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Geology

Facies Analysis of the Volcano-Sedimentary Host Rocks of the Cretaceous Madneuli Massive Sulphide Deposit, Bolnisi District, Georgia

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ABSTRACT. The Cretaceous Madneuli barite-gold-copper-pollymetallic deposit is a major deposit of the Georgian Bolnisi mining district, located in the Artvin-Bolnisi zone. This contribution presents a detailed lithofacies analysis of volcanic host rocks of the Madneuli deposit, including detailed mapping of six outcrop sections, hand samples studies and thin section observations. The rhyolitic volcanoclastic host rocks can be divided into three groups: (1) massive breccias interpreted as massive breccia flows, (2) stratified tuff and lapilli tuff (including ignimbrites, rhyolite and rhyodacite pyroclastic flows), and (3) turbiditic tuff. On the northern level of the deposit two ignimbrite horizons were singled out. One of them (columnar jointed ignimbrite) was first seen and described by the authors. The same should be said about the association of ignimbrite with rhyolitic pyroclastic lava flows and dacitic hyaloclastic rocks.

Key words: *Cretaceous lithofacies, mining district, volcanic host rock.*

Introduction

The key understanding of ore deposits like massive sulphide deposits lies in the past volcanic reconstruction through facies analysis, identification and interpretation of volcanic textures and structures in outcrops and drillcore sections by graphic logs. Recognition of outcrop features diagnostic of a particular depositional setting is a powerful tool in determining the paleogeography and geotectonic environment of volcanic successions. The Cretaceous Bolnisi district of the Lesser Caucasus in Georgia has always been in the sight of interest of several generations of Georgian geologists, with the proposition of several significant models to explain the origin of the ore deposits within the district. However, the district lacks any detailed recent studies based on the reconstruction of volcanic and sedimentary facies architecture in contrast to other well-known ore districts all over the world. The study of volcanic host rocks of volcanogenic massive sulfide (VMS) deposits allows us to clarify the understanding of the volcanic setting of these deposits. The authors of this contribution have made an attempt to describe and interpret some key volcano-sedimentary units with an emphasis on the volcanic lithofacies recognition at the Madneuli deposit in Georgia.

The Madneuli deposit is the main deposit of the Bolnisi mining area. The main ore bodies that were defined in the open pit include [1]: (1) copper-pyrite, (2) barite polymetallic and (3) gold-bearing quartzites, from the base upward. Four structural-morphological ore body types are recognized at the Madneuli deposit [2]: vein, disseminated, breccia and massive stratiform. An intrusive body of granodioritic-porphyry and quartz-dioritic-porphyry composition in the central part of the deposit was dated by K-Ar at 88Ma [3].

2. Regional geological setting.

The Bolnisi ore district is located in the Artvin-Bolnisi tectonic zone, which is continuing to the west into the Turkish Pontides and farther west to the Bulgarian Srednegoria tectonic zone. The Artvin-Bolnisi unit is bordered to the north along the Southeastern Black Sea by the Adjara-Trialeti unit (Santonian-Campanian back-arc) and the imbricated Baiburt-Karabakh unit to the south (Upper Cretaceous fore-arc). It represents the northern part of the southern Transcaucasus and the central part of the Eastern Pontides, which was formed as active margin of the Eurasian continent. The Artvin-Bolnisi unit is characterized by a Hercinian basement, which consists of Precambrian and Paleozoic granites-gneisses and plagiogranites overlain by Carboniferous volcano-sedimentary rocks. Within the Bolnisi volcanic-tectonic depression there are Cretaceous, Paleogene, Pliocene and Quaternary sedimentary rocks. Three main formations are distinguished within the Albian-Upper Cretaceous volcano-sedimentary unit: 1) terrigenous- carbonate (Albian-Senomanian), 2) volcanogenic (Turonian-Santonian) and 3) carbonate (Campanian-Maastrichtian) units. Jurassic and Cretaceous rocks consist of volcaniclastic rocks, limestones and calc-alkaline magmatic arc rocks (andesite, dacite, rhyolite, and basalt and volcaniclastic rocks intruded by granitoids). The sequence is unconformably overlain by Maastrichtian – Paleocene limestone and turbidite. A Lower Eocene formation is represented by terrigeneous clastic rocks. Middle Eocene volcanic rocks overlie unconformably older rocks and are conformably overlain by Upper Eocene shallow-marine clastic rocks. The youngest rocks in the region are Quarternary volcanic rocks and alluvial sedimentary rocks [4].

