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Comparison of Iberian Pyrite Belt (IBP) and Central Pontides: Preliminary geological, Tectonic and Mining Geology findings

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Abstract: *In this study, some mine sites in the region were investigated and literature studies were carried out to determine and evaluate the origin and formation pattern of the massive sulphide mineralizations in the Central Pontides. This study is the first attempt to characterize the geological and structural environments suitable for the mineralization in the region and to compare the region with the geological and tectonic structure of the Iberian Pyrite Belt (IBP) and to identify the Central Pontide Pyrite Belt (CPPB).*

Keywords: *Iberian Pyrite Belt, Central Pontides,Central Pontide Pyrite Belt (CPPB),massive sulphide,mineralization*

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I. Introduction

Taşköprü-Durağan basin is located between the elevation of Çangaldağ bordering southern margin of Sinop basin in the north and the elevation of Elekdağ in the south .The geometry of the basin roughly represents a concave arch to the north (Fig. 1).Today, this basin is present at either side of Gökırmak valley and made of Upper Cretaceous-Pleistocene sediment and ebonite group. The sequence in the basin forms an asymmetric synclinal inverted to south extending east-to-west. The northern wing of this fold is inverted to south due to Ekinveren reverse fault, and the southern wing is transgressive concurrent over Kargı Massive in the south. Units in the basin basically start with an Upper Cretaceous pelagic limestone and shift to Upper Cretaceous-Paleocene volcanic-volcanogenic units, continue with Eocene-Oligocene shallow marine terrestrial sediments, and end with Pleistocene units (Fig. 2).

There are two basic stratigraphic units in the basin. They are a) Palaeozoic metamorphics, b) Liassic weak metamorphic Akgöl formation. The Palaeozoic bedrocks are extending from E to W. They are lithologically composed of chlorite, epidote, graphite, actinolite schist, marble and clay schist and metaradyolarit and cut in partial by quartz veins, and granite and granodiorite. Akgöl formation, which is inharmoniously formed over this metamorphic foundation, is alternated by quartzite and dark grey-black mildly metamorphosed shales (Sarı,1990).

Taşköprü-Durağan basin in the Central Pontides among Pontides tectonic units is an overthrust and fold belt. The area contains reverse faults formed under compressional forces, strike-slip faults, folded constructs, and joint systems. Compressional forces affected the tectonic evolution whereas tensional forces caused to form normal faults. The Taşköprü-Durağan basin is an east-west orientation convex arch shape. Forming the northern border of the basin, Ekinveren reverse fault acts on units of the basin, which form an asymmetric synclinal extending east-to-west. The Taşköprü-Durağan synclinal is in general an asymmetric synclinal and formed by the impact of Ekinveren Fault that affects the entire basin. Looking like a convex arch, the Taşköprü-Durağan basin represents a folded symmetric structure in the west due to lower effect of Ekinveren Fault and this portion of the basin being larger. To further east to the basin, an asymmetric synclinal structure appears due to increased effect of Ekinveren Fault on units. Moreover, the northern wing expresses an inverted asymmetric synclinal shape between Boyabat-Durağan. The northern wing has a high angle whereas the southern wing has a lower angle where the synclinal is asymmetric. As Ekinveren Fault displays an imbricate structure around Hanönü, deformation is higher in this area than that of eastern and western sections (Sanğu, 2010).

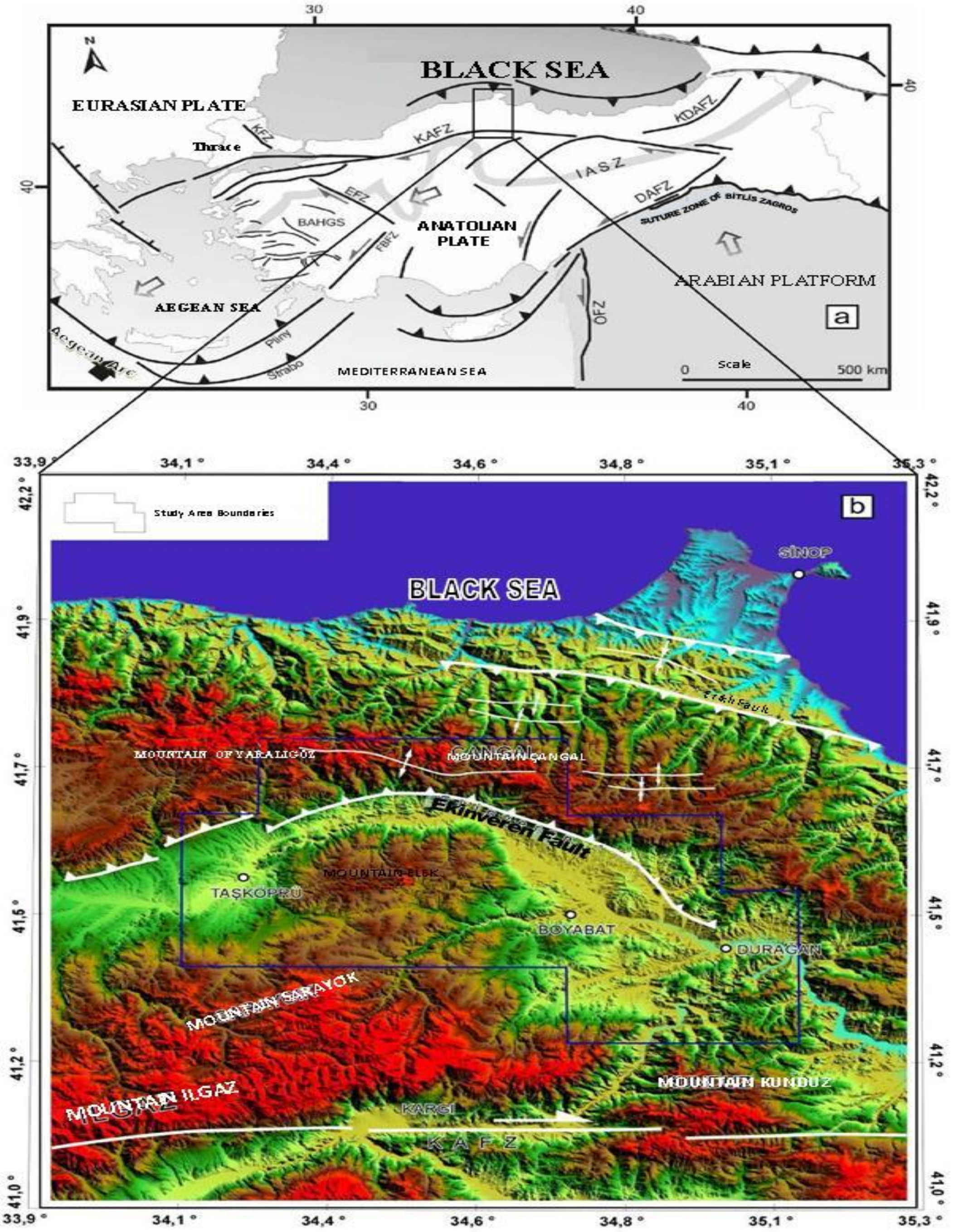


Fig. 1. a) Major tectonic structures of Turkey and surrounding (KAFZ: Northern Anatolia Fault Zone, KDAFZ: Northeast Anatolia Fault Zone, DAFZ: Eastern Anatolia Fault Zone, BAHGS: Western Anatolia Horst-Graben System, FBFZ: Fethiye Burdur Fault Zone, EFZ: Eskişehir Fault Zone, ÖFZ: Ölüdeniz Fault Zone, IASZ: İzmir-Ankara Suture Zone) (Gürer et al., 2003) b) Several structural elements of Central Pontides and area of works (Sanğu, 2010)

II. Geological Evolution of Central Pontides

The Paleo-Tethys was closed in the Jura when southern margin of Eurasian plate and Cimmerian Plate converged, forming a new oceanic basin, known as Neo-Tethys, in the south (Şengör, 1984; Görür et al., 1993). Eurasian plate and Cimmerian Plate completed their evolution and became a continent; and red conglomerate of Bürnik formation, a fluvial environment sediment, is deposited on the basement rocks at the joint of these plates. While Neo-Tethys continues to open, carbonates of İnatlı formation are deposited in the shell to the south of Eurasian plate in the Upper Jura (Fig. 2). In the Lower Cretaceous, the passive continental margin becomes an active one when Tethys Oceanic lithosphere starts to subduct under Eurasian plate (Aydın et al., 1986; Görür et al., 1993). Faulting starts in this active margin with tensional regime to create horsts and grabens (Yılmaz and

Tüysüz, 1984; Yılmaz et al., 1997). The Black Sea basin should be opened this tensional system in Aptien-Albien (Görür, 1988).Due to this subduction in the south, a magmatic arch is formed with back-arch tension in the Late Cretaceous in the area where the Black Sea is located today (Yılmaz and Tüysüz, 1988). In the meanwhile, intermediate and divergent turbidities of Çağlayan formation start to deposit with sin-tectonic sedimentation on grabens as shallow sea deepens. Beach sands, divergent turbiditic sandstones and silty marls are deposited on horsts (Aydın et al., 1995). With activity of faults making up graben-horst system, olistostrome of carbonate of İnaltı formation levels are created in the Çağlayan formation.

In the Late Cretaceous, depression and deepening continue at the southern margin of Eurasian plate, the floor of the Black Sea fully becomes an ocean and Pontide continent is separated from Eurasian plate (Saner, 1980). With deepening of the area, deep marine micritic limestone of Kapanboğazı formation is deposited on the Çağlayan formation and older units in a parallel inconsistency. The oceanic lithosphere of northern Tethys in the south subducts under the Pontide continent, the subducted plate is melted at deep of mantle and a magma is risen, which forms a volcanic arch belt over the area where Black Sea is now located and over Eastern Ponitde orogenesis (Okay et al., 1994; Okay and Şahintürk, 1997; Ustaömer and Robertson, 1997; Tüysüz, 1999; Nikishin et al., 2003). The Pontide continent gradually starts to have an arch massive. While an active arch magmatism remains active in the north, ophiolitic and epiophiolitic materials from oceanic plate subducted along the south ravine join with material from the continent to form growing mélange wedge (Saner, 1980; Yılmaz and Tüysüz, 1984;1988). In the meanwhile, Yemişliçay formation, a volcanogenic flysch, develops in a wide area around the volcanic belt. This volcanic material from the island arch creates a sequence recessed with deep marine sediments. The thickness of Yemişliçay formation, deposited from north to south, becomes thinner to the south (Gedik and Korkmaz, 1984).

The subduction created by convergence of Taurid-Anatolide continent to northern Pontides and the volcanism of island arch continue during Maastrichtian-Middle Eocene, and deposited mélange segments along the ravine in the south are added one under the other so mélange wedge gradually begins to rise in the northern areas. With this compression, units, forming the fore-continent sliced continent and developing on the continent, and mélange wedges draw near. Increasingly growing and rising mélange slices form a non-volcanic outer arch in parallel to island arch. Anaccretionary prism is produced, which is represented by additional arches to the south of Taşköprü-Durağan basin. Deep portions of continental shell, shortened and thickened by compressional regime, are partially melted so magmatic intrusions are formed rising in the accretionary prism (Aydın et al., 1995; Yılmaz and Tüysüz, 1984, 1988; Saner,1980; Yılmaz et al., 1997).

