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STRUCTURAL FEATURES OF THE NİĞDE MASSIF IN THE ÇAMARDI (NİĞDE) DISTRICT

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ABSTRACT

In the Çamardı (Niğde) district, the Niğde Massif is composed of marbles, gneisses, quartzites and amphibolites. These rocks of the Massif have been cut by Cretaceous aged granodiorites. The Paleocene-Eocene aged low-grade metamorphic rocks constitute the autochthonous cover of the Massif. These units are tectonically overlain by the Upper Cretaceous-Paleocene aged flyschoid and island arc type rocks. The Oligocene-Quaternary aged terrestrial and volcanic rocks constitute the youngest units of the district. The metamorphites of the Niğde Massif have been subjected to at least four phase ductile deformation (D_1, D_2, D_3, and D_4) and folding. Through the D_1 phase deformation, the rocks of the Massif have been folded as recumbent-isoclinal folds (F_1-F_2 phase folding) and have gained a structure with a foliation (S_1) which is parallel to the axial planes. Owing to the isoclinal and intense folding of the bedding planes (S_0) of the rocks, bedding transposition have developed and transposed folding structures have formed. Through the D_2 phase deformation, northeast-southwest trending and both northeast and southwest dipping map scale folds (F_3 phase folding) have developed. As a result of the interference of F_1-F_2 and F_3 phase folds, in the district, folds, generated by Type-2 folding, have formed (mushroom folds). Second phase mesoscopic folds are of tight-isoclinal geometry and display asymmetrical and inclined fold feature. In the study area, as a result of D_3 phase folding a large dome structure has developed in the district. And D_4 phase folds have formed map scale synformal and antiformal structures that are trending approximately perpendicular to D_2 phase, plunging southeast and trending northwest-southeast. Through D_4 phase deformation, the cover rocks have been deformed together with the basement rocks (F_5 phase) that they overlie. The microscopic observations show that Cretaceous-Eocene aged rocks have been subjected to low-grade metamorphism in the greenschist facies through D_4 phase deformation. The geometry of the F_5 phase folds reflects cuspate-lobate structure which is the folding type peculiar to the districts where basement rocks and cover rocks have been deformed together.

1. Introduction

The study area comprises Çamardı county of Niğde province and its surroundings (Figure 1). The Kırşehir Massif is one of the most important structural elements in the geological evolution of Turkey (Ketin, 1966; Kırşehir Block, Görür et al., 1984; The Central Anatolian Crystalline Complex, Göncüoğlu et al., 1991). In the area, high grade metamorphic rocks of the Paleozoic-Mesozoic aged Niğde Massif which belongs to the Kırşehir Massif and the Late Cretaceous-aged granodioritic rocks intruded into them constitute the basement of the district (Blumenthal, 1941; Viljoen and İleri, 1973; Kleyn, 1968; Göncüoğlu, 1977; Dellaloğlu and Aksu, 1986).

Most of the studies carried out in the study area and its near surroundings are related to stratigraphy and mineral researches (Yetiş, 1978; Kuşçu, 1992). Detailed structurally weighted works have been carried out in the other sections of the Kırşehir Massif (Seymen, 1981*a,b,* 1982, 1983 and Göncüoğlu, 1991, 1993). There are also some structurally weighted works that have been carried out in the Niğde Massif. Whitney and Dilek (1998) in their work, mention that the Niğde Massif, during the Alpine Orogenesis has been subjected to crustal thickening and associated with it Barrowian type metamorphism; and afterwards depending on the developed magmatism it has been subjected to high temperature-low pressure metamorphism and during this process the Massif has been subjected to extension. Whitney and Dilek (2001) in their work, have carried out studies related to the metamorphism and exhumation of the rocks belonging to Kırşehir, Akdağ, Aksaray and Niğde Blocks which constitute the Central Anatolian Crystalline Complex, and stated in their work that the rocks belonging to the Niğde Massif possess different metamorphism properties compared to the others. Gautier et al. (2002) in their work have tried to reveal the geological evidences of the pre-Eocene exhumation of the Niğde

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Massif. Whitney et al. (2003) in their work, have tried to establish the phases of the regional metamorphism and deformation of the rocks belonging to the Niğde Massif and the emplacement mechanism of the

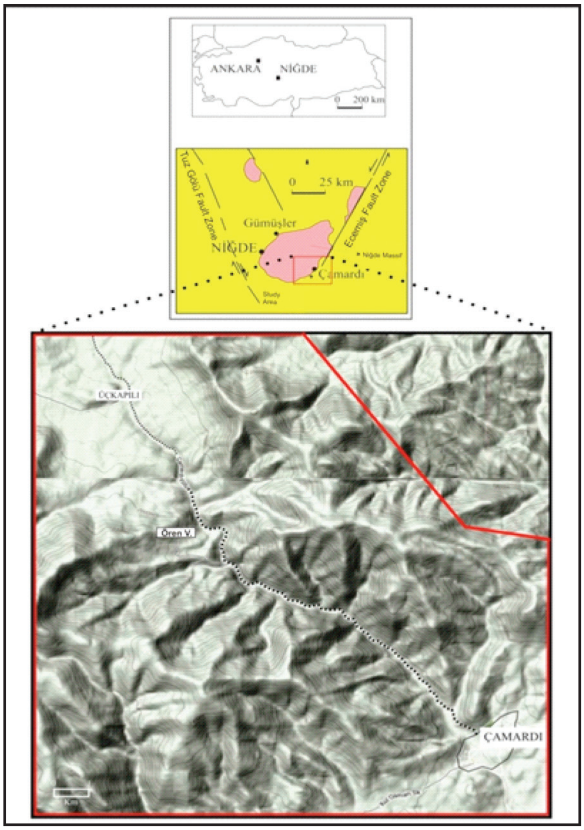

Figure1- Location map of the study area.