3. Litho-petrography of the host rocks

Stratigraphic relationships and textural characteristics of the host rocks of the Madneuli deposit are best exposed in the following key areas: along the road toward the main entrance of the Madneuli open pit (783-911 m above sea level), the northern upper part of the Madneuli open pit (level 1065 - 1120m), the lowermost level of the deposit (level-848m), the eastern part of the Madneuli open pit (levels 1051m and 1069m), and the north-western part (level 948m). Detailed descriptions of the outcropped sections on each level are given below.

The section along the road toward the main entrance of the Madneuli deposit represents the depositional processes before ore mineralization, by contrast, the section along the northern upper part and the eastern part of the open pit (level 1051m and level 1069m) document post-ore events. Syn-ore events are probably revealed by the sections of the north-western part of the open pit (level-948m) and lowermost level – 848m.

The lower part of the section along the road toward the main entrance of the Madneuli deposit (Fig.1) is represented mainly by alternation of bedded tuffs, fine-grained graded tuffs, and massive rhyolite coarse tuffs. Massive bedded tuffs with sharp contacts and microfaults are overlain by alternation of medium grained, thin and medium bedded tuffs (thickness of single bed varies from 5cm to 20-30 cm). These tuffs have sharp contacts and well exposed Bauma Ta Tb Tc intervals. Upwards the thickness of single tuff beds increases. In some places they are interbedded with single beds of coarse-grained debris flow beds. Massive tuffs contain glassy wisps, crystals of plagioclase and fine ash matrix. The middle part of the section represents "jasperoid" with microgranular structure. Its homogeneous matrix consists of microcrystalline quartz grains and small amounts of clay particles and ore minerals. Rhyolite tuff includes ore mineralization, which is well seen in the rock. In the upper part of the section, near the open pit bedded coarse tuff is injected by an intrusion. Here we can single out 2 flow levels. One of dacitic composition with columnar jointing along the frontal part and inside the rhyolite with a porphyritic structure. The dacitic porphyritic rock contains strongly altered plagioclase crystals. Quartz crystals are only present in the matrix.

The cross section along the northern upper part (Fig.2) of the Madneuli open pit (level 1065 - 1120m) with stratified fine grained tuffs at the base is built up by 2 flow units: rhyolite pyroclastic lava-flow with flow foliations and ignimbrite. In the rhyolite, there are shards of tuffs, ignimbrites and other rocks within flow foliations in the lava flow. A flow bends around these shards and creates textures of some kind of flow foliation. Some shards of volcanic rocks have a pumiceous nature. In lavas, the development of foliation begins during flow in the conduit and continues during extrusion and outflow [5]. It is well known that felsic subaqueous lava-flows are divided into lobe-hyaloclastite flows; blocky subaqueous lavas and domes; cryptodomes. VMS deposits can be associated with these three flow types [6]. The above-mentioned rhyolite lava-flow belongs to the