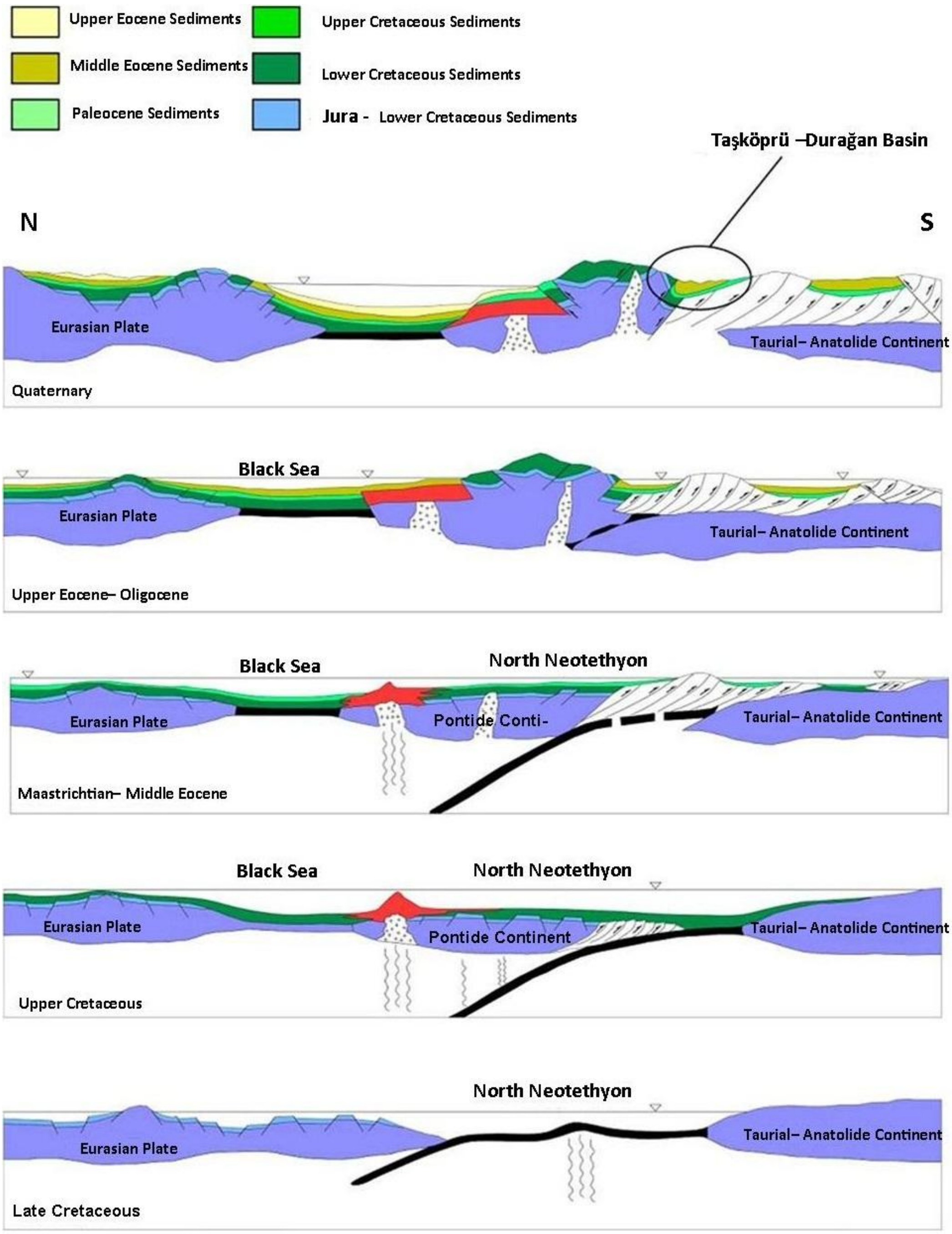


Fig. 2. Evolution of Western Pontides and Taşköprü-Durağan basin (Sanğu, 2010; Saner,1980)

A shallow marine-continental environment is created in the south by rising of accretionary prism that is pushed over the Taurid-Anatolid continent. In the Middle-Late Eocene, the Neo-Tethys is fully closed in the south and this area fully changes into a continental environment in the Oligocene. Collision of Taurid-Anatolid continent and Pontide continent and changes of Black Sea Mountains into today's morphology correspond to the Late Eocene and Oligocene. In the Oligocene, the Taşköprü-Durağan basin is filled with sediments of braided streams and the area between mountains gain a basin character (Saner, 1980).

The Taşköprü-Durağan basin is located between the core of Çangaldağ anticlinal (elevation of Çangaldağ) bordering southern margin of Sinop Basin in the north and the Kargı Massive (elevation of Elekdağ). Previous studies referred to Boyabat Basin (Saner, 1980) or Kastamonu-Boyabat Basin (Yılmaz and Tüysüz, 1984; 1988; Tüysüz, 1999; Ustaömer and Robertson, 1994, 1997). Saner (1980) refers to Boyabat Basin as a fore-arch basin. Other researchers agree on Saner's (1980) judgment regarding structure and tectonic position of Boyabat basin. However, Ustaömer and Robertson (1997) refer to Boyabat Basin as a half graben formed in the Late Jura-Early Cretaceous.

The subduction mélange anterior to Taurid-Anatolid continent and Pontide continent are encountered towards end of Late Cretaceous, which starts compressed regime that produce Pontide belt. The Taşköprü-Durağan basin is located in this belt and continues to evolve. In the Maastrichtian-Eocene, Taurid-Anatolid continent and Pontide continent encounter, and accretionary prism generates structural elevations, resulting in surfacing of some parts and shallow or deep marine environment in some parts. This leads to continental-shallow, marine, slope sediments to be deposited. As a result of this compression and elevation, the Taşköprü-Durağan basin is formed as a compressed basin over, and partly behind, the elevation areas of mélange prism. In the Late Cretaceous-Paleocene, both shallow and deep marine fauna exist in the Akveren formation; slope sediments in the Eocene, continental sediments and ebonite development in another section while Kusuri formation is deposited; they all can be considered as data of different environments due to elevation. From the Late Eocene, the activity of volcanism ends in the volcanic arch. Fore-arch areas are risen and thrusting is formed on Pontide Mountains. Pontide Mountains are created by rising of fore-arch areas and eroded, which provide the sediment material in Black Sea in the Late Eocene. The area completely becomes a continent after Late Eocene to give way to lacustrine sediment, alluvial sediment and continental ebonite (Fig. 3; Sanğu, 2010).

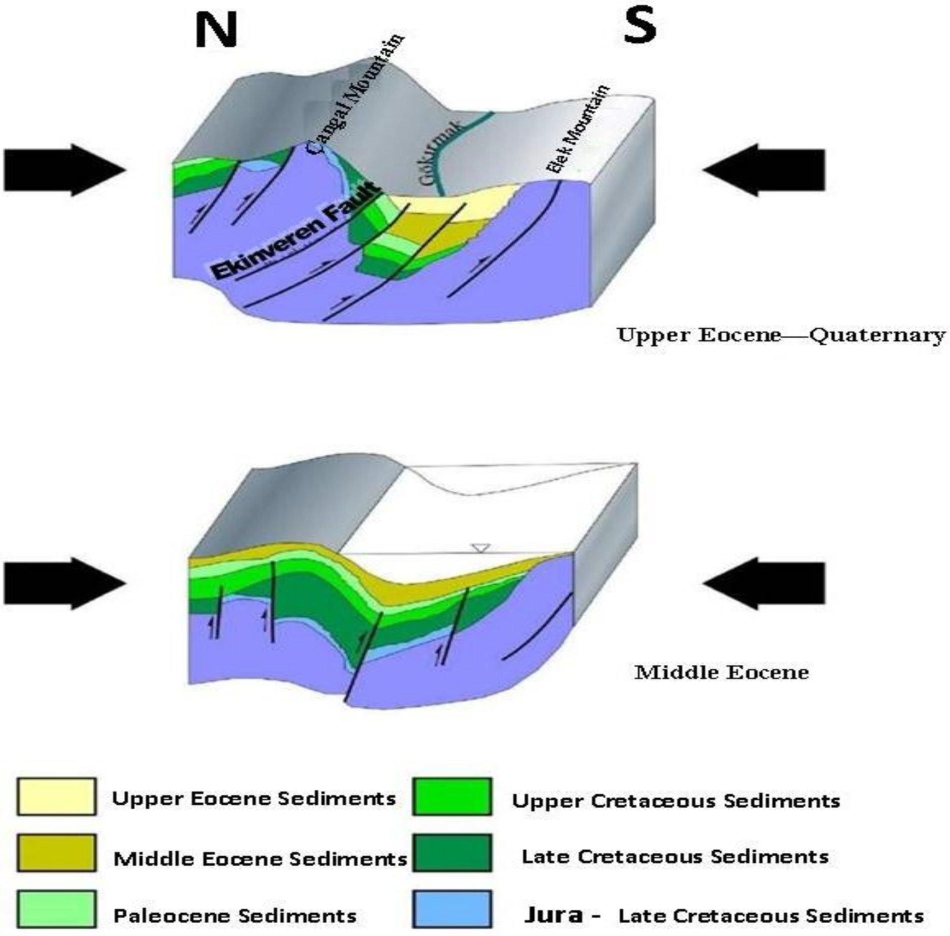


Fig. 3. Evolution of Taşköprü-Durağan Basin in Middle Eocene-Quaternary(Sanğu, 2010; Aydın et al, 1995)

Domuzdağ metamorphic complex has a characteristic similar to conglomerate mélange in the subduction areas and is composed of metamorphic rocks of different degrees. This unit is overthrusted by Elekdağ Meta-ophiolite formed by disappearance of Tethys Ocean. Eclogitic rocks are defined on the basal of this unit with metamorphics (Erol, 2007; Turan, 2007). These two units are covered by Akgöl Formation (unit of including massive sulphide mineralizations) composed of metamorphic rocks of low degree. All these units are inharmonically covered by sedimentary rocks of Boyabat basin started from the cretaceous.

The geodynamic process for study area is as follows: The subduction in north orientation towards end of Mesozoic period produced a high pressure on ophiolitic units and other units of rocks. As a result, eclogites and high-pressure metabazzites in Domuzdağ metamorphic complex were produced. Because, Akgöl Formation (unit of including massive sulphide mineralizations) was not exposed to effects of high pressure, metamorphic units of lower degree were formed in that formation (Figs. 4, 5, 6 and 7).