Üçkapılı Granodiorite and its age. And Whitney et al., (2007) in their work, have examined the Niğde Massif situated in the region between strike-slip fault zones, according to temperature-deformation properties. They mention that the regional metamorphism observed in the Niğde Massif corresponds to the same age as the other massifs (Kırşehir, etc.), however, its deformation types differ from the deformation types of the other massifs. Umhoefer et al. (2007) mention in their work that the rocks belonging to the Niğde Massif have developed under the influence of yo-yo tectonics which has developed within the region situated between the strike-slip faults and possess also a vertical component and which have given rise to the burial and exhumation of the basement and cover rocks. According to this, the rocks belonging to the Massif have been subjected to burial during Late Cretaceous era and at the same time have been subjected to metamorphism and deformation. And during pre-Tertiary era, the basement rocks have exhumed and given material to the Tertiary aged rocks. And in the second burial phase, the basement and cover rocks have been subjected to re-burial and lower grade metamorphism. Afterward, these units have exhumed again during Miocene (17-9 my). Whitney et al. (2008) in their work have carried out fission track dating on the minerals obtained from the rocks belonging to the Niğde Massif and determined the periods of the burial and exhumation of the yo-yo tectonics. Gautier et al. (2008) mention in their work that the Niğde Massif which constitutes the south edge of the Central Anatolian Crystalline Complex is composed of two structural elements, its lower section is the section that has gained a dome structure by migmatites, and its upper section is composed of metamorphites which display lower metamorphism. They also mention that between these two sections, an extensional detachment zone has developed, and the Niğde Massif has exhumed in this way and has supplied material to the Late Maastrichtian aged units in the Ulukışla Basin which is in the form of a graben and which has developed on the hanging wall by way of southward dipping normal faults developed afterwards. The writers have stated that within the Niğde Massif, the direction of the movement observed in the slip zones which is towards south-southwest and the direction of the regional scale thrusts developed during the Alpine Orogenesis are in conformity with each other. Genç and Yürür (2010) have examined, in their work, the extensional tectonic regime developed during Cenozoic era, along the line between Konya and Yozgat, in the massifs belonging to the Central Anatolia Region. The writers have mentioned the uplift of the rocks of the Massif by the thin skin detachment faults developed in this region after Late Cretaceous era depending on the extensional tectonic regime and have tried to explain the relation of the volcanism observed in the Cappadocia region with these events. Idleman et al. (2014) in their work, have determined the burial and exhumation of the Massif according to $^{40}Ar/^{39}Ar$ analyses carried out on the muscovite and alkali feldspars obtained from the rocks of the Niğde Massif. They have stated that the first exhumation of the Massif has occurred during pre-Paleogene period and the massif and the Paleogene-aged units have been subjected to re-burial and undergone metamorphism in the greenschist facies.

2. Lithostratigraphy

In the Çamardı district, the rocks belonging to the Massif have been differentiated as Gümüşler metamorphites at the bottom, and Aşıgediği metamorphites on the top (Demircioğlu, 2001 and Demircioğlu and Eren, 2003). The rocks of the Massif have been cut by Late Cretaceous aged Üçkapılı Granodiorites (Kleyn, 1968; Viljoen and İleri, 1973; Göncüoğlu, 1977 and 1985). The basement units which have been subjected to high grade metamorphism during pre-Paleocene era have been unconformably covered by Late Cretaceous-Eocene aged rocks that have been subjected to low-grade metamorphism, Pliocene-Quaternary aged slope debris and alluviums.

2.1. Gümüşler Metamorphites

With in the study area, the high grade metamorphic rocks that are prevalent on the south and north limbs (Figure 2) the map scale recumbent fold have been called within 'Niğde Series' by Tromp (1942), 'Lower Series' by Kleyn (1970), and 'Maden formation' by Viljoen and İleri (1973). And Göncüoğlu (1977) has named these rocks Gümüşler formation in the detailed works that he carried out in the Niğde Massif.

The gneisses that constitute the most part of the Gümüşler metamorphites display extensive outcrops in the study area. They have thicknesses ranging from several centimeters up to hundreds of meters. Their outward appearance is gray, brown, and black colored and they display distinct foliation planes. Whitney et al. (1998) state in their work that the gneisses within the rocks belonging to the Massif show sillimanite gneiss feature and indicate high grade metamorphism depending on the regional metamorphism. In Demircioğlu (2001) work, large quantities of sillimanite have been encountered during the petrographic examination carried out on the gneisses in the Gümüşler metamorphites. As Demircioğlu and Eren (2000), Demircioğlu (2001), and Eren and Demircioğlu (2003) have stated in their work, Umhoefer et al. (2007) and Idleman et al. (2014) mention in their work that the Paleocene-Eocene aged units within the study area have been subjected to low-grade metamorphism.

