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Sedimentology of the Paleogene Volcaniclastic Gravity Flow Deposit of the Ulukışla Formation, South Central Türkiye

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Abstract

The sedimentological study of volcaniclastic successions is essential for gaining insight into the intricate geological history of the Ulukışla Basin in south Central Anatolia. This study, based on a comprehensive facies analysis of two representative stratigraphic sections, attempts to reconstruct the depositional conditions associated with volcaniclastic sedimentation within the Ulukışla Formation. Facies assemblages dominated by debris-flow deposits and turbidites provide clear evidence for deposition under deep-water conditions related to the proximal environment. Sedimentary characteristics of these deposits made up of volcanogenic conglomerates with basaltic to andesitic clasts of variable size, sandstones, and subordinate mudstone are suggestive of derivation from the nearby Ulukışla volcanic rocks. Almost all the lithofacies display a high tuff content indicative of possible sediment contributions from sub-aerial volcanic sources. The main controlling factors responsible for deposition include submarine gravity flow processes thought to have been triggered by slope instability or the collapse of a volcanic edifice. Thus, the resulting volcaniclastic accumulations are interpreted to be linked to volcanic apron deposits. In the realm of prospective research, the acquisition of geochemical and geochronological data stands as a promising avenue, offering crucial insight into the temporal aspects and tectonic setting of deposition of the Ulukışla volcaniclastic sequence.

Keywords:

Facies analysis, Ulukışla Basin, volcaniclastic sedimentation, gravity flow processes, volcanic apron

1. Introduction

Volcaniclastic successions represent the accumulation of clastic materials derived from the fragmentation of volcanic rocks and their subsequent transport (**Fisher, 1984; Manville et al., 2009; Carey and Schneider, 2011; Lenhardt et al., 2011**). In spite of their limited suitability as hydrocarbon reservoirs, rendering them not very attractive exploration targets (**Mathisen and McPherson, 1991**), the volcaniclastic sequences have the potential to host economically valuable ore-mineral deposits (**Carey and Schneider, 2011**).

They constitute powerful archives documenting significant paleoenvironmental shifts and volcanic activities in sedimentary basins affected by magmatism throughout their development. These formations provide strong paleogeographic constraints, as they form in diverse sedimentary environments, spanning from shallow-water to deep-marine basin floor settings (**Sigurdsson et al., 1980; Fisher, 1984; McCoy and Cornell, 1990; D'Atri et al., 1999; Nichols, 2009; Carey and Schneider, 2011**). Therefore, understanding the mechanisms accountable for the formation of volcaniclastic rocks is crucial for deciphering the origin and the depositional history of these types of basins. An example of a sedimentary basin associated with magmatism during its evolution is the Ulukışla Basin in southern Central Anatolia, which offers an exceptional opportunity to examine the volcaniclastic deposit as it represents a significant part of the basin stratigraphic record.

Despite the significant amount of research undertaken to investigate the tectonic and sedimentary development of the Ulukışla Basin and the related lithostratigraphic units (**Oktay, 1982; Demirtaşlı et al., 1984; Nazik and Gökçen, 1989; Clark and Robertson, 2002 & 2005; Alpaslan et al., 2004 & 2006; Kadioglu and Dilek, 2010; Engin, 2013; Sarıfakıoğlu et al., 2013; Gürer et al., 2016; Seyitoğlu et al., 2017; Akgün et al., 2020; Gürbüz et al., 2020; Esirtgen and Işik, 2021**), the sedimentology and the paleoenvironment of the volcaniclastic deposits of its eponymous formation remain poorly known. The volcaniclastic unit initially was considered as an independent formation known as the Serenkaya Formation (**Oktay, 1982; Nazik and Gökçen, 1989**). However, because of its limited extension and its

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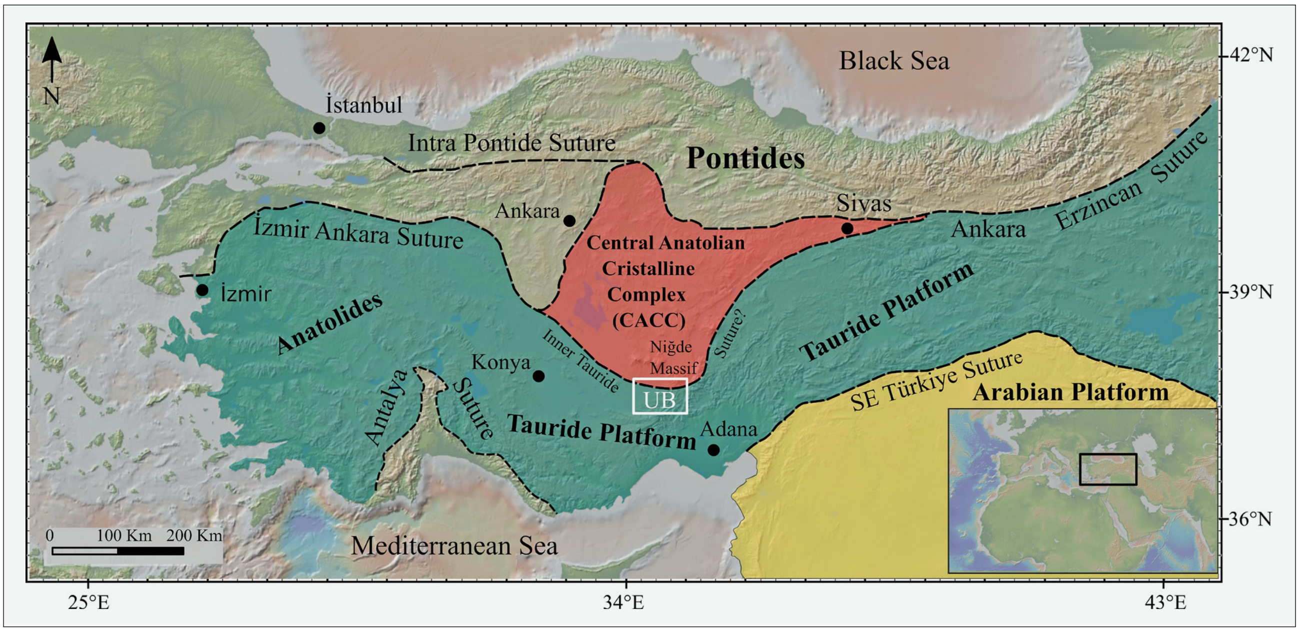

Figure 1: Simplified tectonic map of Türkiye highlighting the Ulukışla Basin's location within the white rectangle (Modified after **Dilek and Thy, 2009**)

genetic link with adjacent volcanic terrain, the unit was subsequently integrated into the Ulukışla Formation (**Clark, 2002; Mahamidou, 2022**).