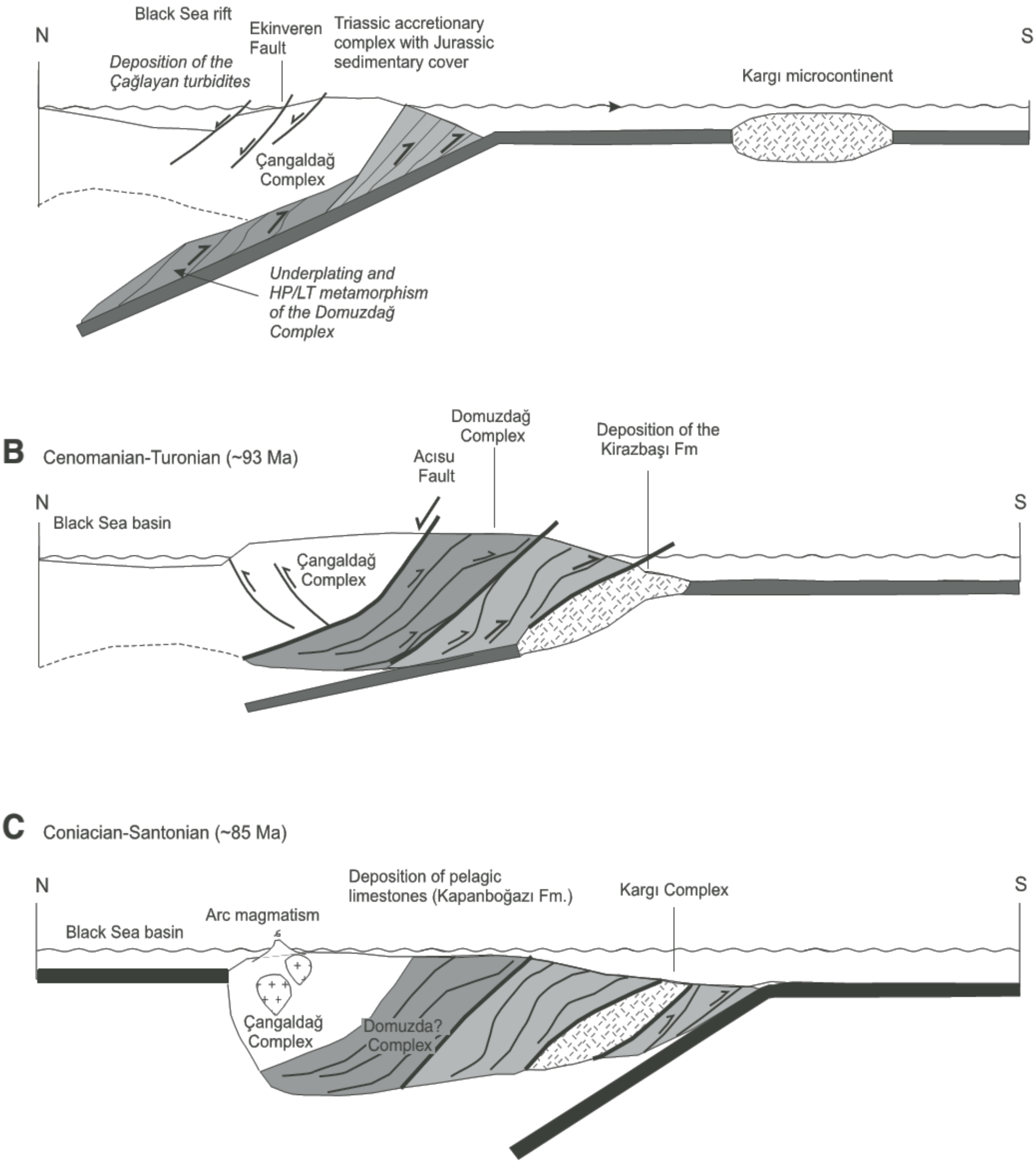


Fig. 4.A model showing tectonic development of the region (Okay et al., 2006).

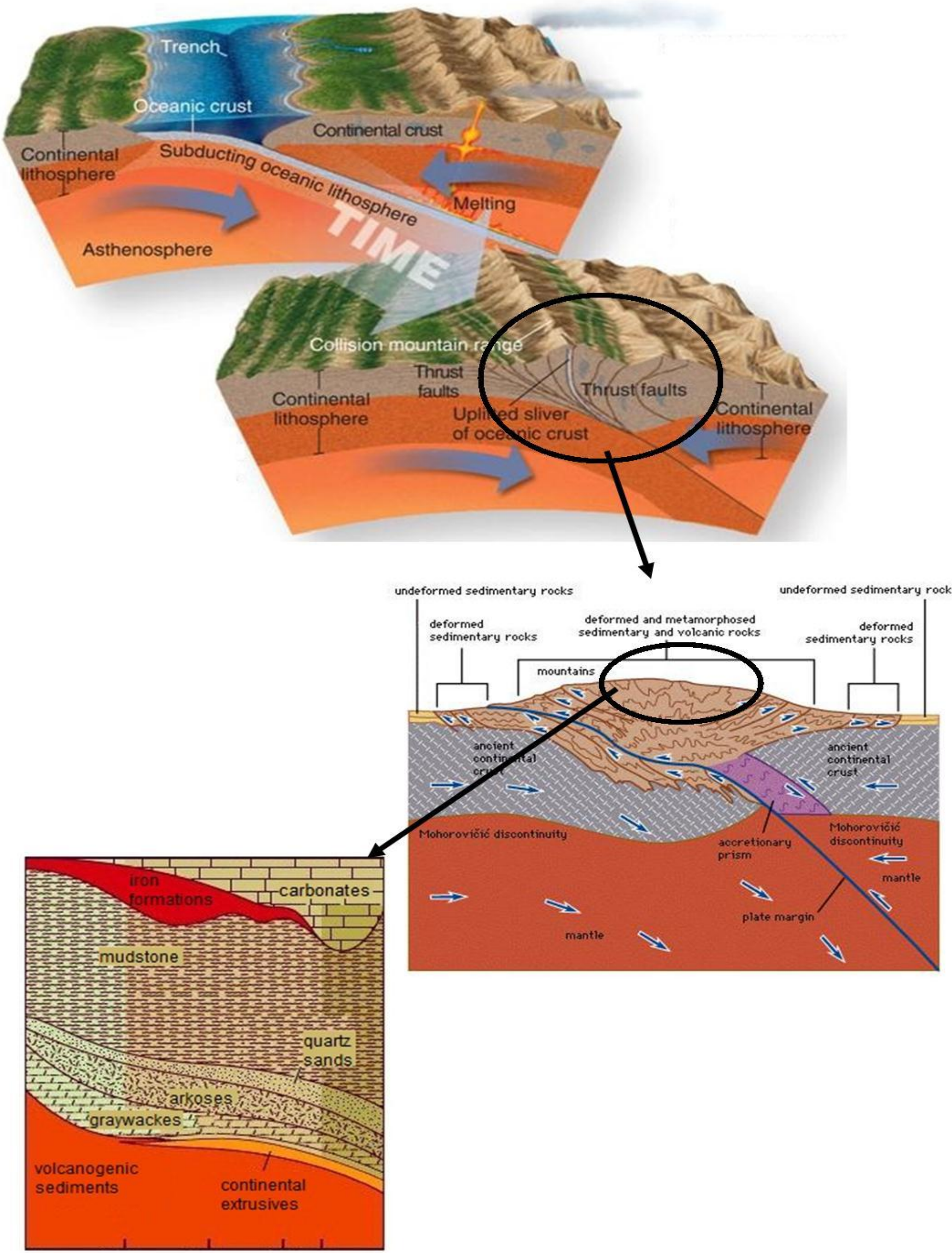


Fig. 5. Accretionary prism model for study area considering lithological units and tectonic structure

III. Comparison of Geological and Tectonic Features of Central Pontides with Iberian Pyrite Belt

Okay et al. (2006) addressed in detail to geological and tectonic characteristics of Central Pontides(Figs. 6 and 7). Local data in that study is consistent with the data from geological and tectonic works performed by Özdemir (2015).Rocks within the Central Pontides are divided into three groups (bottom-to-top): Mafic and Ultramafic Rocks Pre-Liassic period (Elekdağ Meta-ophiolite) and Domuzdağ Metamorphic complex, Liassic Akgöl formation and sediment units after Liassic period. Furthermore, there are volcanic rocks such as gabbro and diorite dykes intruded into some of these rocks.

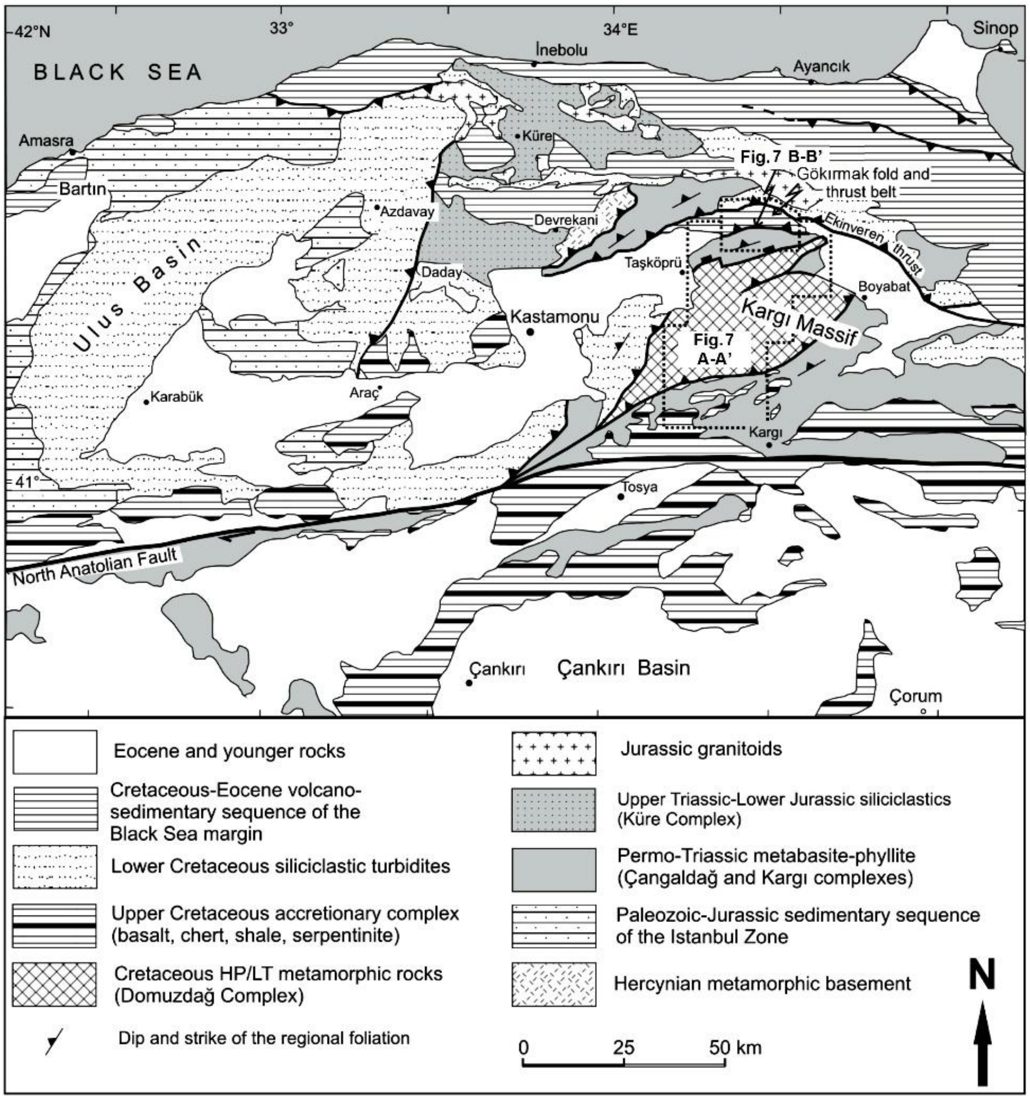


Fig.6. Geological and tectonic map of Central Pontides. Dotted-lined boxes indicate the location of cross-sections (Okay et al., 2006).