One of the rocks which show alternation with the gneisses and amphibolites is the marbles that possess thicknesses up to 20 meters and display various outward appearances. These marbles have been named 'Asmaca marbles' in the work of Demircioğlu (2001). The crystal sizes of the marbles having colors varying from light yellow to white range from macrocrystalline to microcrystalline. And glassy white and yellowish colored quartzites are distinguished as Alıçlıboyun quartzite (Demircioğlu, 2001). These quartzites display alternations with the gneisses and marbles as thin bands.

2.2. Aşıgediği Metamorphites

The metamorphic rocks which crop out in the core of the recumbent fold in the middle section of the study area have been examined within Niğde series by Tromp (1942) and within Niğde Complex by Blumenthal (1952). The same unit has been named 'Upper series' by Kleyn (1970), 'Kılavuz formation' by Viljoen and İleri (1973), and 'Aşıgediği formation' by Atabey et al. (1990). Tromp (1942) has given their age as Devonian.

The marbles constitute the most predominant rocks of the Aşıgediği metamorphites which constitute the uppermost horizon of the Niğde Massif. Alternating with the marbles, metacherts, amphibolites and quartzites are also present within the unit. Demircioğlu (2001), in his work, has named these amphibolites showing alternations with the marbles 'Çıngıllıtepe amphibolites'. They possess a highly folded structure on the map scale, too (Figure 2). They display outward appearances having colors varying from dark brown to black. Their schistosity planes are fairly conspicuous. These planes are in a position parallel to the bandings in the marbles with which they show alternation. This situation is an indication which shows that they have been subjected to the same deformations and metamorphism as the marbles. Their thicknesses range from several centimeters up to hundreds of meters. The metacherty marbles are situated at the transition zones with the Gümüşler metamorphites on each limb of the recumbent fold. The metacherty horizons can show thicknesses from 1 centimeter to 15 centimeters. They present light brown-beige colored appearances. They show competent material feature within the marbles. They have gained boudinage and pinch and swell structure feature depending on the tensions.

2.3.Üçkapılı Granodiorite

The Üçkapılı Granodiorite most prevalently crops out in Üçkapılı village and its surroundings to the north of the study area (Göncüoğlu, 1977 and 1985). In the south it is observed as smaller intrusions. Their appearance is highly fractured and they show widespread alteration. The granodiorite which cuts the metamorphites belonging to Massif is covered by Paleocene-Eocene aged rocks (Figure 2). According

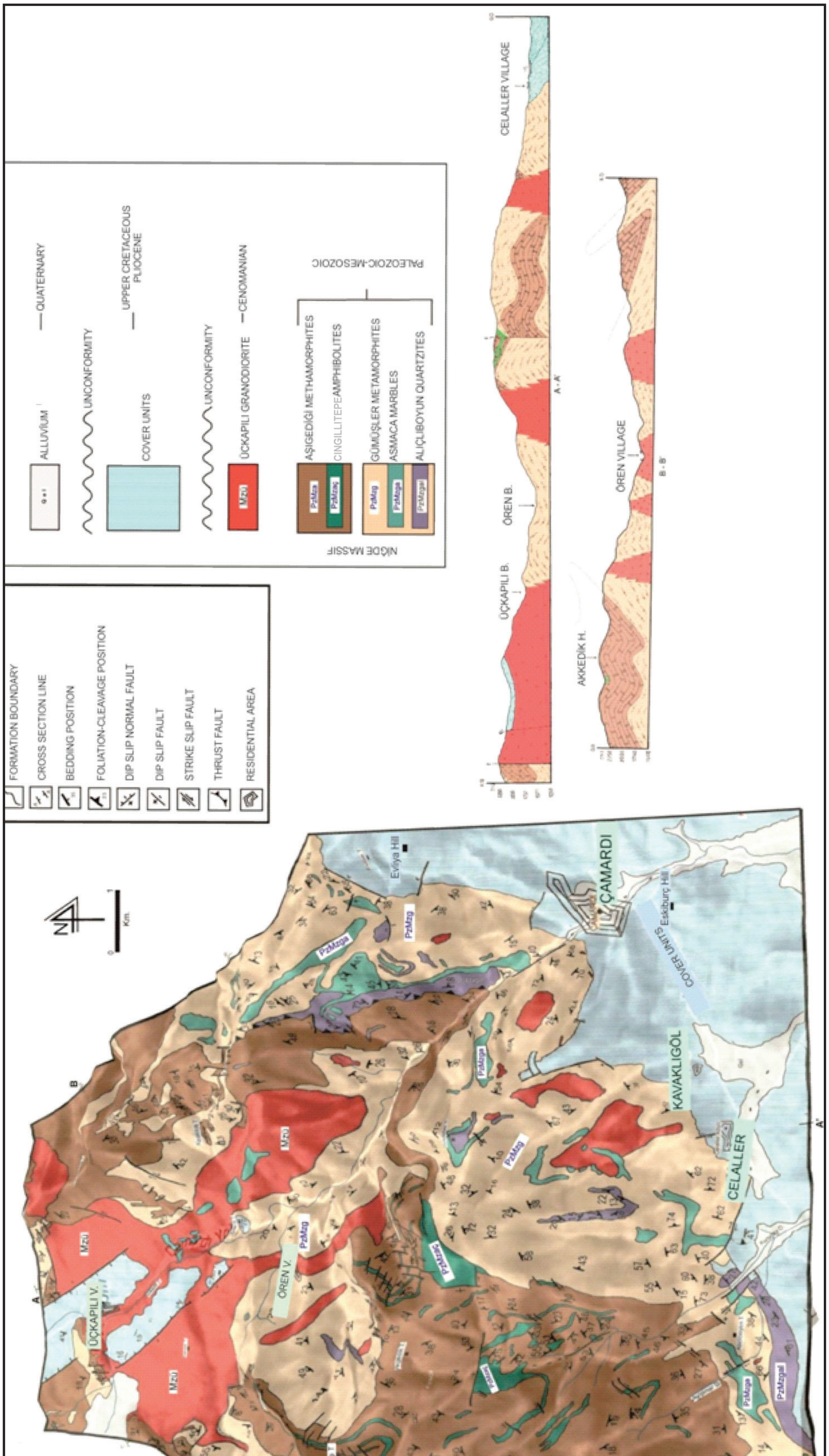

Figure 2- geological map of the study area and geologic cross sections (Demircioğlu, 2001).