This study aims to investigate the sedimentary characteristics of the volcaniclastic deposit of the Ulukışla Formation in order to establish a depositional model and to unravel the key processes that were active during its sedimentation.

2. Geological Background

The Ulukışla Basin is bounded to the north by the Niğde Massif, a metamorphic core complex representing the southern fringe of the Central Anatolian Crystalline Complex (**Görür et al., 1984; Göncüoğlu et al., 1991; Whitney and Dilek, 1997 & 1998; Gautier et al., 2002; Lefevbre, 2011**), and to the south by Bolkar Carbonate platform considered to be the northern edge of the Tauride continental block (**Dilek et al., 1999; Robertson et al., 2012**) (see **Figure 1**). The origin and the evolution of the Ulukışla Basin are highly complex, making its nature puzzling. As a result, various conflicting geodynamic models for the basin development have been suggested: Island arc-related basin (**Oktay., 1982; Baş et al., 1986; Işler 1988**), forearc / intra arc basin (**Görür et al., 1984 & 1998; Gürer et al., 2016**), foreland basin (**Çevikbaş, 1991; Kadioglu and Dilek, 2010**), rift-related basin (**Alpaslan et al., 2004 & 2006; Clark and Robertson, 2005**), transtensional basin (**Clark and Robertson, 2002**), back-arc basin (**Keskin, 2011**), and supra- detachment basin (**Seyitoğlu et al., 2017; Gürer et al., 2018; Gürbüz et al., 2020**).

On the other hand, the stratigraphic record of the basin is characterized by a low-grade metamorphic basement of the Late Devonian to Late Cretaceous age represented by the Bolkar Carbonate platform unconformably overlain by the Upper Cretaceous Alihoca ophiolic mélange (**Demirtaşlı et al., 1984; Özgül, 1997; Clark and Robertson, 2002; Gürer et al., 2016**). The overlying formations are composed of volcanic, volcano-sedimentary, and sedimentary rocks of various ages ranging from Late Cretaceous to Quaternary (**Demirtaşlı et al., 1984; Atabey et al., 1990; Çevikbaş, 1991; Clark and Robertson, 2002; Sarıfakıoğlu et al., 2013; Engin, 2013; Gürer et al., 2016; Gürbüz et al., 2020; Mahamidou, 2022**). These volcanic and volcaniclastic rocks, which occupy a substantial portion of the basin, are part of the Ulukışla Formation.

Located in the northern part of the basin, the Ulukışla Formation constitutes an east-west trending volcanic belt spanning from the Ulukışla town to the Ecemis fault zone for ca. 43 km, representing the most voluminous rocks of the basin. The formation has been variously named, Ulukışla Formation (**Demirtaşli et al., 1975**), Ulukışla Group, (**Oktay, 1982**), Ulukışla Çamardi volcanites (**Baş et al., 1986**), Uukişla Formation (**Atabey et al., 1990; Kuşcu et al., 1993; Clark and Robertson, 2002; Alpaslan et al., 2004; Ulu, 2009; Sarıfakıoğlu et al., 2013; Gürer et al., 2016; Gürbüz et al., 2020; Umhoefer et al., 2020**), Ulukışla Magmatics (**Parlar et al., 2006**), and Lengerhane Volcanics (**Akgün et al., 2021**). The formation consists of basaltic to andesitic pillow lavas, massive lava flows, volcanic breccias, agglomerates, tuffs, and volcano-sedimentary rocks. It is characterized by a complex of large intrusions of acidic rocks, mostly monzonitic and syenitic intrusions (**Atabey et al., 1991; Alpaslan et al., 2004; Gürer, 2016**). The age of the Ulukışla Formation has been mainly constrained

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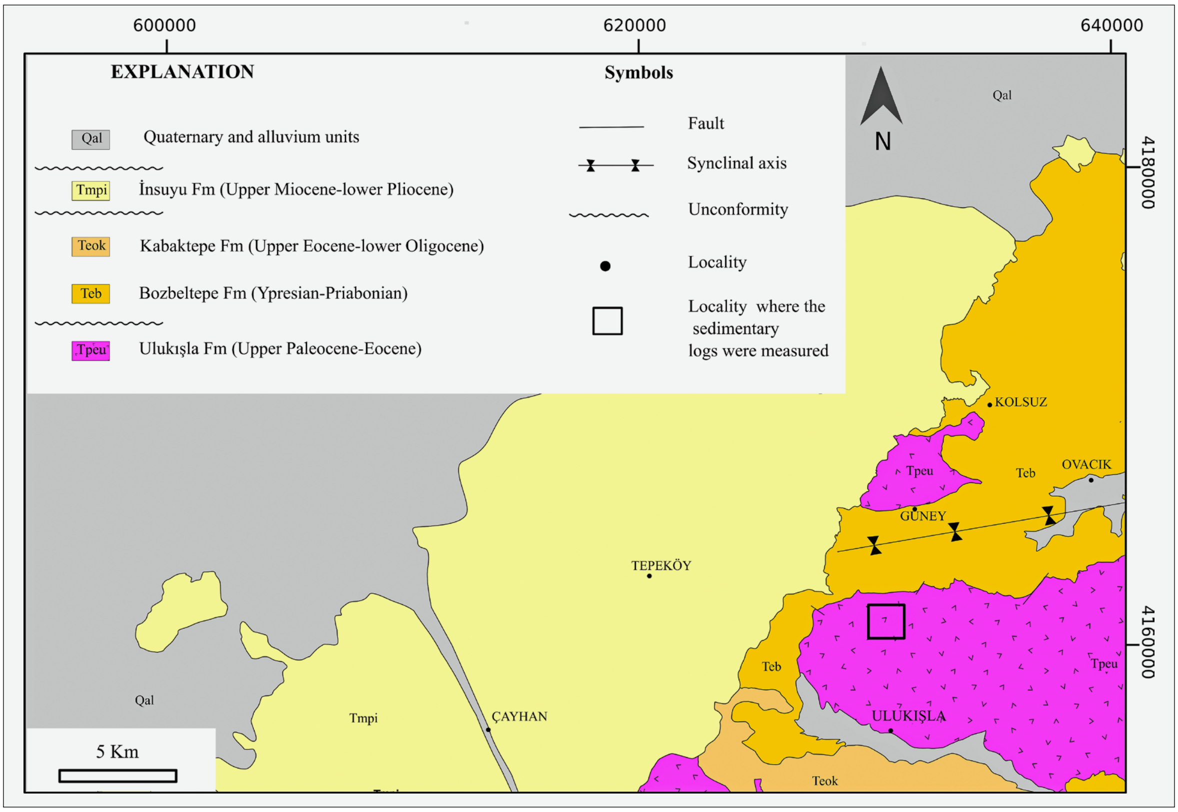

Figure 2: Geological map of the northwestern part of the Ulukışla Basin (Modified after **Mahamidou, 2022**)

stratigraphically and paleontologically, as Lutetian (early middle Eocene) (**Demirtaşlı et al., 1984; Atabey et al., 1991**); Cretaceous Late Paleocene (**Dellaloğlu and Aksu, 1986**); Late Paleocene to early Eocene (**Clark, 2002**); Middle-Late Paleocene (**Gül et al., 1986; Parlar et al., 2006**). However, recent geochronological dating of the Ulukışla volcanic rocks yielded U-Pb zircon ages of 59.6 and 59.7 Ma (**Gürer, 2016**), and 40Ar/39Ar biotite age of 58.8 (**Umhoefer et al., 2020**) representing a Late Paleocene age.

