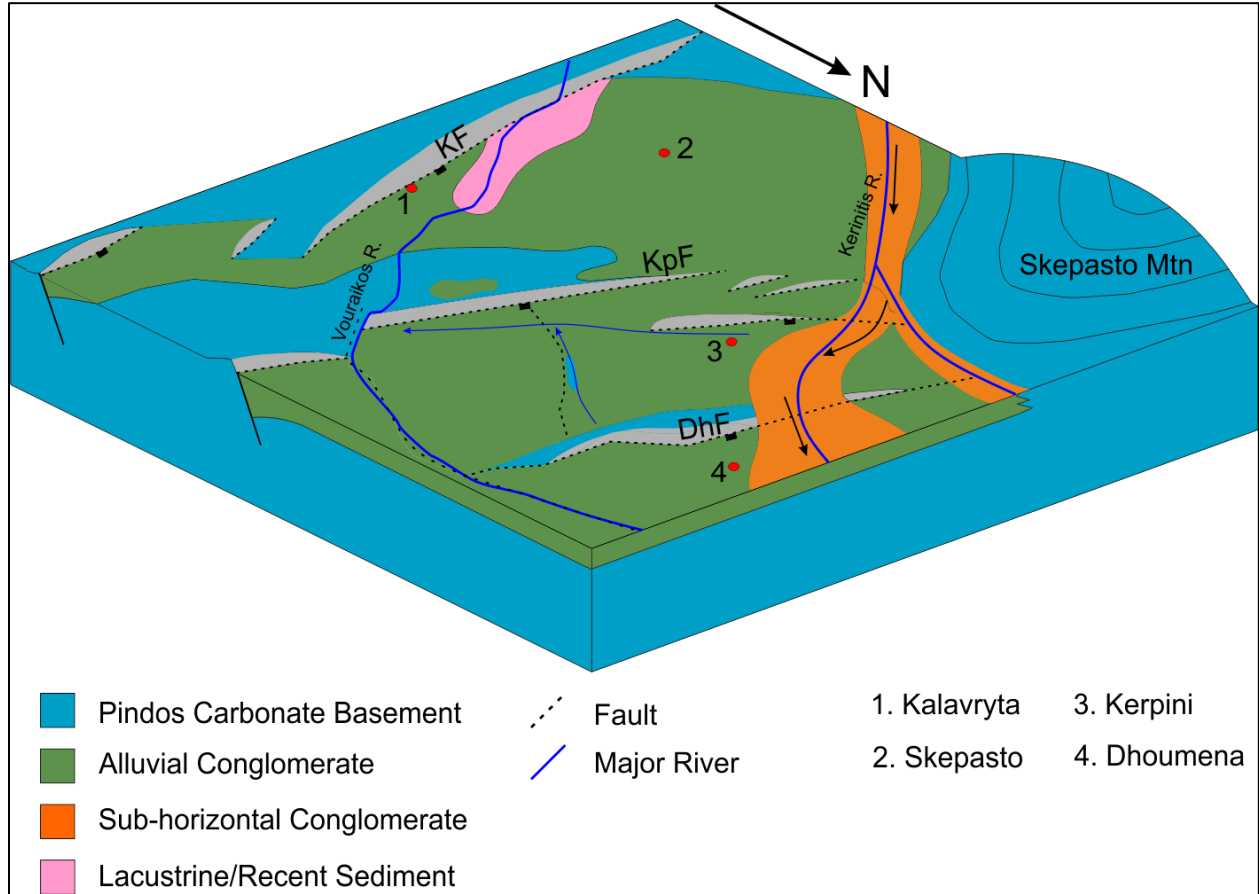


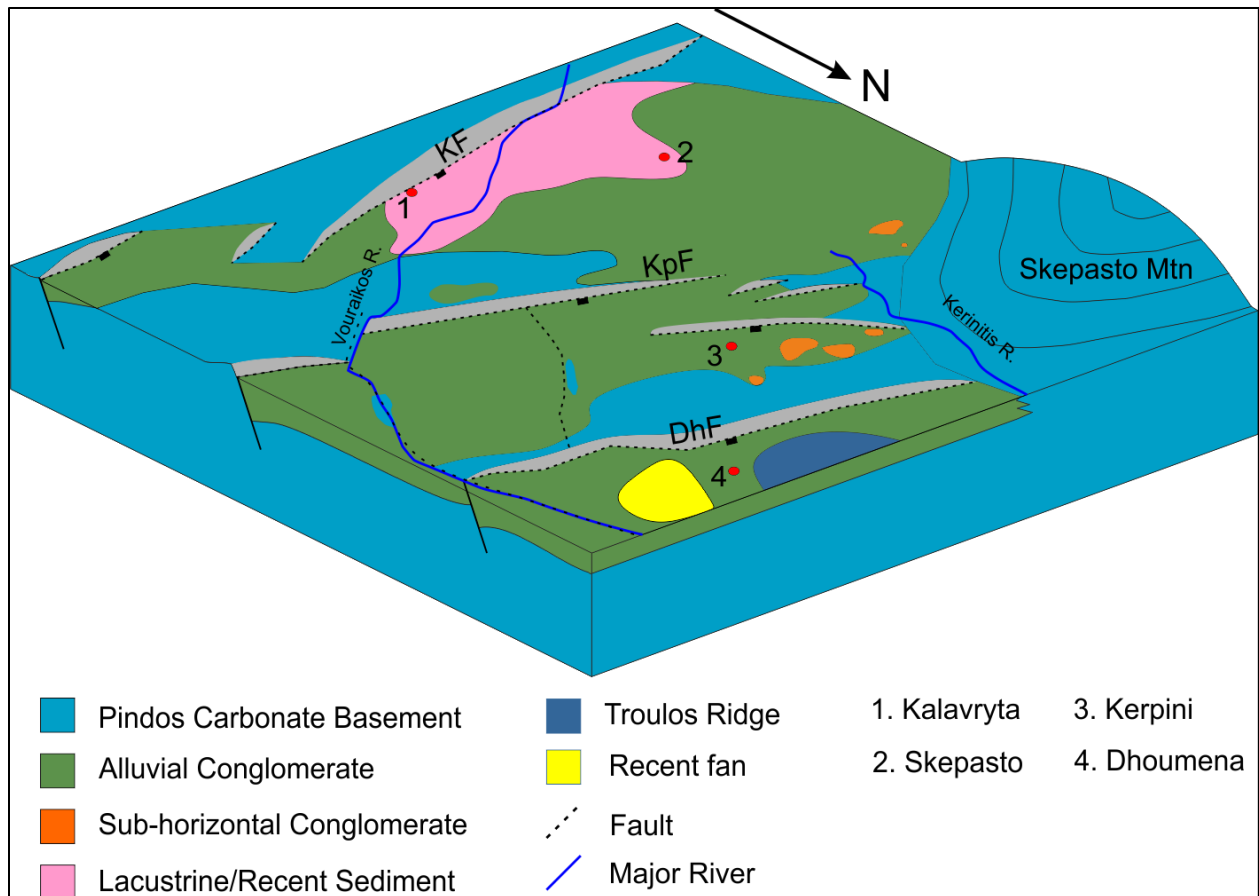
Figure 5-8: Block diagram depicting the late-syn to post Kerpini Fault. At this stage the Kerpini Fault will have ceased movement, i.e. it will have died. The Dhoumena Fault will continue its displacement and propagation. It is at this stage that the sub-horizontal sediment (younger sediment) is assumed to be deposited. The Kerinitis River is proposed to have divided in order to carry the sediment into the Kerpini Fault Block. (Not to scale.)

This stage is placed in the late-syn to post Kerpini Fault (Figure 5-8). It is at this stage that the sub-horizontal sediment is assumed to be deposited. The rotation of the Kerpini Fault Block has ceased and therefore any sediment deposited, especially at elevation, will not be further rotated and may be deposited sub-horizontal. The actual source of the sediment is not known, but based on flow direction, it is highly likely to have originated from the west-southwest as Group 1 shows a flow direction of east-northeast. As the sediment has entered the Kerpini Fault Block, it is likely that it has continued north, flowing into the Dhoumena Fault Block. To cause it to change direction, it is thought that either topography, as a result of the displacement of Dhoumena Fault, or the erosion of the alluvial conglomerate already present in the Kerpini Fault Block has caused this. Whether or not any of this younger sediment (sub-horizontal sediment) was transported south-east towards the Kerpini Fault Block depocentre is



uncertain as there is no evidence in the fault block to support this. At this stage it is also believed that the combination of the Kerpini, Dhoumena, Vouraikos and Roghi Fault South has caused the massive conglomerate of Roghi Mountain to rotate slightly to the east. This rotation is based on the angle of the erosion patterns see in Figure 4-10.