to the study of Göncüoğlu (1977 and 1985) its age is Cenomanian-Maastrichtian.

2.4. Cover Units

In the study area, the Niğde Massif is unconformably covered by Late Cretaceous-Quaternary aged units. The first assemblage of the cover units is constituted by the Celaller and Eskiburç groups which have developed depending on the opening and closing of the Ulukışla Basin in the district. They unconformably cover the metamorphites belonging to the Niğde Massif and the Üçkapılı Granodiorite (Figure 3).Within the Çamardı formation there area pebbles belonging to the Üçkapılı Granodiorite.

The Paleocene-Eocene aged Celaller Group comprises the Paleocene-Eocene aged Çamardı formation and the Eocene-aged Evliyatepe formation. The Celaller Group is tectonically overlain by the Eskiburç Group in the district. The Eskiburç Group is composed of Late Cretaceous-Paleocene aged Ulukışla migmatites and Paleocene-Eocene aged Ovacık formation. They show lateral-vertical transitions with each other. These units have been subjected to low-grade metamorphism (Demircioğlu and Eren, 2000, 2001 and Demircioğlu and Eren, 2003). The above-mentioned units are unconformably covered by the Oligocene-Quaternary aged neo-autochthonous post-orogenic rocks in the district.

3. Structural Geology

According to Göncüoğlu et al. (1981), the rocks belonging to the Niğde Massif are Paleozoic-Mesozoic aged and have been influenced by orogenic activities prior to Late Cretaceous era. Göncüoğlu (1981) states in his work that the rocks belonging to the Massif have been folded and faulted through a deformation having at least 3 phases, one of the phases solid and the other two plastic. Atabey et al. (1986) states that the Caledonian and Hercynian Orogenesis have influenced only the Niğde Massif; but, the Alpine Orogenesis have influenced both the Massif and the young units covering the Massif. Henden (1983) states in his work that the main structure in the district is constituted by dome structures depending on the granitoid intrusion.

For the detailed structural analysis of the Massif, the structural map of the district has been constructed and the area has been separated into sub-areas depending on the trend of map and mesoscopic scale structures (Figure 4). Accordingly, the study area has been separated into four sub-areas as the Ortakaya sub-area, the Akgedik sub-area, the Kartalkaya sub-area, and

Figure 3- The contact between Üçkapılı Granodiorite and Çamardı formation.