The volcaniclastic deposits of the Ulukışla Formation, the focus of this study, consist essentially of a succession of conglomerates, sandstones, and occasional mudstones. These deposits are best exposed in the western part of the basin and relatively few km to the N-W of the Ulukışla town (see **Figure 2**). In some areas, such as in the central part of the Ulukışla Formation, these volcanogenic sequences occur as turbiditic sandstones alternating with andesitic pillow lavas indicative of the submarine character of the volcanism. Their depositional age has been assigned to Ipresian by **Nazik and Gokçen (1989)** and early to middle Eocene by **Clark and Robertson (2002)**.

3. Methods

A detailed facies analysis was carried out to shed light on the paleoenvironmental conditions and depositional processes that were influential during the accumulation of the volcaniclastic rocks of the Ulukışla Formation. Outcrop-based lithofacies description supplemented by the construction of two representative sedimentary logs from the westernmost part of the Ulukışla Formation was conducted. The outcrops were selected because of their excellent exposure, accessibility, continuous bedding, and presence of sedimentary features essential to paleoenvironmental reconstruction. The high degree of alteration in some areas, combined with the lack of continuous outcrops, has restricted the study to a specific locality. The identification and classification of lithofacies in this study were based on several criteria, including grain size, grading, sorting, clast shape, composition, matrix content, bed thickness, and sedimentary structures. Additionally, particular attention was given to the lithology of clasts composing some facies to gain insight into the potential source rocks. The identification of lithoclasts relied solely on macroscopic petrographic analysis conducted on conglomerates during fieldwork, aimed at assessing their potential genetic connection with the adjacent volcanic rocks. This study does not intend to delve deeply into the provenance analysis but rather to provide a sedimentological framework within which the volcaniclastic succession can be better understood.

4. Results and Discussion

Volcaniclastic sedimentary rocks of the Ulukışla Formation in the western part of the basin have been mapped

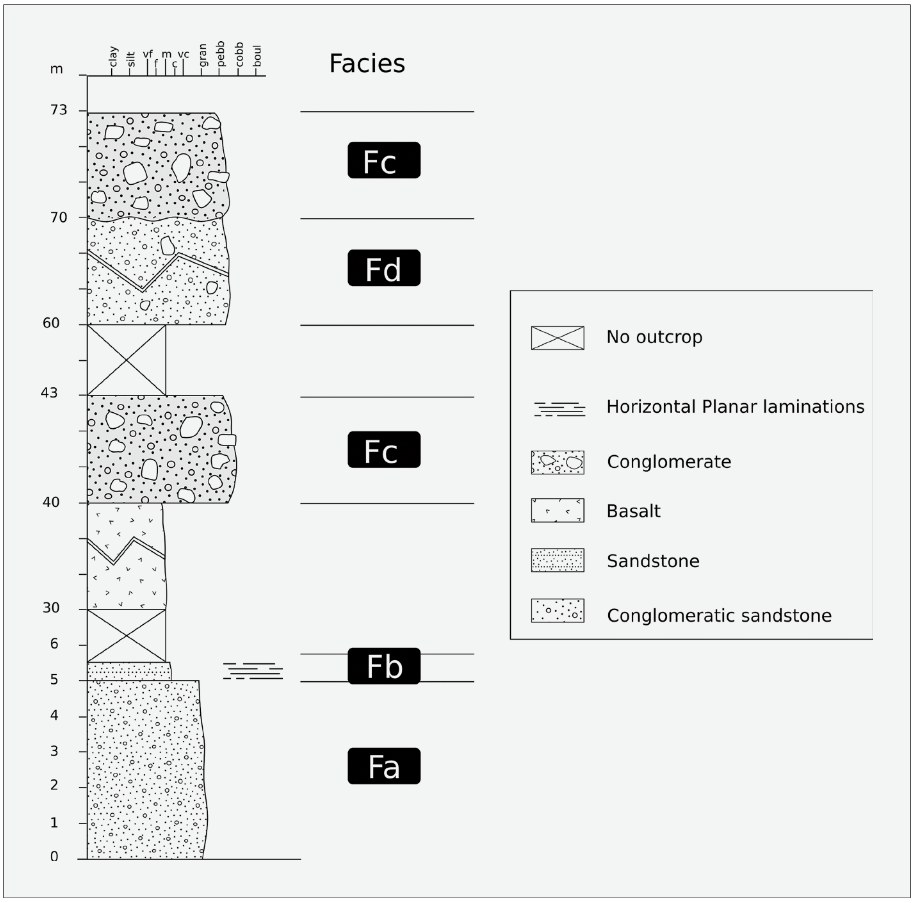

Figure 3: Measured sedimentological log-1 of the Ulukışla volcaniclastic succession (UTM 630282 m E; 4162376 m N).

and considered as the Halkapınar Formation by some previous authors (**Ulu, 2009; Meijers et al., 2016; Gürbüz et al., 2020; Akgün et al., 2021**). However, several lines of evidence show that these volcaniclastics rocks were more likely related to the Ulukışla Formation than the Halkapınar Formation. The clasts composing these rocks derived directly from the weathering and alteration of the adjacent volcanic rocks (Ulukışla volcanic unit). Also, this volcaniclastic unit stratigraphically overlies the Ulukışla lavas.

The study area, where the sedimentary logs were measured, is located approximately 5.7 km northwest of the Ulukışla town. The first studied outcrop (sedimentary log 1) is dominated by thick beds of conglomeratic deposits that are laterally continuous, exhibiting evidence of alteration in some areas. Sedimentary structures are rare in most cases, with their presence typically limited to certain beds. On the other hand, the second outcrop (sedimentary log 2) exhibits an alternating sequence of massive conglomerate with sandstone often featuring well-developed sedimentary structures such as parallel laminations. The mudstone, despite being present, is less prevalent. Four distinct lithofacies (Fa, Fb, Fc, and Fd) were identified on the first sedimentary log (see **Figure 3**), while on the second log, six lithofacies (Gmm, Gcm, Sp, Sm, Sh, FI) forming a sequence of repetitive facies were distinguished (see **Table 1**). In this sequence, lithofacies peculiar to a particular depositional environment and process were grouped into facies assemblages or associations (see **Figure 6**). An outlined description and interpretation of each lithofacies is given in **Table 1**.