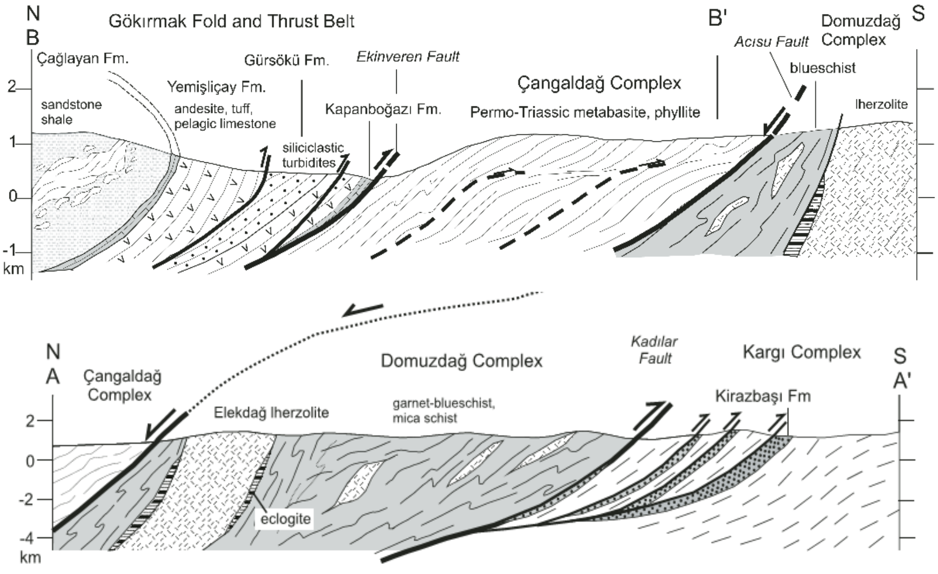


Fig.7. Cross-sections of Central Pontides (see Fig. 6). High pressure-low temperature indicates tectonic structure of metamorphic slice (Okay et al., 2006).

On´ezime et al. (2003, 2002) and Pascual (2013) also comprehensively addressed to geological and tectonic characteristics of Iberian Pyrite Belt.Iberian Pyrite Belt is a well-known and well-defined metallogenic belt. This belt consists of three main structures (Figs. 8 and 9). They are Phyllite-Quartzite Group (PQ), Volcano Sedimentary Series (VSC) and Carbonaceous Sediments (Culm). The Phyllite-Quartzite Group (PQ) has a clastic series is seen to the south of Pulo do Lobo Antiform, which is the oldest unit and its basal is unknown. The Phyllite-Quartzite Group is overthrusted by Volcanosedimentary Complex (VSC). VSC is defined as siliceous siliceous/carbonated shale, volcanogenic fascia, and a bimodal volcanic unit where cherts rich in manganese pass each other. The youngest unit of Iberian Pyrite Belt is defined as Baixo Alentejo Flysh Group (Culm Formation). Culm formation consists of three subunits. They are turbiditic series with basal shale and sandstone. Wide conglomeratic units are defined for Culm formation. Conglomerate pebbles are polygenic. Volcanogenic pebbles indicate that material of conglomerates come from VSC. Sierra Norte batholith, composed of gabbroic and granitic rocks, is intruded into to the north of Iberian Pyrite Belt. To the west of Sierra Norte batholith intruded into northern part locates Gil Marquez pluton as granodioritic apophysis contemporaneous to tectonism (On´ezime et al., 2003; 2002).

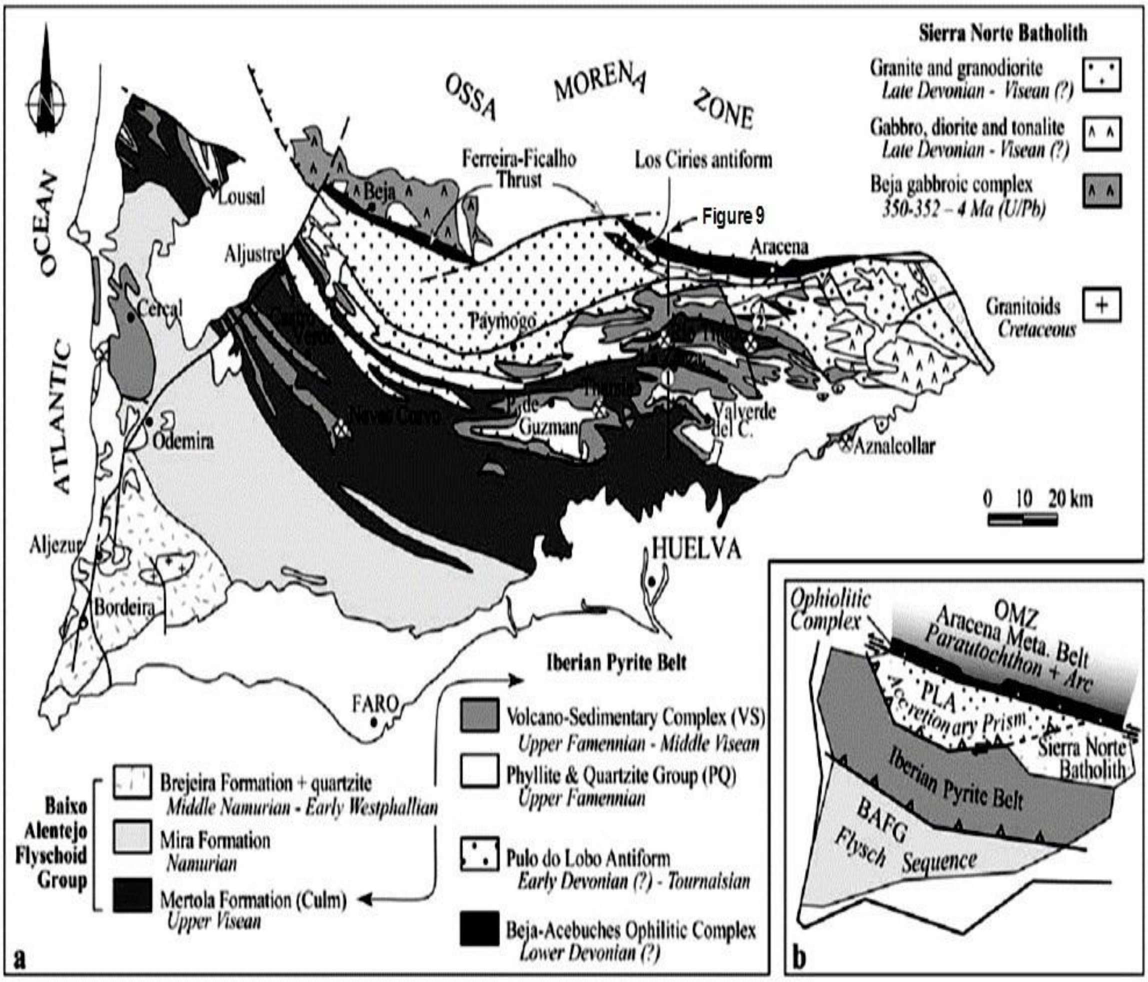


Fig. 8. Iberian Pyrite Belt's geological map (a) and tectonic map (b) (On´ezime et al., 2003; 2002)

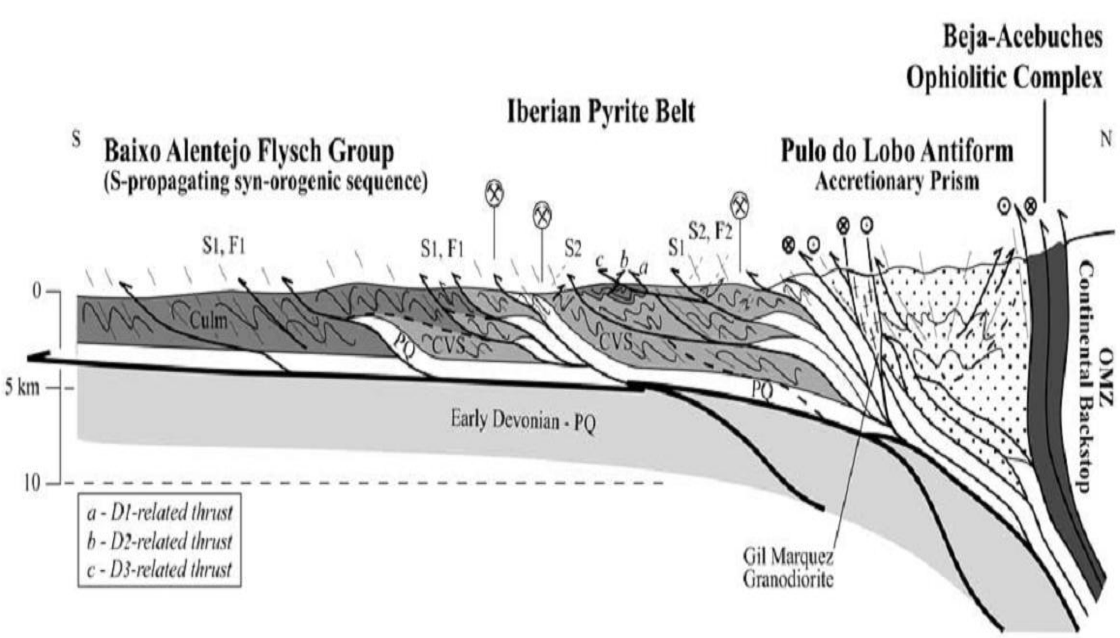


Fig. 9. Iberian Pyrite Belt's geological cross-section (see Fig. 8; On´ezime et al., 2003; 2002)

IV. Comparison of Tectonic and Mineralization Features of Central Pontides with Iberian Pyrite Belt

The model of geodynamic system formed the Central Pontides (Central Pontides) complex volcanic arch within study areas is created by associating remnants of the arch based on current information of the relevant area; movements of alkaline (magmatic) front and tectonic units, movements and weathering during the evolution period of the arch. This adopted approach has facilitated opinions on spaces where axial part of complex arch and especially massive sulfide deposits are originated. Fig.10 gives a general overview of the Central Pontides complex volcanic arch which is convenient for originating of magma and ore metals in any aspect.Mineralization within study areasdates back to Jurassic (Liassic) period and at that time Pontides were in the position of an island arch. The wall rock of mineralization is tholeiite basalts, the initial product of island arch volcanism, and they are derived from a hybrid magma, a mixture of materials both from oceanic shell and continental shell. Because these deposits are older (Liassic) than other massive sulfide deposits in Pontides (for example, Mesozoic Murgul deposits), this proves that they were formed during first steps of island arc process. In the study areas, rocks that are locally referred to as Akgöl formation are mostly metamorphic. In general, there is a very thick black shale (claystone)-sandstone sequence on these massive sulfide-type deposits, and detritic rocks indicate a media shallower than 200 m (Özdemir, 2015).