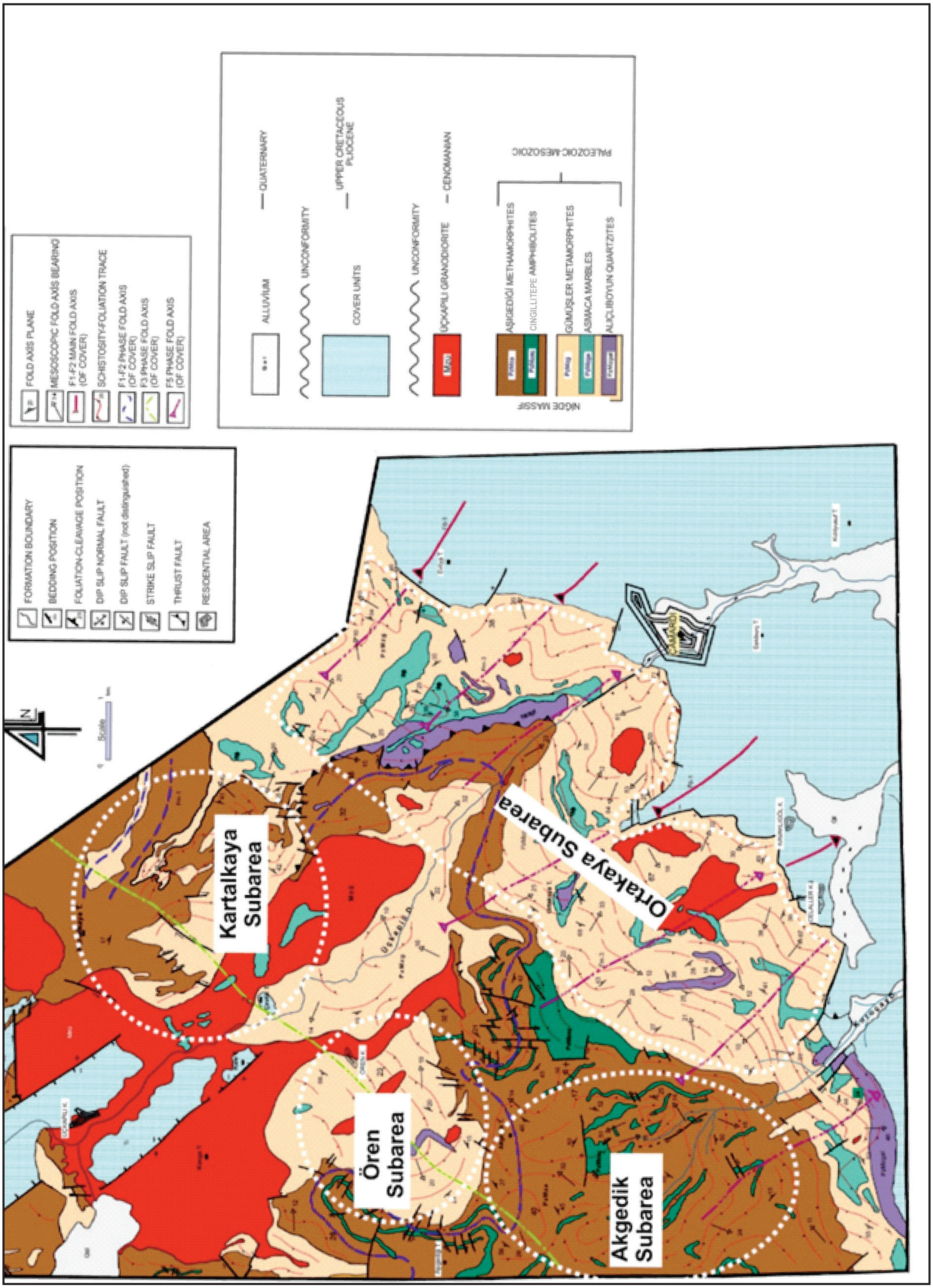

Figure 4- Structural map of the study area and sub-areas.

the Ören sub-area. Field observations and mesoscopic analyses demonstrate that the metamorphites of the Niğde Massif have been subjected to a ductile deformation (folding) having at least five phases (F_1, F_2, F_3, F_4, F_5) (Figure 4).

Through the D_1 phase deformation (F_1 phase folding), the rocks of the Massif have been subjected to map scale recumbent-isoclinal folding and have gained a structure with a S_1-foliation (with gneissose banding) which is parallel to the fold axis planes (Figure 5a). F1-phase folds are encountered mostly in the sections of the study area where there is marble/metachert alternation (Figure 5b). The folds of this phase are generally in the form of recumbent-isoclinal folds and in appearance present similar fold features.

Again through D_1 phase deformation, in the district, (coaxial) Type-3 type folded folds have developed as a result of the overlying of the coaxial F_2 phase folds the F_1 phase folds (Figure 5 c, d).

During this phase, as a result of the isoclinal and intense folding of the bedding planes (S_0) and the rupture of the more competent material within the rock, bedding transposition has developed and transposed folding structures have developed (Figure 5e, f and Figure 6a). The metacherts in the marbles have gained pinch and swell structure depending on the extension during folding (Figure 6b). The metacherts occasionally display pseudo-bedding feature, too (Figure 6c). These structures prove that in the Çamardı district, notwithstanding the intense metamorphism, the primary structures have been preserved.

Through D_2 phase deformation, northeast-southwest trending and dipping both northeast and southwest map scale folds (F_3 phase folding) have developed (Figure 4).

As a result of the interference of F_1-F_2 and F_3 phase folds, in the district, folds, generated by Type-2 folding, have formed (mushroom folds) (Figure 6b) . Second phase mesoscopic folds are of tight-isoclinal geometry and display asymmetrical and inclined fold feature.

In the study area, as a result of D_3 phase folding a large dome structure has developed in the district (F_4 phase folding). This folding is most probably the result of the deformation that the Üçkapılı Granodiorite formed while it was intruding into the rocks of the Massif. D_4 phase deformation has deformed both the Massif and the Paleocene-Eocene aged cover rocks simultaneously (Figure 4). The folds which have formed during this phase (F_5 phase folding belonging to the Massif) have formed map scale synformal and antiformal structures that are trending approximately perpendicular to F_3 phase, plunging southeast and have northwest-southeast trend.

As a result of this deformation (D_4), cuspate-lobate type structures have developed which are peculiar to the districts where basement rocks and Paleocene-Middle Eocene aged cover rocks have been deformed together. As a result of the folding, the cover units have formed tight synclinals inside the rocks of the Massif, and the basement rocks have formed, towards the cover units, map scale folds having broad and round anticlinal geometry (Figure 4). The Üçkapılı Granodiorite in the area has gained meta granodiorite feature and fracture systems have developed in it.

In the study area, for the geometrical analysis of the map scale folds, foliation (gneissose banding), banding, and schistosity measurements have been taken from the rocks belonging to the Massif, and these have been evaluated on the stereographic projection depending on the sub-areas (Figure 7).

In the Kartalkaya sub-area, when the banding measurements of the Aşıgediği marbles and the banding measurements in the quartzites are jointly evaluated, fold axis trends are observed in almost every direction (probably depending on the dome structure) (Figure 4). However, the general fold axis trend in this area has been determined as N58E/20NE (Figure 7a).

In the Akgedik sub-area, when the bandings observed in the marbles and the measurements of the schistosity planes in the amphibolites are evaluated on the diagram, the general fold axis trend in this area has been determined as N44E/12SW (Figure 7b).

These fold axis trends obtained from the Kartalkaya and the Akgedik sub-areas correspond to the F_3-phase folding phase.