4.1 Facies A (Fa)

This facies consists of coarse-grained to conglomeratic muddy sandstone with subordinate subangular clasts, mainly andesitic (see **Figure 4a**). The sandstone is essentially tuffaceous, moderately sorted, and massive with no clear grading. The facies is laterally extensive, with a thickness that can reach 5 m in some areas. The contact with the overlying lithofacies is sharp.

The massive conglomeratic sandstones marked by the lack of internal structures are characteristic of deposition by high-density turbidity currents witnessing rapid deposition (**Bouma, 1962; Lowe, 1982; Mutti, 1992; Zakaria et al., 2013; Orme et al., 2020**). The andesitic clast floating in the sandstone makes the facies very similar to the sandy debris flow deposit (**Walker, 1978; Shanmugam, 2000**). Therefore, this unit is interpreted as a sandy debris flow deposit.

4.2 Facies B (Fb)

This facies is composed of medium to coarse-grained, moderately sorted, tuffaceous sandstone. The sandstone is thinly bedded sheet-like with normal grading and dis-

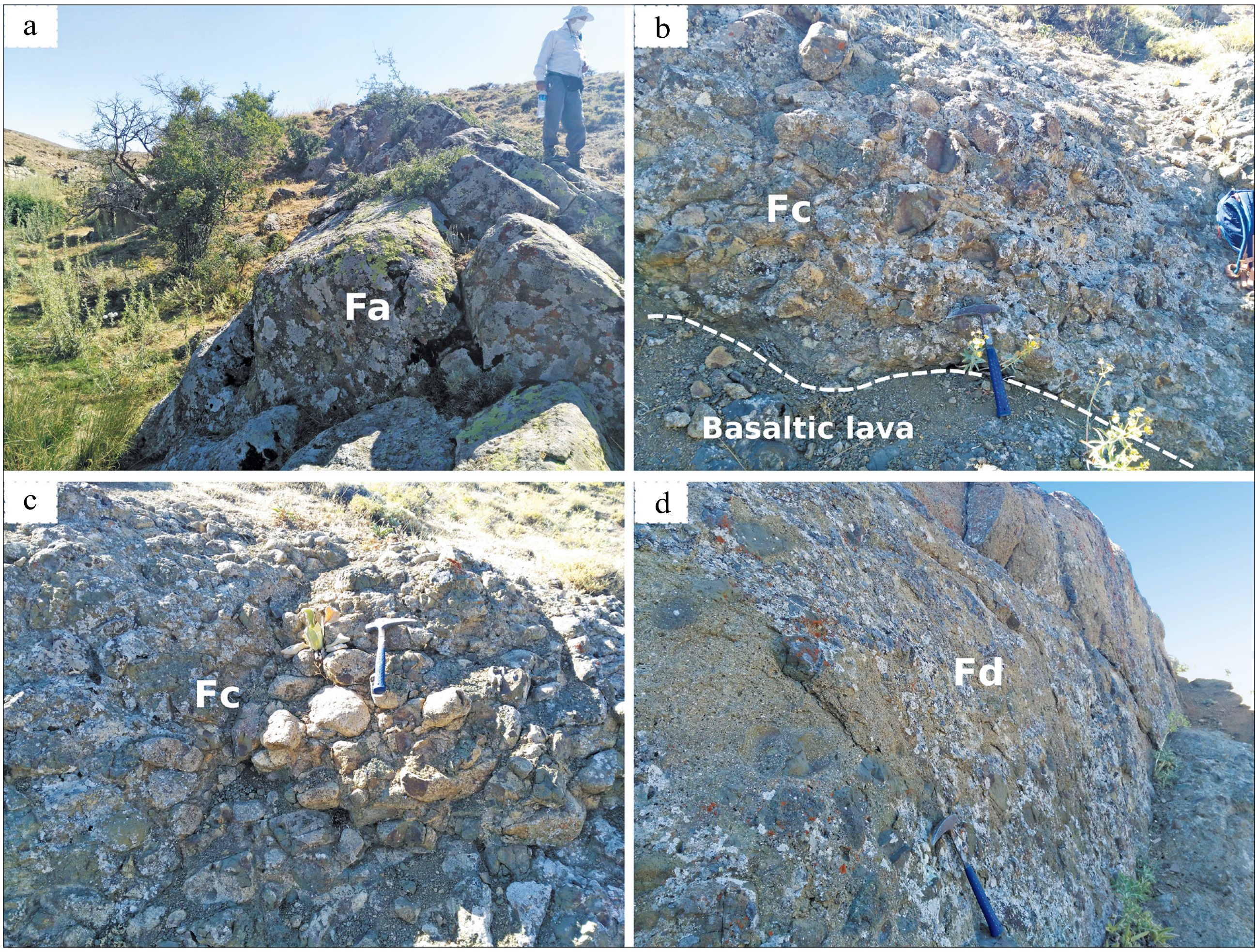

Figure 4: Representative field photographs of various lithofacies recognized on the sedimentary log-1
a) Conglomeratic sandstones (Fa); b and c) Poorly sorted clast supported conglomerates (Fc);
d) Poorly sorted, matrix supported conglomerates (Fd).

plays horizontal planar laminations. The thickness of the facies is around 50 cm.

The presence of normal grading associated with horizontal planar laminations and coarse-grained texture reflects deposition by high-density turbidity currents (**Lowe, 1982; Mutti, 1992**).

4.3 Facies C (Fc)

It is made up of poorly sorted grayish to pinkish clast-supported conglomerates with minor tuffaceous sandy matrix (see **Figure 4b & 4c**). The clasts consisting predominantly of andesite with minor basaltic fragments, display a subangular to subrounded shape, with size varying between 10 cm up to 40 cm. Some lithoclasts are pinkish and show porphyritic texture similar to subvolcanic rocks of acidic composition. This facies is around 3 m thick and shows significant weathering. The absence of clast imbrication and grading is obvious in this facies.

The lack of grading and clasts imbrication, in addition to the disorganized structure of this facies, strongly suggest deposition by subaqueous debris flow (**Mutti, 1992; Miall, 2000; Zanchetta et al., 2004**). The pinkish color probably reflects a significant sediment contribution from a source rock of intermediate to acidic composition. The occurrence of a quartz monzonitic intrusion in the vicinity may support this interpretation (**Mahamidou, 2022**).