The Kastamonu-Sinop area is located in the Mesozoic-Tertiary central of pontide metallogenic belt. This area was under influence of Alp-Tethys orogenesis and important ore deposits are formed in this area. The eastern Pontide from Samsun to Trabzon is famous Cretaceous felsic dominant volcanic VMS (Volcanologic Massive Sulfide) Cu-Au, Pb-Zn-Ag deposits. The central part of the same belt, that is Kastamonu, contains rather older mafic volcanic Cyprus-type Cu deposits (Fig. 11). The best example would be Küre mine with 40 million ton reserve. In addition, Eti Bakır A.Ş has a smelter in Samsun. New copper deposits have been explored by exploration works performed on ophiolitic field near Kastamonu (particularly) Hanönü district over last five years. The examples would be Hanönü with estimated reserve of 20 million ton (feasibility study performed by Asya Maden İşletmeleri A.Ş), Cozoğlu mine with known reserve of 1 million tone owned by Eti Bakır A.Ş (Fig.11).

The Kastamonu-Sinop area is on Intra-Pontid suture zone. It is composed of Paleotethysstratigraphic units and Neotethys units covering Paleotethys units. For VMS, Triassic-Jura volcanic arch, ophiolitic mélange and associated accretionary prism containing schist and covering young areas make up the targeted stratigraphy. In the area, targeted formations for VMS deposits include Akgöl and Bekirli Formations composed of phyllite, pelitic schist, carbonaceous schist, mafic volcanoclastic, gneiss, marble, calcschist and metadiabase gabbro up to 2000 m in thickness referenced in MTA (General Directorate of Mineral Research and Exploration of Turkey) and other sources (Özdemir, 2015).

The wall rock of massive sulfide deposits in Iberian Pyrite Belt is Carbonaceous Sedimentary Group (Culm) that are cap rocks of Volcanosedimantery Complex (VSC) and Volcanosedimantery Complex (VSC) (Fig. 12).

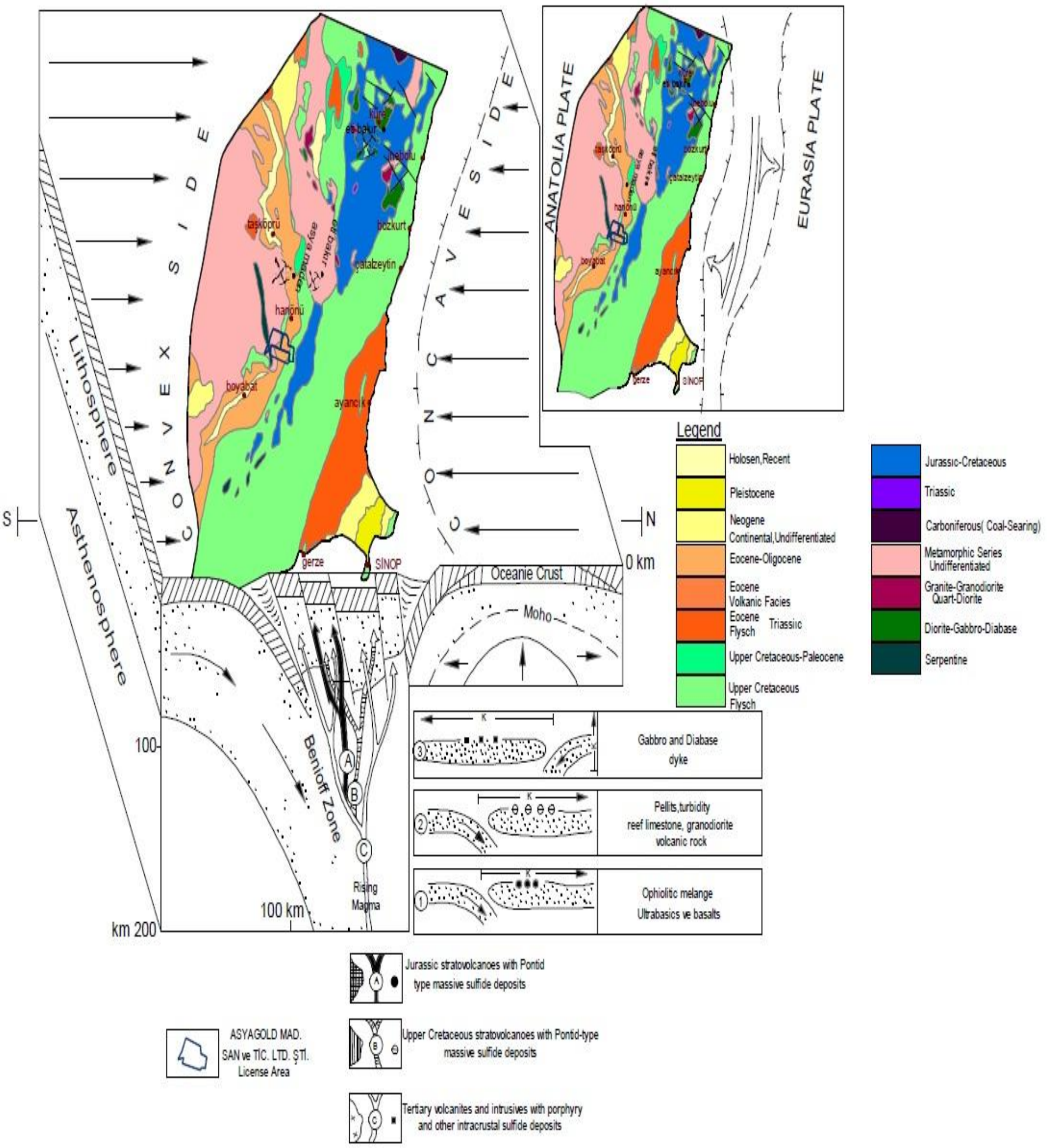
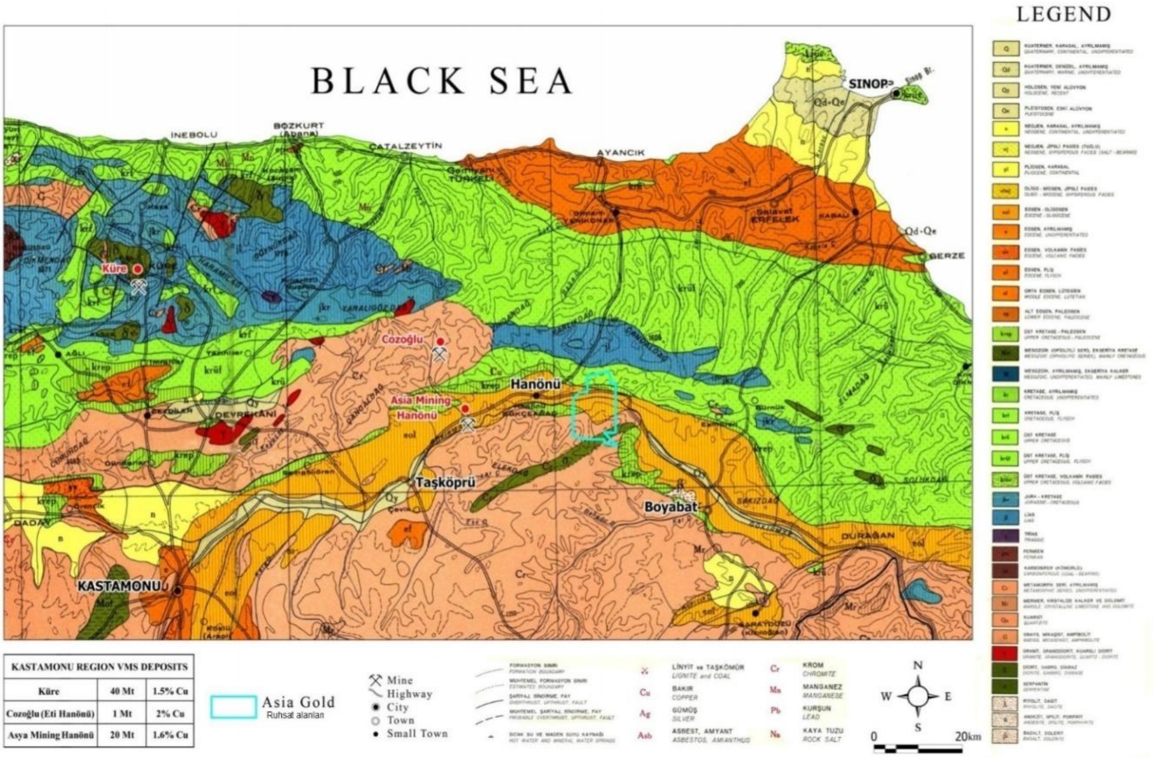


Fig. 10. Formation model of massive sulfide deposits associated with plate tectonics in the Central Pontides (adapted from Pejatoviç, 1979). The upper right corner shows local position of the arch and lower right corner shows evolution order and orientation of movement and sedimentation of alkaline (magmatic) front



KASTAMONU REGION VMS DEPOSITS		
Küre	40 Mt	1.5% Cu
Cozoğlu (Eti Hanönü)	1 Mt	2% Cu
Asya Mining Hanönü	20 Mt	1.6% Cu

Fig. 11. A geological map with a scale of 1:500 000 indicating mines in the region (modified from MTA map)

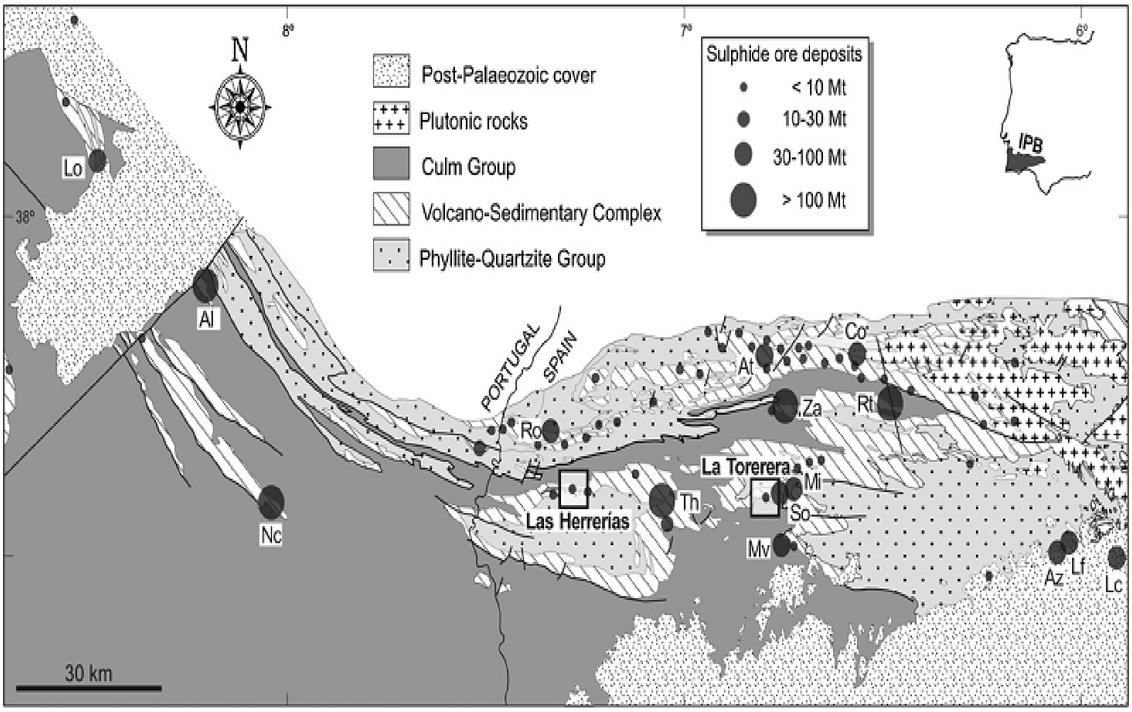


Fig. 12. Geology map, distribution and size of major massive sulfide deposits in Iberian Pyrite Belt (IBP). (Al, Aljustrel; At, AguasTeñidas; Az, Aznalcóllar; Co, Concepción; Lf, Los Frailes; Lc, LasCruces; Lo, Lousal; Mi, Migollas; Mv, Masa Valverde; Nc, Neves-Corvo; Ro, Romanera; Rt, Riotinto; So, Sotiel-Coronada; Th, Tharsis; Za, La Zarza) (Sáez et al., 2008).