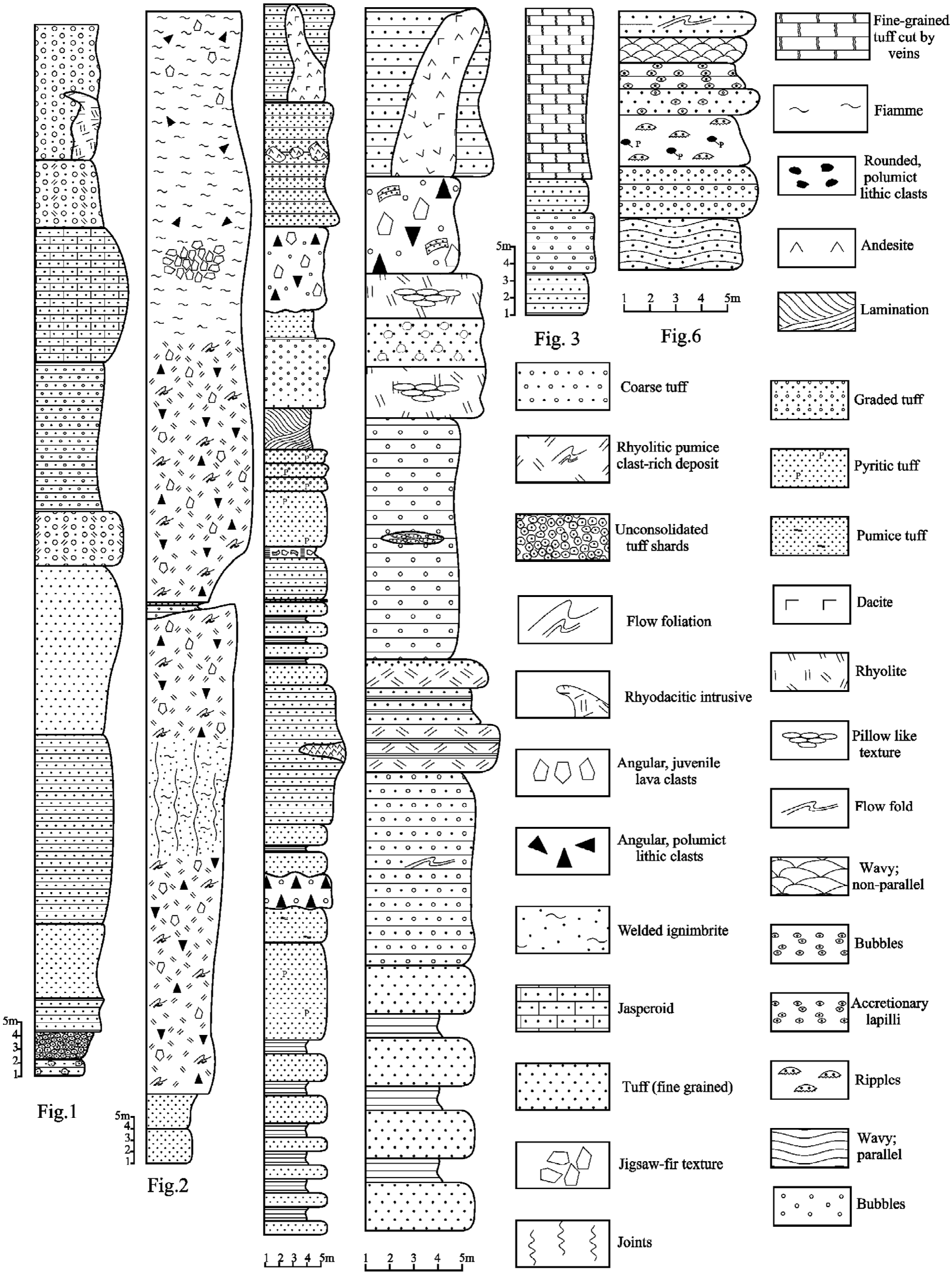

Fig.1 Fig.2 Fig. 3 Fig.4 Fig.5 Fig.6

lobe hyaloclastite flow type and it is flow-bended and a brecciated lava-flow from the proximal part of the section, but more closely with distal part. In the bottom part of the rhyolitic lava-flow there are sharp discontinuities with columnar-jointed, compositionally zoned ignimbrite (thickness 6-8m), which indicates hotter emplacement in contrast to the unjointed rhyolite base. The shapes of the columnar-jointed ignimbrite are rectangular. The ignimbrite contains crystals and crystal fragments (quartz, plagioclase, altered amphibole). The matrix which develops between crystals and shards is glassy, brown colored and fine grained. Perlitic fractures are also within the matrix, indicating that the shards were thoroughly welded coherent glass [7]. In these ignimbrites, we have typical spherulitic textures of volcanic glass, which is evidence of high-temperature devitrification of some initially glassy, welded ignimbrites [5]. This rhyolite lava-flow is divided into two parts. The contact between them represents a much altered, unconsolidated zone - rhyolite coarse tuff and volcaniclastic tuff (thickness 0, 5-1, 5 m) which consists of volcanic glass and fragments of rocks and crystals of different shapes and sizes. In some places there are recrystallized relict pumice clasts. Ignimbrites constitute the uppermost part of this section and of the open pit as well. Ignimbrite with welding structure contains lapilli and crystal shards or lapilli and matrix. Crystal shards are plagioclase, orthoclase, quartz. In some places, there are well preserved perlitic structures (spherulitic textures) within the matrix of the ignimbrite. The fractures are accentuated by concentrations of very fine opaque grains and overprint the welded matrix shards [5]. In the thin sections, there are shards with cuspate and platy shapes.