#### 5.4.4 Present Day



**Figure 5-9:** This shows the present day situation based on the observations made during the field study. At this stage the Dhoumena Fault has died. Note that the sub-horizontal sediment (Group 3) is not included in this diagram as they are no-longer considered to be part of the sub-horizontal layers.

Figure 5-9 is a depiction of the present day status based on observations done. Here the faults shown in the figure are inactive. The Kerinitis River has been diverted away from the Kerpini Fault Block as the Dhoumena Fault has propagated further west and the area close to the Dhoumena Fault has been eroded and basement has been exposed. Whether or not the Troulos Ridge is a result of erosion of the uplifted Dhoumena footwall or from the possible influx of sediment as a result of the Kerinitis River (Figure 5-8) is uncertain, as the Dhoumena Fault Block has not been studied.

## Chapter 6: Conclusion

Earlier studies into the Kerpini and Kalavryta Fault Blocks have often overlooked the presence of the sub-horizontal sedimentary layers that are found here. They have often been dismissed or categorised as basal conglomerates. This study hopes to suggest a plausible interpretation based on fieldwork that may aid in understanding their evolution. In order to do this the evolution of the fault blocks themselves had to be revisited as previous work done in the region did not correlate with observation made.

Alluvial conglomerate make up the bulk of the sediment found in the Kalavryta and Kerpini Fault Blocks. This conglomerate is interpreted to be pre-Kerpini faulting and believed to have its origin from the Kalavryta Fault. The subsequent fan that propagated from Kalavryta Fault is believed to have covered both of the fault blocks in this study area and may have continued into the Dhoumena Fault Block. Because the alluvial conglomerate is overlying the pre-rift Pindos Carbonate basement, it is considered the oldest sediment in the two studied fault blocks. Roghi Mountain is considered to be part of the alluvial fan.

The sub-horizontal layers that have been the focus of this study have been divided into three groups: 1, 2 and 3. Group 3 has been interpreted as not being part of the sub-horizontal layers, largely based on characteristics that are more consistent with the south-dipping alluvial conglomerate. Groups 1 and 2 have been attempted correlated by looking at texture, location and potential flow paths based on present day basement topography. Groups 1 and 2 also exhibit features that have allowed them to be classified as a fluvial influenced conglomerate. The timing of their deposition of Groups 1 and 2 has been interpreted to be in the late-syn Kerpini Fault to post-Kerpini Fault. Influx of the sub-horizontal sediment is assumed to be in the south-west of the Kalavryta Fault Block, entering the Kerpini Fault Block in the west and continuing north towards the Dhoumena Fault Block.

A new evolutionary model of the area studied has been proposed. This model takes into account the large alluvial fan radiating from the Kalavryta Fault and the influx of the sediment that is deposited as the sub-horizontal layers. It also attempts to answer some of the structural features observed in the Kerpini Fault Block that have not been addressed before.

There are still several unanswered question within these two fault blocks. This study has carried out a sedimentological study of the sub-horizontal layers and only briefly touched the surface of Roghi Mountain. One observation that was made in this study during the field work is the apparent lack of syn-Kerpini Fault deposits. Therefore the following future study is proposed:

- The area between the Kerpini Fault and the interpreted Western Kerpini Fault has not been studied in detail in this thesis. A study of this area could answer the question why there is an apparent lack of syn-Kerpini Fault deposits in the Kerpini Fault Block.
- Roghi Mountain needs to be properly mapped and possibly with the aid of UAV's or LIDAR. Furthermore Unit H should be revisited to verify whether the apparent horizontal layers are the result of faulting or deposition.
- If the influx of sediment was carried over into the Dhoumena Fault Block, as has been suggested in this study, it needs investigating. The eastern part of Dhoumena Fault Block has been mapped. However the western region with Troulos Ridge has not been mapped in great detail.
- This study has assumed that the alluvial conglomerate has its origin from the Kalavryta Fault. However, could there be another source? And what is the extent of this large fan, and how far does it prograde?

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