Massive sulfide deposits of Hanönü-Boyabat are contained in the basaltic series forming the upper unit of Elektağı Meta-ophiolite. Basalts (metabasic) are covered by a clastic sedimentary series with prevailing claystone (black shale) at lower level and alteration of claystone-sandstone to the upper levels.

Massive sulfide deposits of Hanönü-Boyabat are contained in the basaltic series forming the upper unit of Elektağı Meta-ophiolite. In the study areas, the primary association is generally lost due to tectonism, which is between gabbro composed of tectonite serpentinized harzburgite, little amount of dunite, and intrusive gabbrodiorite and lerzolide at lower levels of basalts, and of basaltic volcanic rocks and a sedimentary cover. Sedimentary and volcanic units in study areas are found in the form of imbrication on the harzburgite located at the lower level in a normal ophiolite array (Fig. 13).Gabbro and diorites are found in the form of dykes mainly to the south and northwest of study areas. Lerzolides are observed in the form of intrusive masses located to the southern edge of study areas. Lerzolides are considered to represent the upper mantle oxidized in the form of mixture of magma-crystal with erzolides being partly melted; and metasomatism-formed in a later period and under depth conditions- is thought to be associated with melts derived from subducted plate, which is still debated.

In the borehole samples collected from drilling works performed on study areas, claystones (shale) are generally dark grey, black rocks with foliation in millimetric thickness and bright sliding-surface that are weaker than basalts. They are often folded in centimetric and desimetric size, and display a compact structure due to partial re-crystallization of quartz at folding axis. The rock primarily contains illite, quartz, chloride and muscovite, and minor amounts of pyrite, chalcopyrite, chromite, ilmenite and hematite (Özdemir, 2015).

Tüysüz (1986) expressed that Elekdağ meta-ophiolite basalts, which he considered to be continuation of Küre massive and which form a uniform array, are found alternated with similar sedimentary rocks to the upper level. This is important as it indicates that claystone (black shale) series located on upper levels of, and on, basalts were formed approximately in the same time interval and geological environment.As the general character of the series, which is covered in inharmonic with basal conglomerate, can be said clastic and sandstones partly contain pieces of metamorphic rocks, this indicates that this unit was precipitated in a media close to continental margin. Based on this data, it can be expressed that volcanic and sedimentary series representing the top unit of Elekdağ meta-ophiolites was formed near ocean ridge close to continental margin during Liassic period and placed on the continent due to closing during Dogger. As it is, Elekdağ meta-ophiolite massive rather appears pieces of an oceanic shell whica was very narrow and short lived and is interpreted as residues of Paleo-Tethys'oceanic shell (Şengör et al., 1980; Tüysüz, 1986), which keeps the debate current that can be resolved by systematic geo-chronologic data in particular.

Volcanic and sedimentary series that is a wall rocks of ore deposits in the relevant area is cut by gabbro and dioritic rocks. At observation location (Y: 629068, X: 4607646), a dyke that is excessively faulted and brecciated exist at the road cut between Hıdırlık and Demirci. This dyke is the extension of granite and granodioritc rocks in the area. Yılmaz and Boztuğ (1986) reports the age of granodioritc rocks with similar characteristics located in Daday-Devrekani to be Dogger and a product of magmatism due to northing subduction of Paleo-Tethys' oceanic shell. As dykes observed in the region involving study area are approximately in the same orientation of other structural elements, this is important that these rocks were placed in parallel to fault system acquired during opening phase and appear to be the part of same mechanism.

In this respect, the opinion gains importance that oceanization that formed the Elekdağ meta-ophiolites was associated with the same subduction mechanism and study areas represent pieces of back-arch marginal basin. Reaching the same conclusion based on main and trace composition of various units around Küre (Ustaömer and Robertson, 1994) appears to be a factor strengthening such assumption. The study areas are structurally in northwest-southeast orientation, appear as a northwest subducted crest, and are, in general, sliced by faults perpendicular to the axis.It is considered that mineralization was primarily formed around probably propagation axis of a narrow and short lived back-arch marginal basin as a result of Liassic subsea volcanism, followed by hydrothermal processes, and was exposed to re-mobilization due to plutonic intrusions.

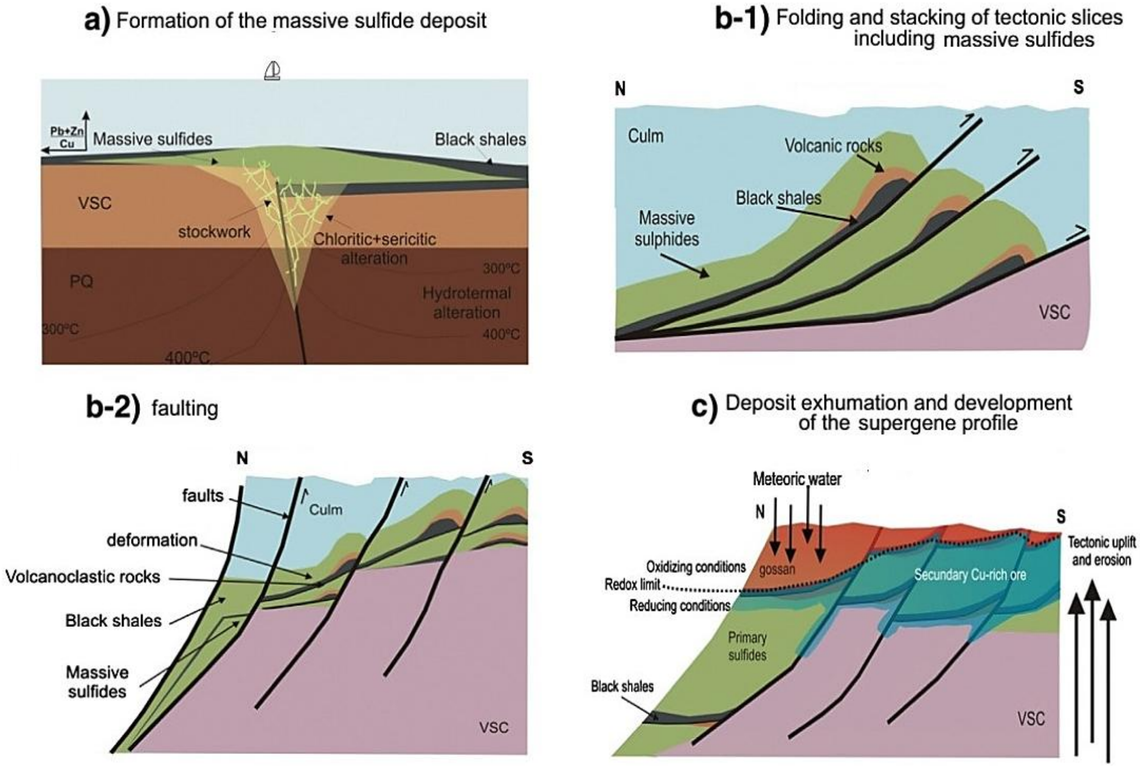


Fig. 13. 3-phase formation model for massive sulfide deposits of Hanönü-Boyabat (from Yesares et al., 2015)

In study area, mineralization can be seen between basalts and clay stone (black shale) at upper levels of basaltic series, which exists in masses with no specific geometrical shape (Fig. 13). The mineralization is expected to have a massive structure and high grade right below the claystone (black shale) that serves as a roof rock, and switch to a somehow reticular structure to lower levels and finally a disseminated structure (Fig. 14).

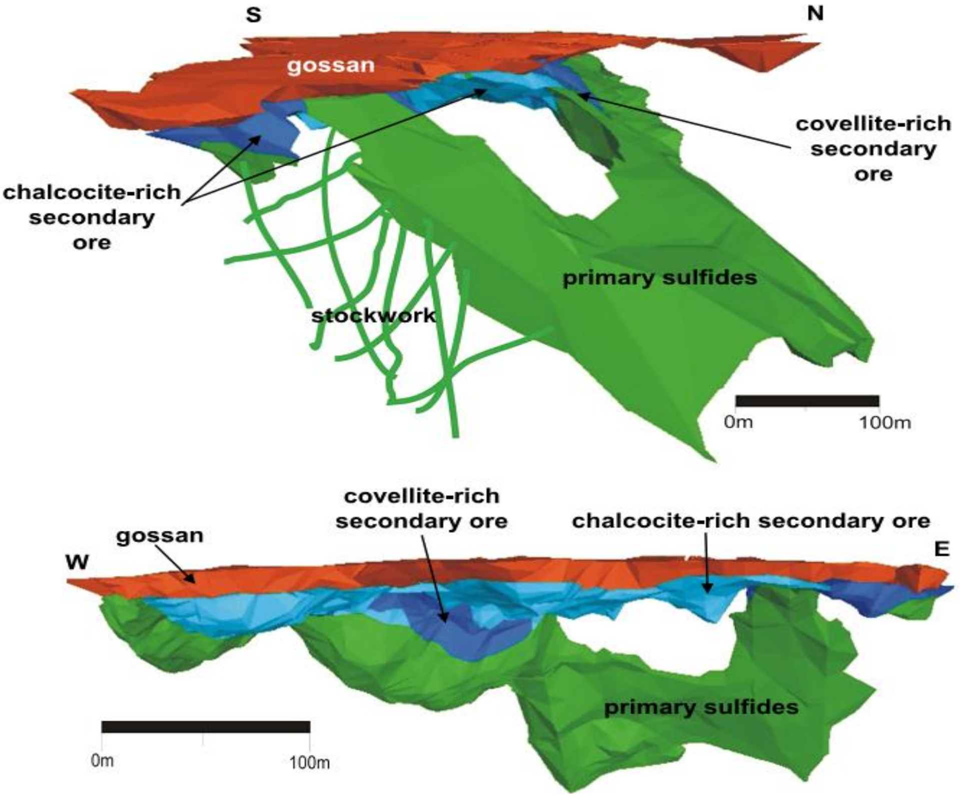


Fig. 14. Expected 3D model for massive sulfide deposits of Hanönü-Boyabat (Yesares et al., 2015)

In study area, ore deposits are estimated to have two types:
1- One type that follows the contact of basalts and claystone (black shale) at upper levels of metabasalts, has their axial plane to be in parallel to basalt-shale boundary plane and intermittent lenses of various sizes,
2- The other type that is in the form of intermittent masses with no specific shape and extends along the axis, close to peak point of anticlinal in case where association of basalt-shale creates a secondary anticlinal.