In the lowermost level of the open pit, the beds are almost horizontal. (Fig.3) Rosy-grey fine-grained tuff within disseminated copper-pyrite ores has clastic vitroclastic psammitic texture. Here, there are strongly silicified (fully filled with quartz) clasts of rocks and minerals, revealing the tuff nature of the rock. Big quantity of pyrite is found. In some parts there are quartz–pyrite veins with relicts of perlite. The section is followed by green, strongly altered, coarse tuff with a crystalline-vitroclastic texture. The size of clasts varies widely. Quartz clasts occur in the whole mass and locally as large fragments. Pyrite and chalcopyrite are also present. The cross-section continues with very fine-grained grey tuffs, which look like ash tuffs. They are almost homogeneous, and contain very fine grains of quartz, and ore minerals occur in it. The cross-section ends with the ore bearing horizon of fine grained grayish tuff cut by copper-pyrite-chalcopyrite mineralized veins.

The lower part of the 1051m level cross section (Fig.4) consists mainly of alternations of bedded, fine-grained tuffs and pyrite-rich tuffs. Two rhyolitic flows occur in the tuffs. One flow is a rhyolitic volcaniclastic breccia, which contains relicts of pumice clasts and, in contrast to the second flow, it also contains fragments of fine-grained tuff. This flow is covered by tuffs containing pebbles and has a channel-like geometry in section. Inner flow stratification within a single layer shows fine-grained lamination, normal grading and lamination, thick units with clasts and reverse grading at the top and fine-grained pelitic in the upper part. We interpret them as water-settled pyroclastic fall deposits. Flow stratification is most common in surge deposits, but may also occur in the distal parts of ignimbrite [8]. Tuffs are bioturbated. The upper part of the section consists of a thick breccia-flow, which is essentially poorly sorted, and consists of angular to subrounded fragments of tuff and rhyolite. The rock is strongly silicified and the matrix contains relicts of pumice lapilli. This massive breccia is interpreted as being deposited directly from steam-rich, high-density flows that are emplaced under a stream cupola in shallow water conditions. Between the bedded tuff horizons, there is an andesitic lava flow with pillow-like shapes, which is evidence for a subaqueous environment during emplacement of the andesitic flows. In the upper part of the cross-section, these tuffs are intruded by a dacitic body.