4.4 Facies D (Fd)

The facies comprises a massive matrix-supported conglomerate with subrounded to subangular andesitic clasts with sizes ranging from 5 cm to 40 cm (see **Figure 4d**). The matrix consists of coarse-grained gray tuffaceous sandstone, mostly composed of volcanic lithic fragments. The facies is characterized by poor sorting and the absence of distinct grading. Clasts in this facies are moderately weathered with no evidence of imbrication.

The absence of internal structures combined with the disorganized nature of this facies points to a deposition by gravity-induced mass-flows particularly by subaqueous debris flow (**Wagreich, 2003; Zanchetta et al.,**

Table 1: Overview of the key features of volcaniclastic lithofacies within the Ulukışla Formation and their corresponding interpretations (from the sedimentary log 2)

Lithofacies (codes) (Modified after Miall, 2000)	**Description**	**Sedimentary structures**	**Interpretation**
Gmm	Matrix to clast supported polygenic conglomerate with clasts size in the range of 2-50 cm. Angular to subrounded clasts	Poorly sorted, no grading, no imbrication	Volcaniclastic debris flow (**Zanchetta et al., 2004**)
Gcm	Clast-supported conglomerate with sub angular to subrounded andesitic to basaltic clasts with size ranging from 2 to 30 cm	Poorly sorted (Chaotic), No imbrication	Debris flow (**Mutti, 1992; Miall, 2000**)
Sp	Coarse grained to conglomeratic sandstone with subordinate subrounded andesitic granules and cobbles	Massive	High density turbidity current deposit (**Walker, 1978; Mutti, 1992**)
Sm	Coarse muddy tuffaceous sandstone	Massive	High density turbidity current deposit
Sh	Medium, fine to coarse grained tuffaceous sandstone	moderately sorted, normal grading, horizontal planar bedding or laminations	High density turbidity current deposit
FI	Mudstone	Faint laminations	Low energy, suspension fallout (**Mutti, 1992**)

2004). Given the high degree of alteration of the volcanic fragments within the conglomeratic facies, clasts reworking and remobilization likely took a significant part in the sediments routing system. Also, prolonged exposure of the volcanic substrate to weathering in a subaerial environment possibly played a major role in the production of altered volcanic detritus (**Caballero et al., 2020**).

4.5 Facies associations

Five different facies associations have been recognized on the second sedimentary log of the volcaniclastic sequence (see **Figure 6**).

4.5.1 Facies association 1 (FA1): Sh, Sm: Turbidites

This facies association is around 3 m thick and essentially tuffaceous. It consists of intercalations of normally graded medium to coarse muddy sandstone exhibiting thin horizontal planar laminations (Sh) with coarse massive sandstone facies (Sm). The thickness of individual beds varies between 0.5 m and 1 m. In addition, the contacts between the different facies range from transitional to sharp. Bioturbation is absent.

The occurrences of horizontal planar laminations, normal grading, and coarse-grained texture suggest deposition by high-density turbidity currents (**Normark and Piper, 1991; Einsele, 1992; Stow, 1994; Ballance et al., 2004**). The tuffaceous component possibly derived from the alteration of pyroclastic deposits in the nearby source area.

4.5.2 Facies association 2 (FA2): Gmm, Sm: Debris flow deposit

This association is characterized by a sandy matrix-supported conglomerate with a high proportion of andesitic to basaltic clasts (Gmm) (see **Figure 5e**). These clasts, mostly subangular to subrounded, display some evidence of significant alteration. Their size ranges from 2 cm to 50 cm. This conglomerate is poorly sorted, without grading and imbrication (Gmm). It is associated with coarse massive, muddy, tuffaceous sandstone (Sm) not displaying any sedimentary structure (see **Figure 5a**).

The matrix-supported, disorganized, and poorly sorted structure characterizing this facies association is typical of subaqueous volcaniclastic debris flow deposits (**Zanchetta et al., 2004; Mutti, 1992; Miall, 2000**).

4.5.3 Facies association 3 (FA3): Sh, Sm, Sp: Turbidites

This association consists of medium to fine, moderately sorted sandstone with normal grading and horizontal planar laminations (Sh), coarse muddy massive sandstone (Sm), and light grey to pinkish poorly sorted coarse to conglomeratic sandstone with subrounded andesitic granules and cobbles (Sp) (see **Figures 5a & 5b**). The thickness of the conglomeratic sandstone can reach 6 m.

This association is interpreted to represent deposition by high-density turbidity currents (**Lowe, 1982; Mutti, 1992; Ballance et al., 2004**).