Massive sulfide deposits of Hanönü-Boyabat were formed associated with opening of Cimmerician basin as other massive sulfide deposits of Black Sea Cimmerician belt described in detail by Üşümezsoy (1990). As with massive sulfide deposits of Küreorogenic belt,massive sulfide deposits of Hanönü-Boyabat are contained in Liassic sandstone, black shale (claystone), and bimodal volcanic composed of basalt-rhyolite alternated with these units (Bailey et al., 1966; Güner, 1980). Küre massive sulfide deposits controlled by north-south orientation fault zones mainly contain pyrite, chalcopyrite, bornite, covellite, sphalerite digenite, marcasite and tennantite (Güner, 1980). In addition, it, in economic terms, includes cobalt (linneite andbravoite) minerals and pure gold (Çağatay et al., 1980). Mineralization is formed by reaching of hydrothermal system circulating inside the volcanic rocks to the sea floor through fault zones and discharging contained metallic elements. Top massive sulfide lens or mass will switch to stockwork type mineralization towards down levels (Fig. 13a).

Massive sulfide deposits of Cimmerician orogenic belts were formed in a basin similar to the Red Sea associated with bimodal rift volcanism composed of basalt-rhyolite during the opening of the Black Sea Cimmericianage (Üşümezsoy, 1990, 1988; Üşümezsoy et al., 1989).

The expected mineralization in the study areas is considered to be formed as a result of hydrothermal processes during Liassic period and subsea volcanism and subsequent phases. All possible deposits in the study areaswould be located at upper levels of volcanic series representing top unit of Elekdağ meta-ophiolite. However, ore-bearing levels may be encountered on the basal of claystone (black shale) unit. It can be thought that pillow lavas, which make upper levels of basaltic series (metabasic) under the claystone (black shale) are completely turned into mineralization. This is interpreted that mineralization continued in the phase following volcanism, including mainly replacement process at upper levels.

The expected mineralization in the study areasinvolves hydrothermal and sedimentary phases. It is considered that metals of ore minerals were transported by hydrothermal solutions and spread under the sea to form mineralization as a result of replacement at upper levels of basalts as well as sedimentation on the surface.The expected mineralization in the study areasis assumed to form as follows when compared to current formations in Galapagos ocean ridge in the East Pacific region (Corlis et al., 1979; Haymon and Kastner, 1981): The sea water, which entered inside bottom basalts along the fault zones and propagation axis of oceanic shell that was tectonically active, was heated and re-uplifted and created a wide convection currents. The high temperature center around the magmatic chamber located at 1-2 km in depth of ocean ridge level is considered to be the motor of these currents. Subject to temperature and water-rock ratios, ions dissolved from basalts formed the ore deposits by replacing the wall rock along the fault zones during uplifting, or as a result of sedimentation occurred the boundary of sea water-basalt on the surface.

Study areas appear a NW-SE-orientation crest. study areasare sliced by normal and reverse faults, which are generally perpendicular to axial orientation and sloped vertically, and appear rotated. Lower levels of basaltic series are exposed by abrasion of ore-bearing levels and sedimentary rocks in the uplifting southern part. A variety of NE-SW-orientation structural elements (faults) observed in the volcanic and sedimentary series should be considered. Study areasare faulted by imbrication and strike-slip faults (Figs.13b1 and b2). In general, strike-slip faults in approximately N-S orientation are important as they partly control the mineralization. Particularly, considering that diabase dykes that cut the basaltic series and gabbro-diorite and lerzolitic intrusions were formed subject to opening phase during the oceanic phase before ophiolite was placed on the continent, this supports the opinion that the crest structure that shows parallelism to them represents a primary structure created during formation. Evaluation of faults, which are positioned in parallel to axis of the crest and create a kind of host-graben system by slicing the study area, within the same context gives the geologic structure-looking like a conflicting issue- an explainable integrity. An interpretation would be appropriate that these faults, which are thought to be formed before mineralization and can be regarded as possible channels of ore-bearing solutions, activated following placement of the continent including study areasand broke down the ore deposit.

The upper slice is in imbrication state that has lost its own cover due to uplifting and eroding (Fig. 13c). The very long continuity of claystone (shale) unit-contained partly in this slice-between basalts along the slope appears to be an important issue that should be considered. Identification of basalt-shale contacts during both surface geology and subsurface geology surveys gives the impression that this is due to a primary structuring. The imbrication breaking up the Elekdağ meta-ophiolite massive is assumed to be formed selecting massive placement and particularly basalt-shale boundary plane in subsequent phases.

In phases following main mineralization in Hanönü-Boyabat massive sulfide deposits, data can also be observed that indicate remobilization based on possible granitic intrusions. They are:

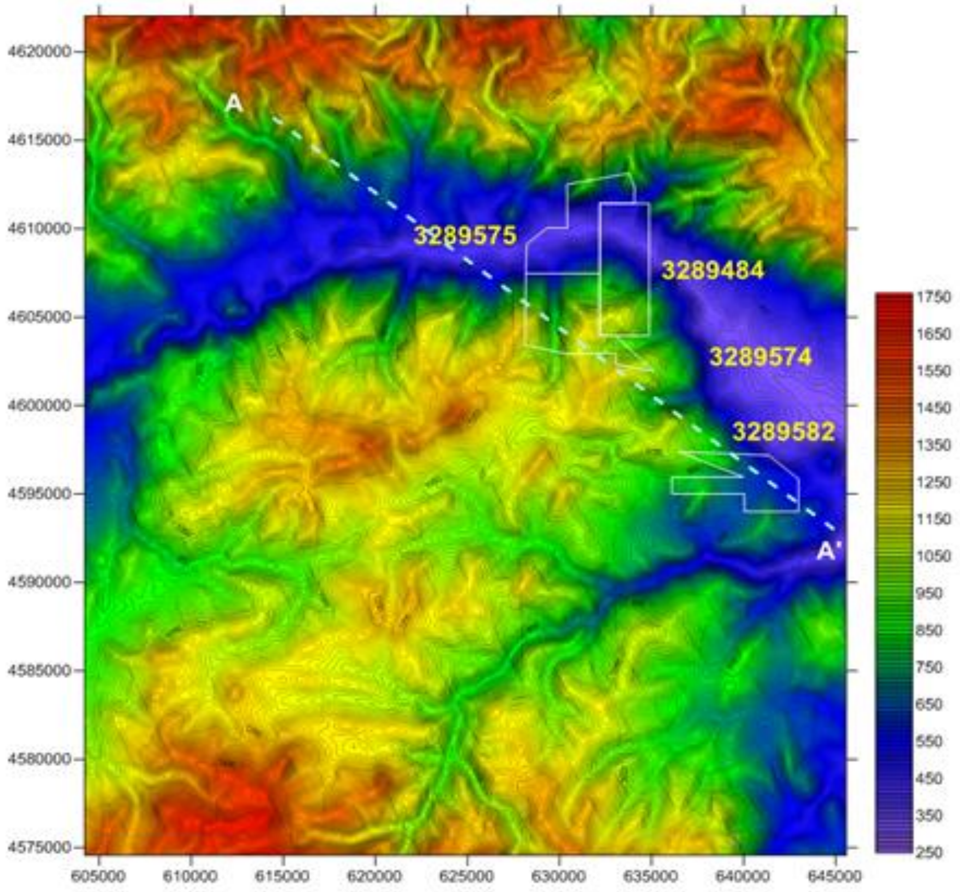
1 - Mineralization masses along the axis of secondary anticlinal that is thought to occur due to tectonic movements after placement,

2 - Ores that are rich in copper and have a massive structure right under the claystone (black shale) series show first a reticular structure then disseminated structure that become poorer to lower levels,

3 - Mineralization in the form of intermittent veins within fault zones,

4 - Pyrites defined as euhedral primary in all deposits are replaced by chalcopyrite that fills the spaces and fissures.

Plutonic intrusions will create the secondary mineralization by reactivating ore elements that increase the temperature of media and have a high mobility and placing in structural spaces below the claystone (black shale) level that serves as an impermeable screen and in fault zones in part (Fig.14c).The area involving study areascorrespond to accretionary prism in the section defined as fore-arch on the subduction zone of subducted oceanic plate to the north. A geological cross-section in 40 km length passing over the study areasis obtained between northwest of Hanönü and Akyürük in the SE in order to see the accretionary prism in a local scale (Fig. 15).This cross-section clearly shows the accretionary prism and drift faults makin up the accretionary prism. As seen in the figure, the area is drifted from NW to SE. Given that average slope angle of thrust faults is 35 degrees, continuity of the ore that is transported to the surface through thrust faults can be estimated by presenting the geometry of thrust fault. Because thrust faults are orientation to NW, it can be estimated that ores would be close to the surface in elevation towards NW depending on the geometry of thrust fault and would be located at rather lower levels towards SE. Location of mineralization in the mine sites of Asya Maden İşletmeleri A.Ş. and MTA being near Gökırmak is considered to be associated with this tectonic structure (Fig. 15).



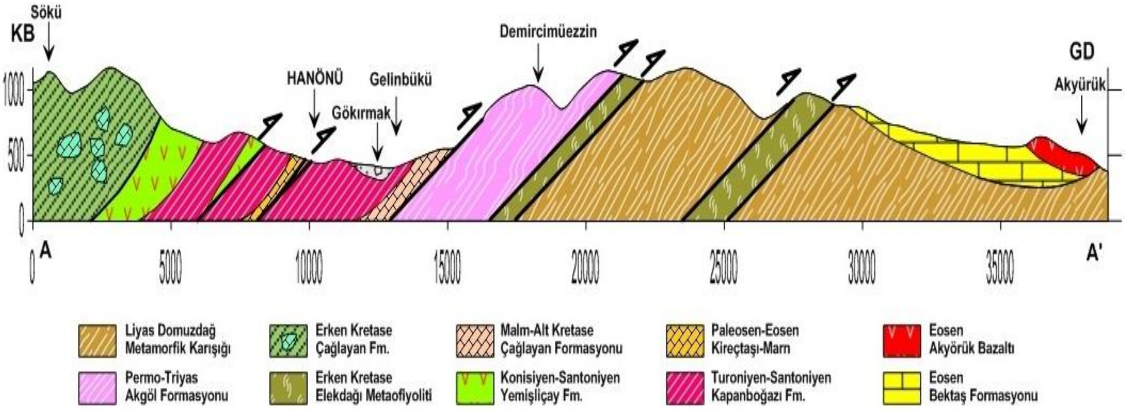


Fig.15. Geological cross-section in approximately 40 km long between the northwest of Hanönü and Akyürük

The geological and tectonic characteristics of the Central Pontides involving lstudy areasare very similar to those of Iberian Pyrite Belt. Geological and tectonic characteristics of other massive sulfide deposits such as Las Cruces (Fig. 13), Tharis (Fig. 16), LasHerrerías and La Torerera (Fig.17), Masa Valverde (Fig. 18) etc. on the Iberian Pyrite Belt are very similar to data of massive sulfide deposits of Hanönü-Boyabat that is presented by Özdemir (2015).