The lower part of the section from the level 1069m (Fig.5) is represented by fine-grained, bedded tuffs interlayered with pelitic rocks. They are overlain by bedded tuffs with oval shaped cavities and a slide-slump unit. Two rhyolitic lava flows are separated from each other by bedded tuffs. The lower flow is stratified and the upper part is a rhyolitic grain flow with volcanic glass in the matrix and relicts of pumice clasts. In its upper part, the section contains two flows: (i) a porphyry rhyolitic flow, which is strongly brecciated; and (ii) a carapace breccia flow, which is associated with andesitic hyaloclastic rocks, showing in some places pillow-like shapes. Andesitic hyaloclastite is a lobe hyaloclastite, in some places it contains glass-like selvages now altered to chlorite developed in response to rapid quenching of lava in contact with water, or it represents quenched selvages which were broken and spalled during this process to form hyaloclastic rocks [6]. Thin section observation shows that the spherulitic hyaloclastic rocks are vesicular, which are now filled with quartz, feldspar, sericite and epidote. The carapace breccias consist of lobe fragments. They are massive and flow-bended. The section ends with a dacitic intrusion emplaced into fine-grained tuffs. The tuffs are brecciated and crosscut by barite veins.

The cross-section from level 948m is near the lead-zinc ore (Fig.6). The whole section is represented by alternations of wavy parallel and graded tuffs. In some places there are ripple-like forms on the tuff surfaces. The rocks contain pyrite, in some places 1-2 cm-thick pyrite lenses. Near the ore bodies, there are fine-grained tuffs with accretionary lapilli of variable sizes. The lapilli have a core of coarse-grained ash, surrounded by a rim of graded ash (=rim type lapilli [5]. Based on textural evidence, we conclude that the accretionary lapilli formed during rainfall through a “dry” ash cloud.

4. Interpretations and conclusions

The origin and classification of ignimbrites is a matter of debate to the present. It is the subject of much recent research among Georgian scientists too. In the northern upper part of the Madneuli open pit we have two types of ignimbrites. One of them is a columnar jointed ignimbrite, and is described for the first time in this contribution. Reliable evidence for hot emplacement is columnar jointing and high-temperature crystallization textures (e.g. spherulites), which is described in the columnar jointed ignimbrite. They are similar to the Gradle Mountain Link Road ignimbrites (from the Cambrian Tyndall Group, western Tasmania, Australia), which are interpreted as an entirely below-storm-wave-base environment [7]. In the ignimbrites (northern upper part of the Madneuli open pit) there are recrystallised welded shards, which are well preserved in the matrix. The shards are deformed, stretched and compacted at the margins of quartz crystal fragments and indicate a hot emplacement of the volcaniclastic unit even though the depositional setting was below wave base and submarine [5].

The cross section toward the road, up from the entrance of the mine to the panorama area at the edge of the Madneuli open pit, clearly represents how all the volcanic-sedimentary succession has been built up before the time of ore formation. This unit is interpreted to be generated by volcanogenic turbidity currents and single low density medium-grained debris flows.

It is well known that lobe-hyaloclastic flows are characterized by 3 flow facies, including: massive; lobe-hyaloclastite; and breccia [6]. At Madneuli, we can recognize the lobe-hyaloclastite facies. Flows belonging to this facies form during extrusion in response to rapid chilling and quench fragmentation of lava by water or by wet hyaloclastite formed from previous lobes (carapace breccia). The chaotic character of these breccias and the absence of bedding and grading suggest an origin dominantly through autobrecciation. Hyaloclastite is interpreted to be the product of quench fragmentation and granulation of glassy crusts that envelops lobes and massive lava, and is very common in subaquaeous andesitic flows.