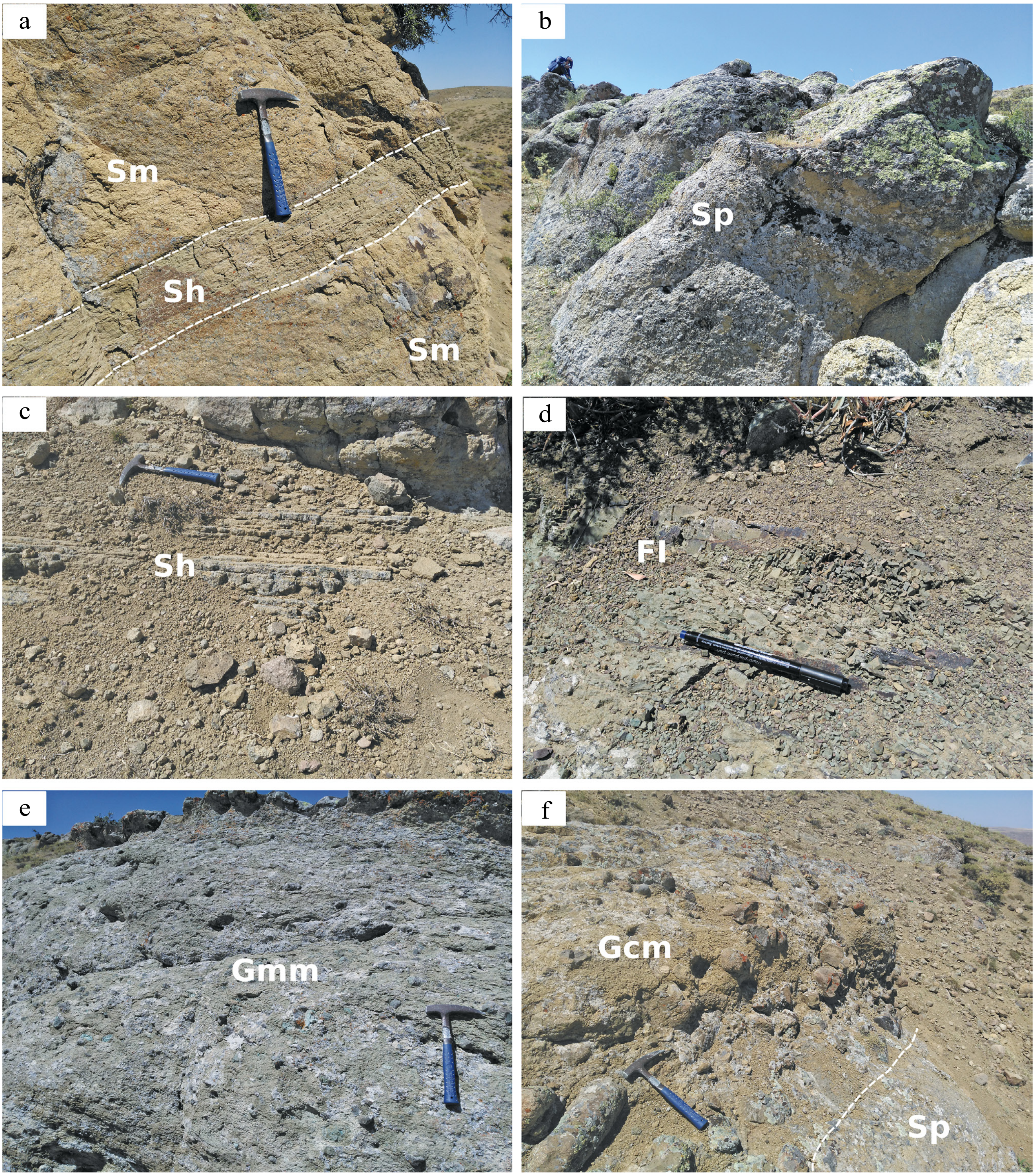

Figure 5: Representative field photographs of different lithofacies recognized on the sedimentary log-2. a) Massive tuffaceous sandstone (Sm), tuffaceous sandstone with horizontal planar laminations (Sh); b) Massive conglomeratic sandstone (Sp); c) Tuffaceous sandstone with horizontal planar laminations; d) Mudstone (FI); e) Matrix-supported volcaniclastic conglomerate (Gmm); f) Clast-supported volcaniclastic conglomerate.

4.5.4 Facies association 4 (FA4): Sm, Sh, FI: Turbidites

The facies assemblage is composed of coarse-grained massive yellowish sandstone (Sm) alternating with fine-grained moderately to poorly sorted sandstone displaying normal grading and horizontal laminations (Sh) (see **Figures 5a & 5c**). A grey laminated mudstone (FI) with no evidence of bioturbation overlies this facies (see **Figure 5d**). The thickness of this association is around 6.5 m.

The occurrence of normal grading reflects sedimentation processes associated with turbidity current (**Bal-**

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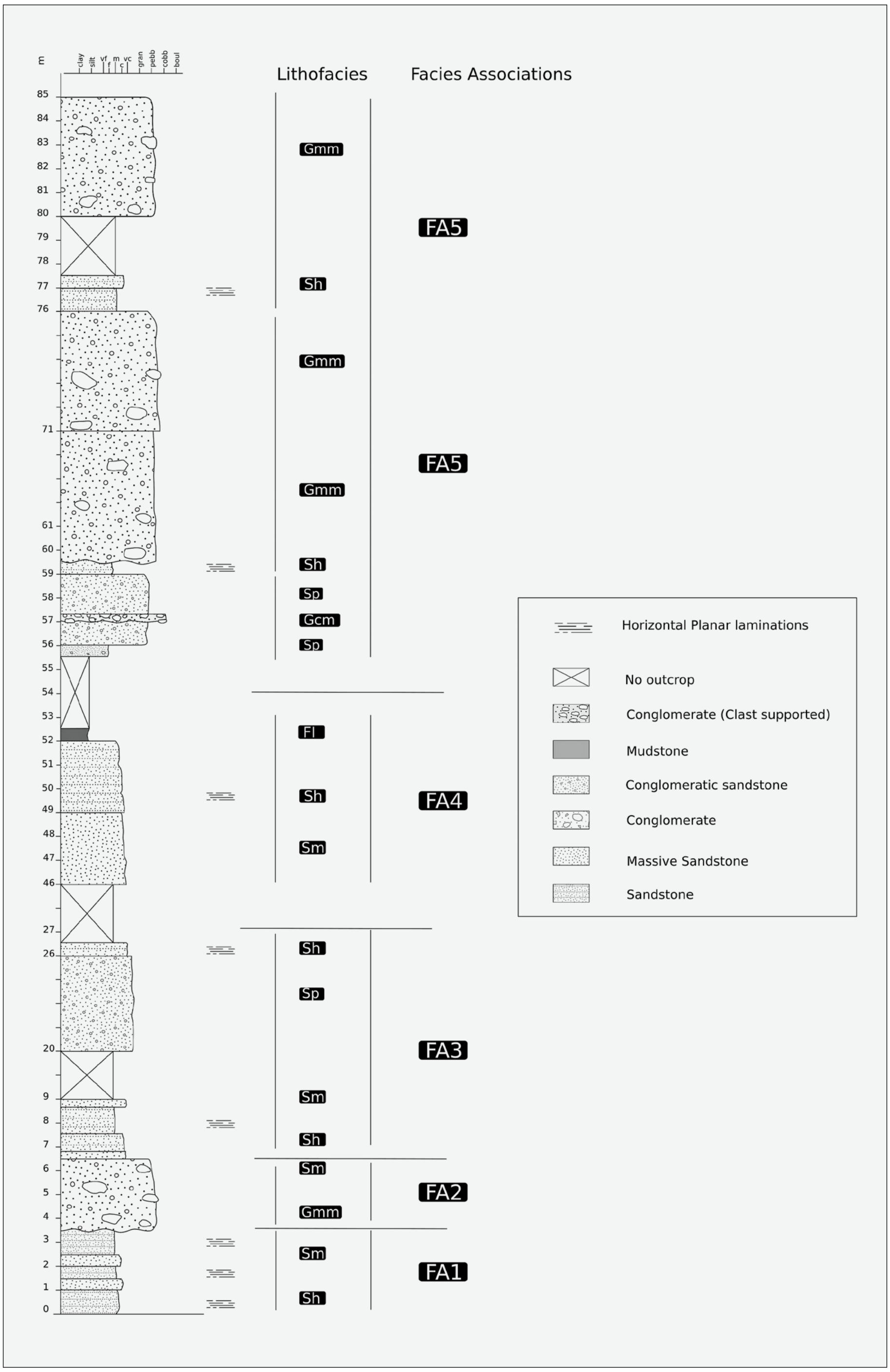

Figure 6: Measured sedimentological log-2
of the Ulukışla volcaniclastic succession (UTM 630284 m E; 4162240 m N).

lance et al., 2004). Accordingly, the massive and the horizontally laminated sandstone represent deposition from high-density turbidity current (**Lowe, 1982; Boggs, 2009**). On the other hand, the overlying mudstone deposited from suspension fallout arising from the waning of low-density turbidity current (**Lowe, 1982; Mutti, 1992; Martinsen et al., 2003; Henstra et al., 2016**). And so, the transition into the mudstone lithofacies implies a significant decrease in sediment supply and a depositional switch into a low-energy environment.