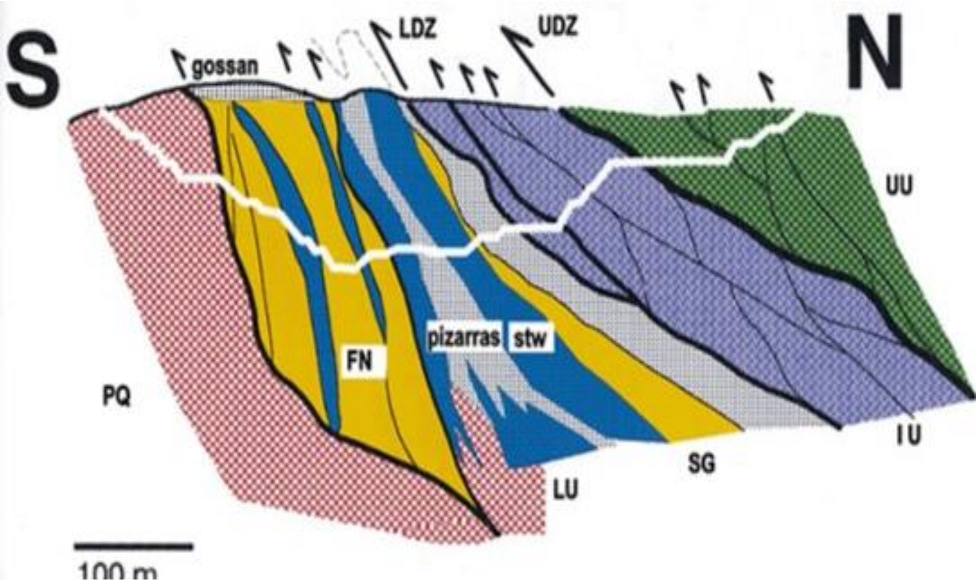


Fig. 16.. Structural cross-section of Northern Vein Open Mining of Taris massive sulfide deposits. PQ: Continental shallow platform silicic-clastic sediments, shale and quartz-arenite, FN: Northern vein massive sulfides, SG: San Guillermo massive sulfide deposit; LDZ: Lower deformation zone UDZ: Upper deformation zone (Tornos et al.,.....).

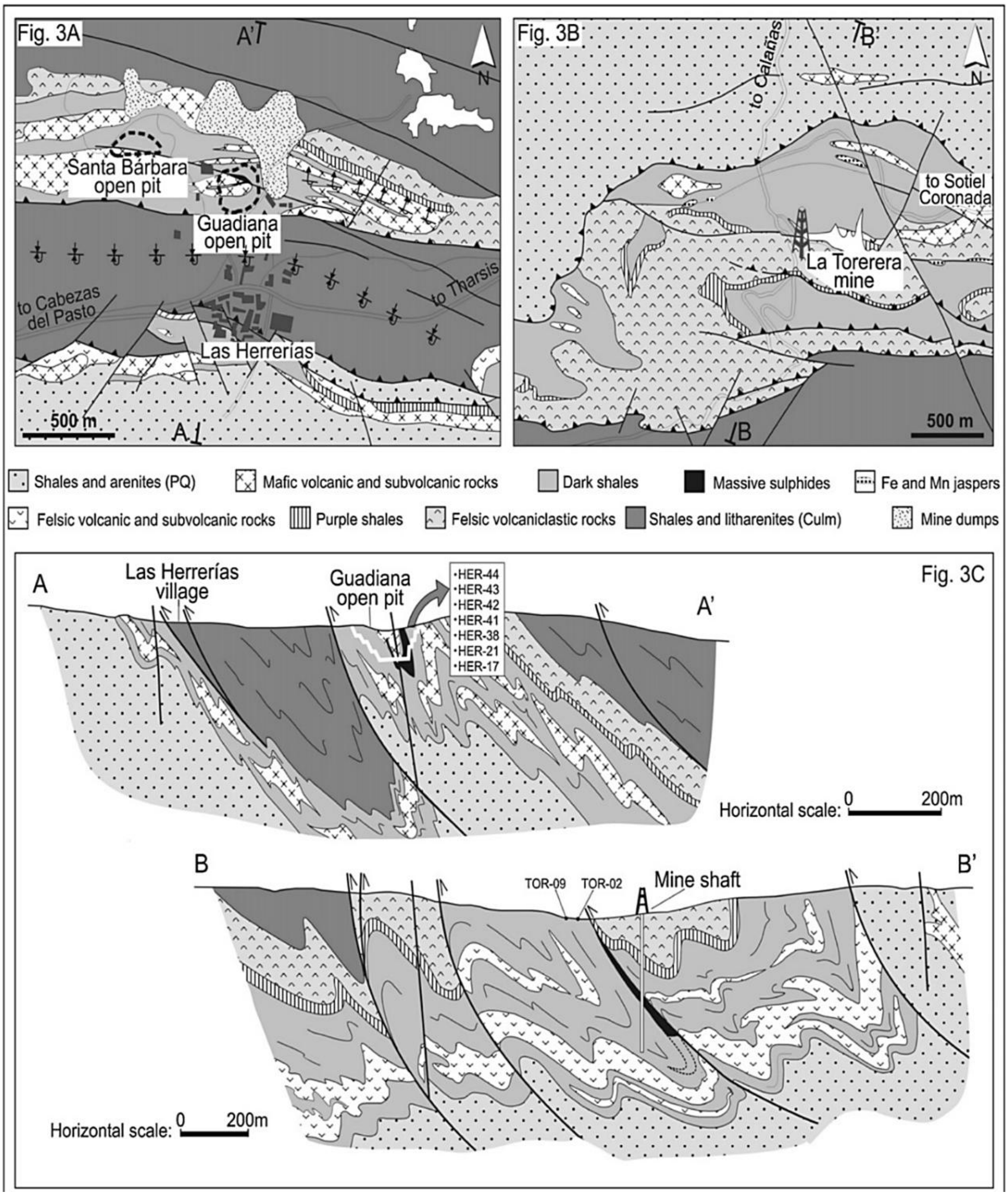


Fig. 17. Geology of LasHerrerías (A) and La Torerera (B) massive sulfide deposits and geological cross-sections (C) (Sáez et al., 2008).

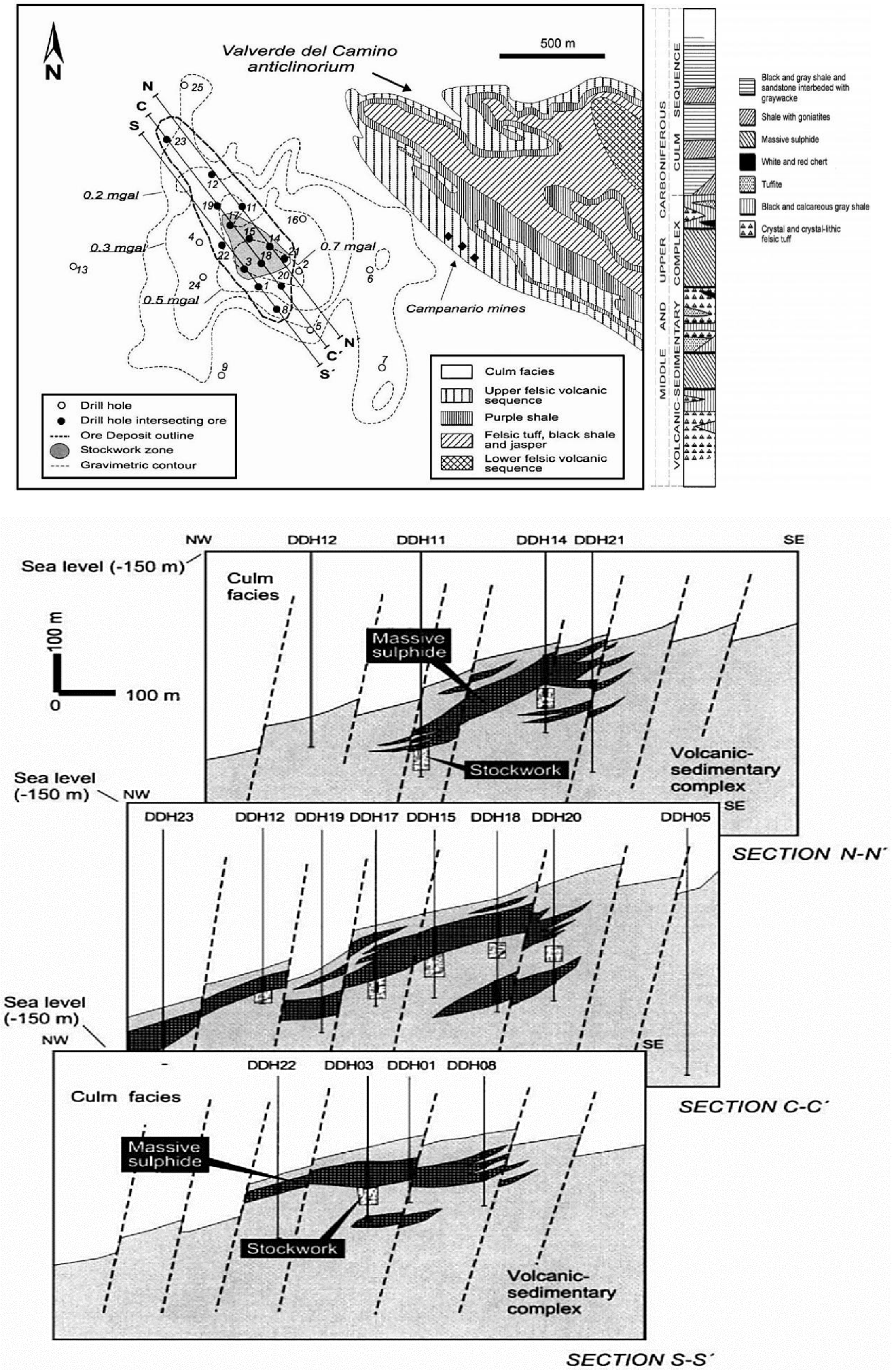


Fig. 18. Geology map, stratigraphy and subsurface geology of Masa Valverde massive sulfide deposit and mineralization (Ruiz et al, 2002)

V. Result

In the light of this detailed field data and surveys including analyses and modelling, geological, tectonic and drilling exploration works have been completed in Central Pontides (Central Pontides) (Eti Bakır A.Ş. Küre massive sulfide mine site, Eti Bakır A.Ş. Hanönü massive sulphide mine site, Asya Maden Hanönü massive sulfide mine site), and there are mine sites that are operated (Etibakır A.Ş. Küre massive sulfide mine site, Etibakır A.Ş. Hanönü massive sulfide mine site) or to be operated (Asya Maden Hanönü massive sulfide mine site). Because geological, tectonic and mineralization characteristics of this mine sites are very similar to those of Iberian Pyrite Belt (IPB), it will be appropriate to refer to the area as Central Pontide Pyrite Belt (CPPB). Iberian Pyrite Belt contains over 100 large and small massive sulfide deposits.It is obvious that a large number of and larger reserve sites can be explored by future exploration works involving the Central Pontide Pyrite Belt as with Iberian Pyrite Belt.

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