The petrographic descriptions of thin sections show a high proportion of volcanic glass, which is common in subaqueous lavas. Strong jointing and intensive microfracturing during cooling, and additional porosity development during devitrification [5] are probably important factors in promoting permeability in lavas for hydrothermal fluids. The abundant pumiceous ash and lapilli, the absence of subaerial lithic clasts, and the relatively good hydraulic sorting are consistent with the source vents being submarine [9]. Moreover, the predominant fine grain size and the ragged margins of the fiame suggest a pyroclastic origin for the original pumice clasts. Cuspate shapes were formed by alteration of classical perlite, whereas welded shard fabrics formed from bent perlite. Perlitic fractures develop in glassy volcanic rocks (mainly rhyolites and dacites) after emplacement. The fractures resulted from expansion of the glass during hydration and associated release of residual stresses incurred during cooling [10]. In the water-settled pyroclastic fall deposits, the tops are usually graded and commonly highly modified by bioturbation [11]. Various forms of bioturbation have been observed at Madneuli, which require further detailed studies.

The location and orientation of synvolcanic dikes and sills is a reflection of the structures that were operative during volcanism [6]. In the eastern part of the deposit, along the upper horizons, there are pyroclastic flows, injected by dikes and sills, which is a common observation in VMS type deposits.

Most accretionary lapilli form in subaerial environments, but there are examples that they may be deposited, redeposited or reworked in subaqueous settings. Fresh accretionary lapilli that are rapidly cemented and hardened can survive immersion in water and can be preserved in water-settled fall deposits, and in syn-eruptive subaqueous volcaniclastic mass-flow deposits [5]. In the studied sections, tuff layers have tops with wavy lamination or possibly ripple marks, which indicate a subaqueous environment of deposition. Accretionary lappili also form when rain falls through a “dry” ash cloud. Some accretionary lapilli are thought to develop when raindrops, moist lithic clasts or crystal fragments fall on and roll across freshly deposited ash [5].

In the lower part of the deposit (on level 948m), there are accretionary lapilli present and in the upper part of the eastern flank (on level 1051m) there are relicts of wavy ripples and signs of bioturbidation, which are evidence for shallow marine conditions.

გეოლოგია

მადნეულის მასიურ სულფიდური საბადოს შემცველი ცარცული ვულკანურ-სედიმენტური ქანების ფაციალური ანალიზი (ბოლნისის რაიონი, საქართველო)

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** ჟენევის უნივერსიტეტის დედამიწისა და გარემოს შემსწავლელი მეცნიერებების განყოფილება, ჟენევა, შვეიცარია

(წარმოდგენილია აკადემიის წევრის დ. შენგელიას მიერ)

მადნეულის ცარცული ბარიტ-ოქრო-სპილენძ-პოლიმეტალური საბადო მთავარი საბადოა ბოლნისის მადნიან კვანძში და მდებარეობს ართვინ-ბოლნისის ზონაში. ნაშრომი ასახავს მადნეულის საბადოს შემცველი ვულკანური ქანების დეტალურ ლითოფაციალურ ანალიზს, რასაც საფუძვლად უდევს 6 საყრდენი ჭრილი. საბადოს ძირითადი ამგები რიოლითური ვულკანოკლასტური ქანები შეიძლება დაიყოს 3 ჯგუფად: (1) მასიური ბრექჩიები, რომლებიც ინტერპრეტირებულია როგორც მასიური ბრექჩიული ნაკადები, (2) სტრატიფიცირებული ტუფები და ლაპილური ტუფები (მოიცავენ იგნიმბრიტებს, რიოლითებს და რიოდაციტურ პიროკლასტურ ნაკადებს) და (3) ტუფო-ტურბიდიტები. საბადოს ჩრდილო დონეზე გამოყოფილი იქნა იგნიმბრიტების 2 ჰორიზონტი, რომელთაგან ერთ-ერთი (სვეტური განწევრებების იგნიმბრიტები) პირველად იქნა ნანახი და აღწერილი ავტორთა მიერ. იგივე შეიძლება ითქვას საბადოს აღმოსავლეთ დონეზე იგნიმბრიტებთან ასოციაციაში მყოფი რიოლითურ პიროკლასტური ნაკადებისა და დაციტური ჰიალოკლასტიტების შესახებ.

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