4.5.5 Facies association 5 (FA5): Sp, Gcm, Sh, Gmm: Debris flow deposit

This facies association is around 20 m to 22 m thick and is laterally extensive. It consists of coarse-grained to conglomeratic sandstone with subordinate subrounded andesitic granules and cobbles (Sp) (see **Figure 5b**); poorly sorted clast-supported conglomerate with sub angular to subrounded andesitic to basaltic clasts of size ranging from 2 to 30 cm (Gcm) (see **Figure 5f**); medium

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to fine, moderately sorted sandstone with normal grading and thin horizontal planar bedding with faint laminations (Sh) (see **Figures 5a & 5c**). The association contains a muddy sandstone matrix-supported to clast-supported polygenic conglomerate with clast sizes between 2 cm and 50 cm. This conglomerate is poorly sorted, with neither grading nor imbrication (Gmm) (see **Figure 5e**).

The disorganized nature of the conglomeratic facies (Gcm, Gmm, and Sp) representing the most abundant lithofacies of the assemblage, combined with their chaotic internal structures and the complete absence of sedimentary structures, are highly indicative of deposition by subaqueous debris flow processes (**Ineson, 1989; Nichols, 2009; Lenhardt et al., 2011**). The size of clasts and their shape, mostly sub-angular to subrounded, suggest short-distance transport and redeposition relatively in the proximity of the source.

4.6 Depositional model

The detailed examination of the facies and facies assemblage of the volcaniclastic succession related to the Ulukışla Formation constituted the building block for the construction of a depositional model. In this succession, it is possible to recognize sedimentary features and distinctive depositional patterns that form under particular conditions, giving insight into the accumulation history. The lack of wave-induced structures, combined with the extensive occurrence of debris-flow deposits and turbidite deposits within the volcaniclastic unit of the Ulukışla Formation, provides compelling evidence for the deep-sea nature of the sedimentary sequence. Additionally, the presence of mudstone is suggestive of deposition in a low-energy environment, likely associated with a distal setting. However, debris flow deposits may not be typical of this area. The paleo bathymetry is hard to constrain due to the complete absence of fossils, which provide invaluable information on the paleoenvironmental conditions prevailing during the deposition of the succession (**Reading, 2009**).

The debris flow deposits mostly made up of large subangular to subrounded clasts reaching 50 cm in some areas, are indicative of short-distance transport along with the existence of slope gradient. Andesitic to basaltic fragments making the bulk component of the debris flow deposit are highly weathered, reflecting reworking and re-deposition in a proximal setting adjacent to the source. The matrix and the associated turbidite deposits are mainly composed of volcanic alteration products hinting remobilization and transport of the clastic materials, located on the flank of the volcanic edifice.

The lithological characteristics of the Ulukışla Formation, marked by the occurrence of pillow lavas and tuffaceous horizons within the volcanogenic sequences, strongly point to a volcanism associated with both subareal and submarine conditions (**Mahamidou, 2022**). The presence of basaltic lavas between sedimentary beds suggests sporadic volcanic activities characterized by a period of quiescence during which deposition occurred mostly.

The high tuff content within lithofacies is crucial for understanding the paleoenvironmental conditions prevailing during the basin evolution and allows inference about past volcanic activity (**Carey and Schneider, 2011**). Volcanic activity exerts a notable influence on sedimentary basins because of the substantial volume of material it introduces and its typically much higher supply rate compared to non-volcanic sedimentary systems (**Orton, 1996; Manville et al., 2009; D'Elia et al., 2018**). In many instances, volcaniclastic deposits generally exhibit numerous features indicative of their origin (**Carey and Schneider, 2011**). The tuffaceous component occurring in almost all the facies implies a material supply from sub-aerial volcanic activities either contemporaneously as ash-fall or as remobilization of previously deposited pyroclasts. However, in the latter case, no tuffaceous lithoclast of noticeable size was found in the conglomeratic facies to support the remobilization scenario. The most probable explanation is that a high degree of alteration and erosion must have occurred, which led to the complete fragmentation of the primary pyroclastic deposits into fine particles. These sediments were then mixed with the accumulating volcaniclastic sequences in a submarine environment (see **Figures 7 & 8**). The two interpretations are not mutually exclusive.

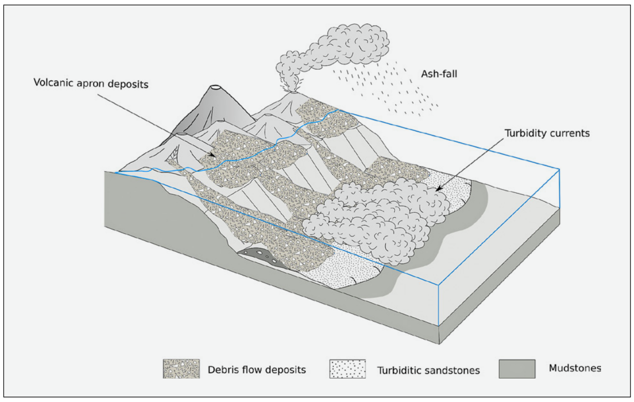

Figure 7: Depositional model of the volcaniclastic sedimentary sequence of the Ulukışla Formation

Sediment gravity flows, especially debris flows and turbidity currents (**Lowe, 1982; Suthren 1985; Mulder and Alexander 2001; Dasgupta 2003; Mulder, 2011; Carey and Schneider 2011; Cisterna and Coira 2014; Shanmugam, 2020**) constituted the main transport agents, thought to have been triggered by slope instability or collapse of volcanic flank affecting the apron deposits. This, in turn, favored volcaniclastic sedimentation at the base of a volcanic slope in a deep submarine setting.