It is observed that the mesoscopic fold axis trends determined in the Ören sub-area are in every direction (Figure 4). Also, when the fold axis trends measured

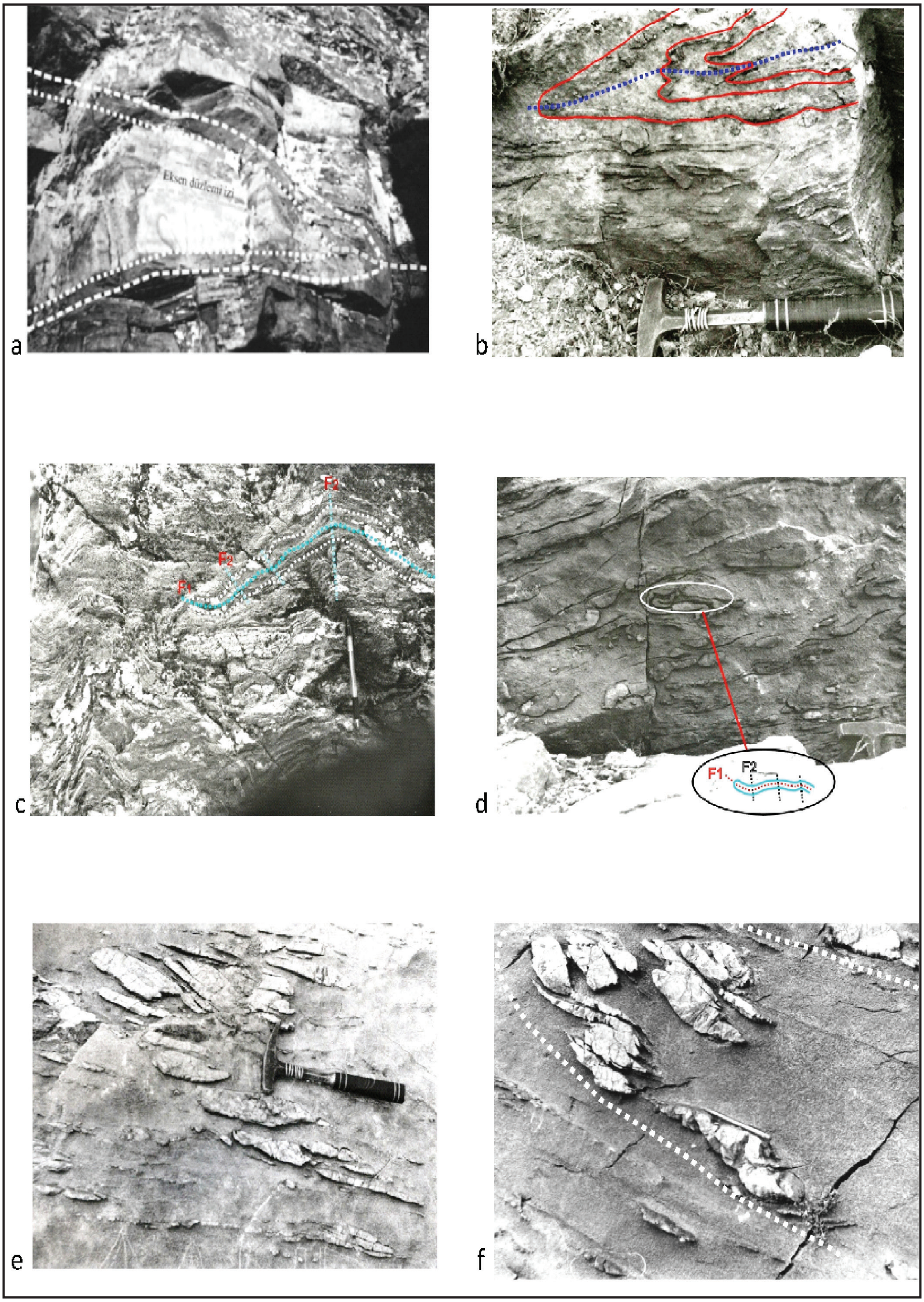

Figure 5- Folds and structural elements observed in the rocks of the Massif.

a - Recumbent-isoclinal folding and structure with S1-foliation (with gneissose banding) parallel to the fold planes b- F_1 phase folds in sections with marble-metachert alternation c, d - (coaxial) Type-3 type folded folds developed in the district as a result of the overlying of the coaxial F_2 phase folds the F_1 phase folds e, f - bedding transposition-transposed folding structures developed as a result of the isoclinal and intense folding of the bedding planes (S_0) and the rupture of the more competent material within the rock.

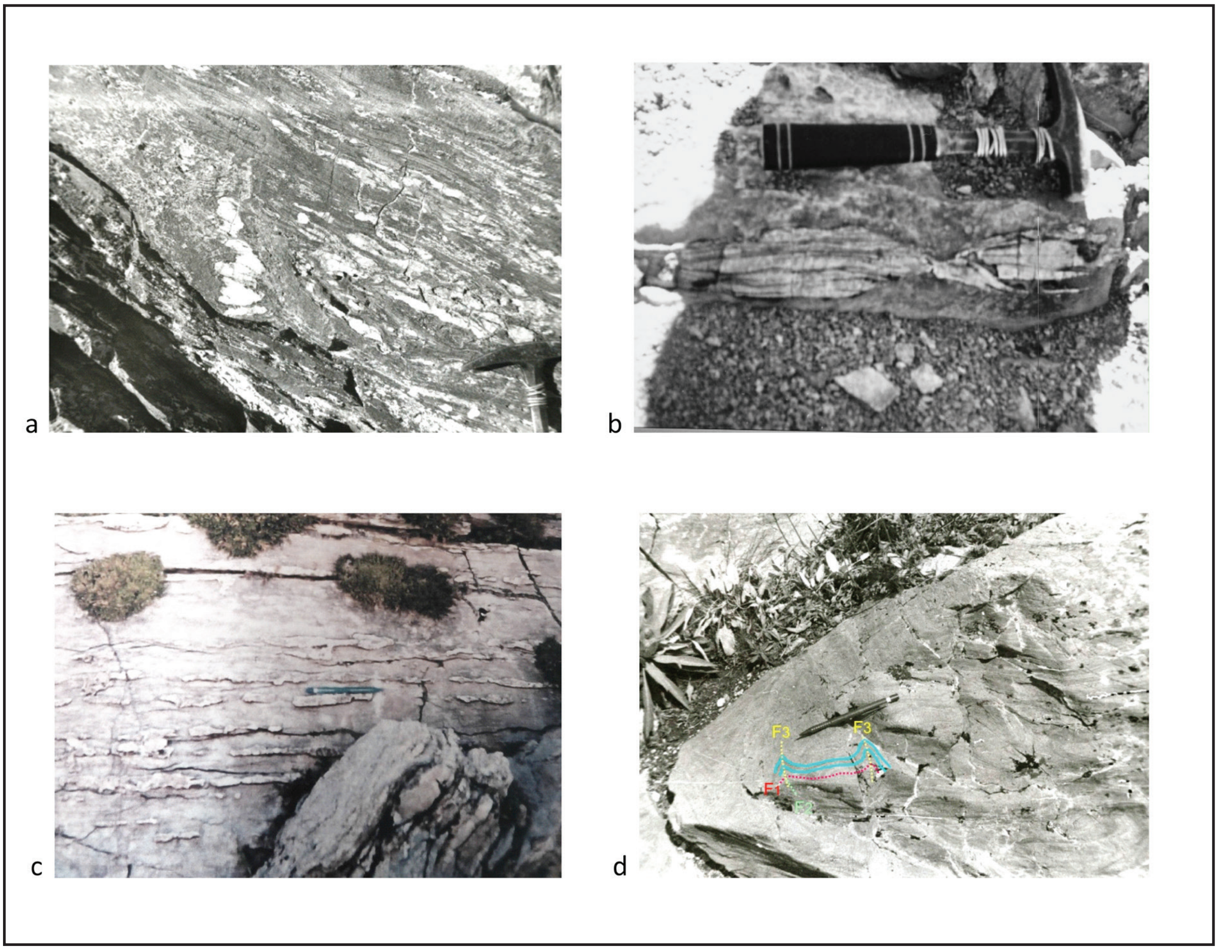

Figure 6- Structures observed in the rocks of the Massif.
a. Bedding transposition and transposed fold structures observed in the gneisses within the Gümüşler metamorphites,
b. In the Aşıgediği metamorphites, pinch and swell structure depending on the extension in the metacherts within the marbles,
c. Pseudo-bedding observed in the metacherts,
d. Type-2 type folded folds (mushroom folds) developed as a result of the interference of F_1-F_2 and F_3 phase.

in this area are evaluated on the diagram, it has been determined that the fold axis trends are in every direction (Figure 7c). This situation can be related to the doming developed in the area depending on the intrusion of the Üçkapılı Granodiorite, and the folding developed depending on it (D_3-phase deformation). It is thought that this doming has also caused the folding of the rocks belonging to the Massif (F_4-phase folding).

In the Ortakaya sub-area, the general fold axis trend obtained as a result of the evaluation of the foliation measurements, taken from the gneisses belonging to the Gümüşler metamorphites , on the diagram, has been determined as N56W/14SE (Figure 7d).

When the mesoscopic fold axes measured in the same sub-area are evaluated on the diagram, it is observed that the general trends of the fold axes are tending northwest-southeast and the plunge of these axes are toward southeast (Figure 7e). These fold axis trends give the F_5-phase fold axis trend of the Massif, and are in conformity with the map scale fold trends obtained from the Paleocene-Eocene cover rocks (the fold axes obtained from the bedding positions measured from the formations of the Celaller Group and the Eskiburç group and belong to F_1 and F_2 phase of the cover units) (Figure 7f and Figure 7g) (Eren and Demircioğlu, 2003). As to the fold axis trends of the cover units, it has been found as N43W/28SE in the units of the Celaller group (Figure 7f) and as N46W/40SE in the units of the Eskiburç group (Figure 7g) (Eren and Demircioğlu, 2008).