The outcomes of this study should be considered within the context of certain limitations. Given the difficulties stemming from the nature of the outcrops, the

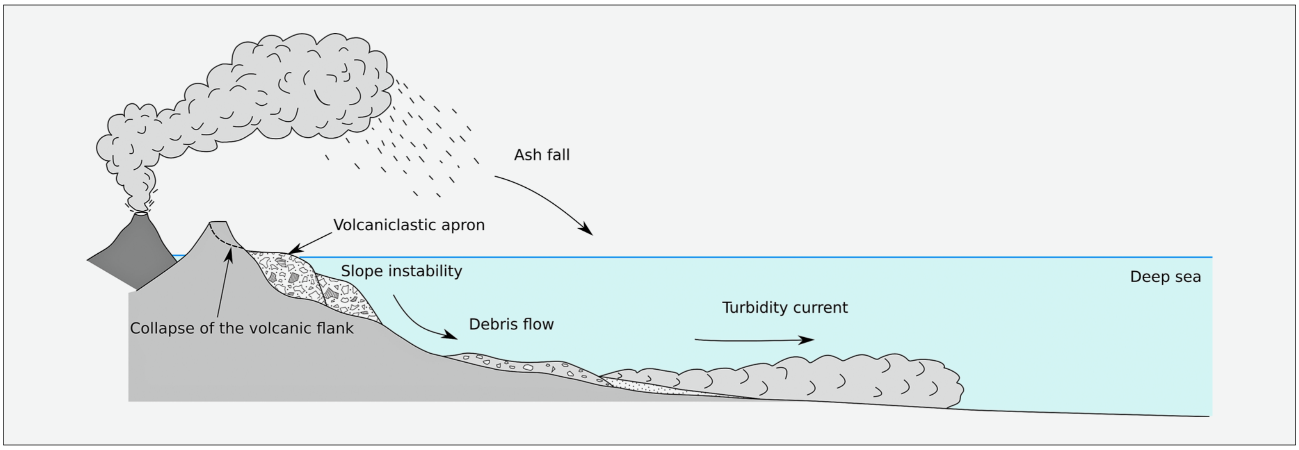

Figure 8: 2D reconstruction model depicting the depositional environment of the Ulukışla volcaniclastic sequence and the associated processes.

sedimentary logs were restricted to a specific area of the formation, rendering the facies analysis vulnerable to possible sampling bias that could arise from the selection of outcrop location. Such results may fail to reflect the complete range of lithofacies variability and distributions throughout the Ulukışla Formation. Consequently, certain lithofacies or sedimentary environments may be overrepresented or underrepresented in the studied area, leading potentially to erroneous interpretations of the geological record. Moreover, paleoenvironmental interpretations based solely on proxies such as grain size, sedimentary structures, and clasts composition may fail to provide the whole picture of the depositional conditions, as post-depositional modifications may affect the primary sedimentary signal. Therefore, further research is needed to overcome these limitations. A more comprehensive sedimentological investigation throughout the Ulukışla Formation supplemented by a detailed paleontological study is expected to increase the accuracy of paleoenvironmental interpretations of the volcaniclastic sedimentary unit. Furthermore, by analyzing the modal compositions of these volcaniclastic rocks, it may be possible to determine and more precisely characterize their source regions. Further research integrating petrographic, geochemical, geochronological, and isotopic data into quantitative provenance analysis holds the potential to offer valuable insight into both the sediment source and the maximum depositional age of the volcaniclastic deposit.

5. Conclusions

The detailed sedimentological study of the volcaniclastic succession of the Ulukışla Formation resulted in the following conclusions:

- Sedimentary facies distribution is suggestive of deposition in a deep-marine proximal environment.
- The sequence consists primarily of gravity flow deposits, especially debris flow deposits and turbidites. The conglomeratic facies are almost entirely composed of basaltic to andesitic clasts derived mainly from the erosion and remobilization of volcanic apron deposits. The size and shape of these lithoclasts are compatible with short-distance transport.
- Slope instability or collapse of the volcanic flank possibly triggered the gravity-induced mass movement of clastic materials down the volcanic slope to the basin.
- The sequence is characterized by a high tuffaceous material content indicative of significant fine pyroclastic particle input. Volcanic ash fall contemporaneous with the deposition is inferred to have constituted an important sediment source.

By examining the sedimentary characteristic of the Ulukışla sequence, this study sheds light on the depositional processes governing the formation of volcaniclastic deposits and refines our understanding of how volcaniclastic sequences accumulate over time. These findings hold significant implications not only for the Ulukışla Basin development but also for the paleogeography of the entire south Central Anatolian region during the Paleogene.

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SAŽETAK

Sedimentologija paleogenskih vulkanoklastičnih naslaga gravitacijskih tokova formacije Ulukışla, južna središnja Turska

Sedimentološka studija vulkanoklastičnih sukcesija naslaga ključna je za dobivanje uvida u zamršenu geološku povijest bazena Ulukışla u južnoj središnjoj Anatoliji. Ova studija, koja se temelji na opsežnoj analizi facijesa dvaju reprezentativnih stratigrafskih horizonata, pokušava rekonstruirati uvjete taloženja povezane s vulkanoklastičnom sedimentacijom unutar formacije Ulukışla. Skupovi facijesa u kojima dominiraju naslage debrita i turbidita pružaju jasan dokaz taloženja u dubokovodnim uvjetima povezanim s obližnjim okolišem. Sedimentne karakteristike ovih naslaga sastavljenih od vulkanogenih konglomerata s bazaltnim do andezitnim klastitima promjenjive veličine, pješčenjaka te podređeno muljnjaka upućuju na podrijetlo iz obližnjih vulkanskih stijena formacije Ulukışla. Gotovo svi litofacijesi pokazuju visok sadržaj tufova što upućuje na moguće doprinose sedimenata iz subaerskih vulkanskih izvora. Glavni kontrolni čimbenici odgovorni za taloženje uključuju procese podmorskih gravitacijskih tokova za koje se smatra da su potaknuti nestabilnošću padina ili kolapsom vulkanskoga tijela. S obzirom na navedeno, rezultirajuće vulkanoklastične akumulacije povezane su s naslagama vulkanskih lepeza. Daljnja istraživanja kao što su prikupljanje geokemijskih i geokronoloških podataka mogu dati ključne uvide u vremenske aspekte i tektonsko okruženje taloženja vulkanoklastične sekvencije Ulukışla.

Ključne riječi:
analiza facijesa, bazen Ulukışla, vulkanoklastična sedimentacija, procesi gravitacijskoga toka, vulkanska lepeza

Author's contribution

Mach houdou A. Mahamidou (1) (Dr): conducted the conceptualization, the fieldwork and the data collection, the facies analysis, the interpretation of results and the article drafting. **Hayrettin Koral (2)** (Prof. Dr.): carried out the conceptualization, fieldwork, data collection, and supervision and acquired the funding. All the authors reviewed and approved the final version.