When the general banding measurements obtained from the marbles and the quartzites belonging to

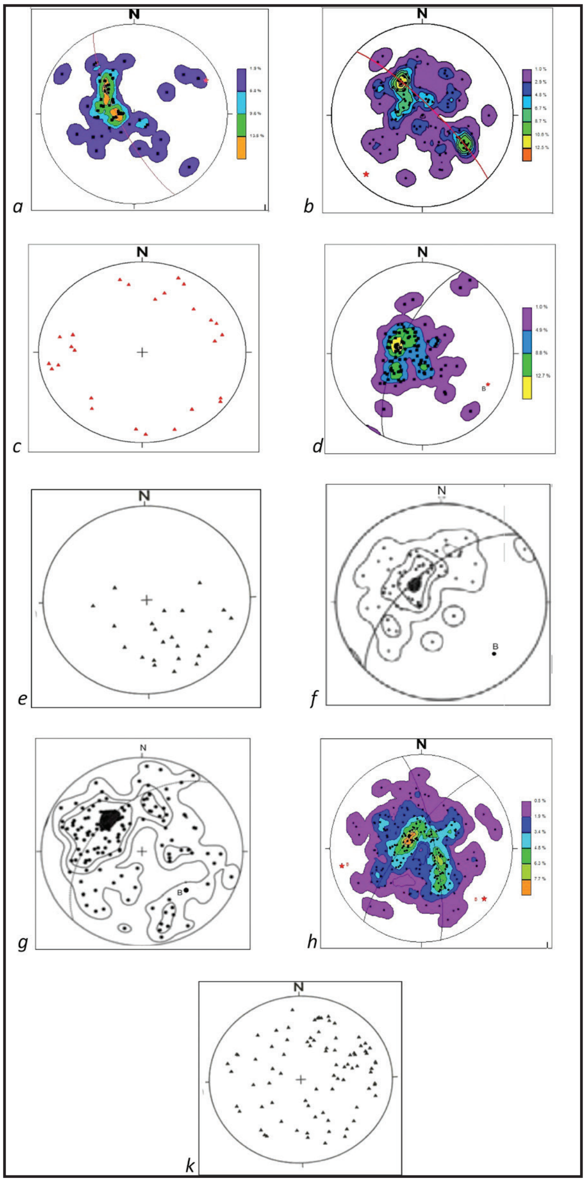

Figure 7- Lower hemisphere projection diagrams of the mesoscopic data in the study area.

the Aşıgediği metamorphites have been evaluated on the diagram, the general fold axis trends have been determined as N52W/16SE and N78E/15SW (Figure 7h). Of these fold axis trends, the fold axis with N52W/16SE trend is in conformity with the fold axis trend obtained from the Ortakaya sub-area (F_5 phase folding). And the fold axis with N78E/15SW trend shows similarity to the fold axis trend (F_3-phase folding) obtained from the Akgedik sub-area.

In the study area, when the mesoscopic fold axes trends measured in the rocks of the Massif are evaluated on the diagram (stereographic projection), it is observed that the fold axes trends show distribution in every direction (Figure 7k). This situation is an indication which shows that the rocks of the Massif have been subjected to deformation in every direction and depending on it to polyphase folding.

In the study area, there are some situations showing similarities and differences with the previous studies. In the previous studies; there are differences between the geologic map used by Gautier et al. (2002, 2008), Whitney et al. (2003, 2007), Idleman et al. (2014) and the geologic map used by Demircioğlu (2001). In addition, while the studies carried out after 2000 are generally related to the burial-exhumation and the metamorphism of the Niğde Massif, this study aims to reveal the polyphase deformation of the rocks belonging to the Massif and the developed fold-fold interference types. During the burial-exhumation, yo-yo tectonics and metamorphism of the rocks belonging to the Massif, the rocks have been subjected to polyphase folding and fold interference structures have formed.

In the area, during the thin section examinations carried out on the metasandstones taken from the Paleocene-Eocene aged units, which have been mentioned in this study as cover units without giving into detail, asymmetrical pressure shadow structures have been determined that have developed in the ductile detachment zones. These structures might be the indication of a detachment fault developed after Middle Eocene. In addition, within the metasandstones of Middle Eocene aged Evliyatepe formation, the existence of outcrop scale sigmoidal veins developed in the brittle-ductile slip zones has been determined (Demircioğlu, 2001). In the rocks of the Massif, a thrust fault developed on the map scale is present. It is thought that this thrust has formed during the compressions causing map scale folding (D_4-phase deformation).

According to this study, differing from the previous studies, in the study area, the metamorphic rocks of the Niğde Massif have been subjected to a deformation with at least 4 phases (D_1-D_2-D_3-D_4). 5-phase folding (F_1-F_2-F_3-F_4-F_5) has developed in the rocks belonging to the Massif. Within the rocks of the Massif, depending on the deformations and foldings, mesoscopic fold axes have developed which are trending-plunging in every direction.

Through D_1 phase deformation, the metamorphic rocks have been subjected to recumbent-isoclinal folding and they have formed coaxial Type-3 type fold structures with the development of F_1 and F_2 phase foldings.

Through D_2 phase deformation, the rocks of the Massif have been re-folded (F3 phase folding) and as a result of the fold interference, they have formed mushroom-shaped Type-2 type folds. According to the data obtained from the sub-areas, the general fold axis trends belonging to this phase have been found as N58E/20NE and N44E/12SW.

D_3 phase deformation has probably developed during the intrusion of the Üçkapılı Granodiorite into the rocks of the Massif and has re-folded the rocks of the Massif (F_4 phase folding). During this phase, folds have formed which are trending and plunging in every direction.

Through D_4 phase deformation, the rocks of the Massif have been subjected to folding (F_5 phase folding). The fold axis trends (N58W/21SE) obtained from the rocks of the Massif and the F_1-F_2 phase fold axis trends (N43W/28SE and N46W/40SE) of the cover units are compatible with each other.

Again during this phase, the units of the Massif and the units of the cover have been together subjected to folding and have formed cuspate-lobate structures.

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