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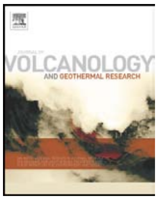

Phreatomagmatic deposits and stratigraphic reconstruction at Debunscha Maar (Mt Cameroon volcano)

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ABSTRACT

The Debunscha Maar (DM) is located on the southwest flank of Mount Cameroon, an active stratovolcano on the Cameroon volcanic line (CVL). Here, we present the physical characteristics of the pyroclastic deposits at DM with the aim of deciphering tephra emplacement mechanisms, evolution of water–magma interaction and reconstructing the stratigraphy beneath the maar. From GPS measurements, the crater has long and short axes of 500 m and 320 m, respectively. Generally, the pyroclastic deposits are well stratified and present a variety of depositional bed forms including structureless/massive beds, massive beds with faint internal stratifications, inversely graded beds, lens- shaped units, impact sags, cross lamination, planar beds as well as dune-like beds. Clast sizes include ash, lapilli-tuff, bombs and blocks (pyroclastic breccia), with clast lithologies consisting of entrained lithics of porous ankaramite pillow lavas, lithified sediments (sandstone and shale) and juvenile material. The porous ankaramite pillow lavas have glassy margins and vesicle zonations typical of pillow lavas formed by subaqueous eruption. The pillow fragments are more common in early-formed eruption products at the base of the deposit. The lithified sandstones show planar laminations and together with the shales occur predominantly in stratigraphic positions above the ankaramite pillow lavas. The juvenile materials include basaltic bombs with low vesicularity (<15%) and moderate vesicularity (15–50%). The bombs have chilled surfaces and their abundance increases towards the top of the deposit. The presence of accretionary lapilli, fragments of country-rock and juvenile clasts with ragged surfaces as well as curved and chilled margins, is unambiguous evidence in support of phreatomagmatic activity. Of the observed lithic clasts, only the pillow lavas would appear to have the porosity necessary to furnish the required amount of water to feed the phreatomagmatic maar eruption. The clast stratigraphy suggests that the maar is underlain by ankaramite pillow lava that erupted on a consolidated sedimentary substratum. Studying deposits resulting from maar eruptions has a direct implication for hazards assessment at areas of active maar volcanism because many surface processes occur around such volcanoes well after the eruptive activities have stopped.

1. Introduction

Maar volcanoes are, after scoria cones, the second most common type of subaerial volcanoes (Wood, 1980; Cas and Wright, 1987; Vespermann and Schmincke, 2000; Schmincke, 2004). Maar volcanism involves individual phreatomagmatic explosive eruptions and associated collapse processes (Lorenz, 1973, 1985, 1986, 2000, 2003a,b) and occurs in all subaerial volcanic settings (Lorenz, 2007). In all these settings, maars are formed when rising magma interacts explosively with water (fuel-coolant interaction) close to the surface, in the process fragmenting both the magma and country rocks (Wohletz, 1983; Wohletz and McQueen, 1984; Zimanowski et al., 1986; Zimanowski et al., 1991, 1995, 1997a,b; Büttner and Zimanowski, 1998; Zimanowski, 1998; Büttner et al., 1999; Lorenz et al., 1999; Morrissey et al., 2000; Büttner et al., 2002; Zimanowski et al., 2003; Büttner et al., 2006). Maars can be produced from monogenetic activity as well as from several episodes of eruption (i.e. polygenetic). The eruption can involve a single ascent path or a network of multiple conduits involving numerous feeder dykes tapping magma from deep seated chambers (McClintock et al., 2008) Pyroclastic deposits from maar eruptions often bear evidence of switching between explosive and effusive activity (McClintock et al., 2008), influenced largely by the availability of groundwater in the conduit. Conduit processes, the nature of eruption column, as well as tephra depositional processes can also be deduced from the physical characteristics of deposits around maars. Such investigations make use of the nature of bedding in the deposits, variations in components from top to bottom of

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the deposit, the presence or absence of spatter, vesicularity of juvenile clasts and the presence of accretionary lapilli.

Maars generally have dimensions of up to 2 km diameter and 200–300 m depth (Lorenz, 1985; Zimanowski, 1998). Maar volcanoes pose a suite of diverse hazards (earthquakes, eruption clouds, tephra fallout, volcanic gases, as well as formation of lahars) before, during and after their formation. This is due to the mechanisms involved in their eruption, the composition of the magma and the products they erupt that include a variety of plucked clasts and tephra as well as magmatic gases. The management and mitigation of these hazards call for the monitoring of such structures (Lorenz, 2007) as about 10% of the world's population lives around areas of active volcanism (Baxter, 2000). Effective monitoring calls for awareness in three stages in the vicinity of such structures: pre-eruptive, syn-eruptive and post-eruptive. Post-eruptive monitoring in such vicinities can be achieved by many methods amongst which are the physical studies of resulting deposits and erupted materials. These have a direct implication for hazards assessment at areas of active maar volcanism worldwide because many surface processes occur around such volcanoes well after the eruptive activities have stopped. Some of these post-eruptive processes include the formation of lahars from resulting deposits, erosion and deposition of reworked material in some areas, rock falls and slumping of country rocks from lower wall. The formation of unstable scree slopes into lakes has also been reported (Moreaux et al., 2004).

A number of maars are present along the Cameroon volcanic line (CVL), including the Nyos maar at an altitude of 1100 m and surface area of 1.4 km^2 (Aka et al., 2008), the Monuon maar at an altitude of 1080 m (Sigurdsson et al., 1987), the Barombi Koto maar which is 1400 m in diameter, 226 ha in surface area and 6.2 m in depth (Tamen et al., 2007), the Barombi Mbo Maar at an altitude of 301 m (Maley et al., 1990) and the Debunscha Maar (Fig. 1). These lakes to different extents pose threats to the population within their vicinity. For example, the 1984 gas

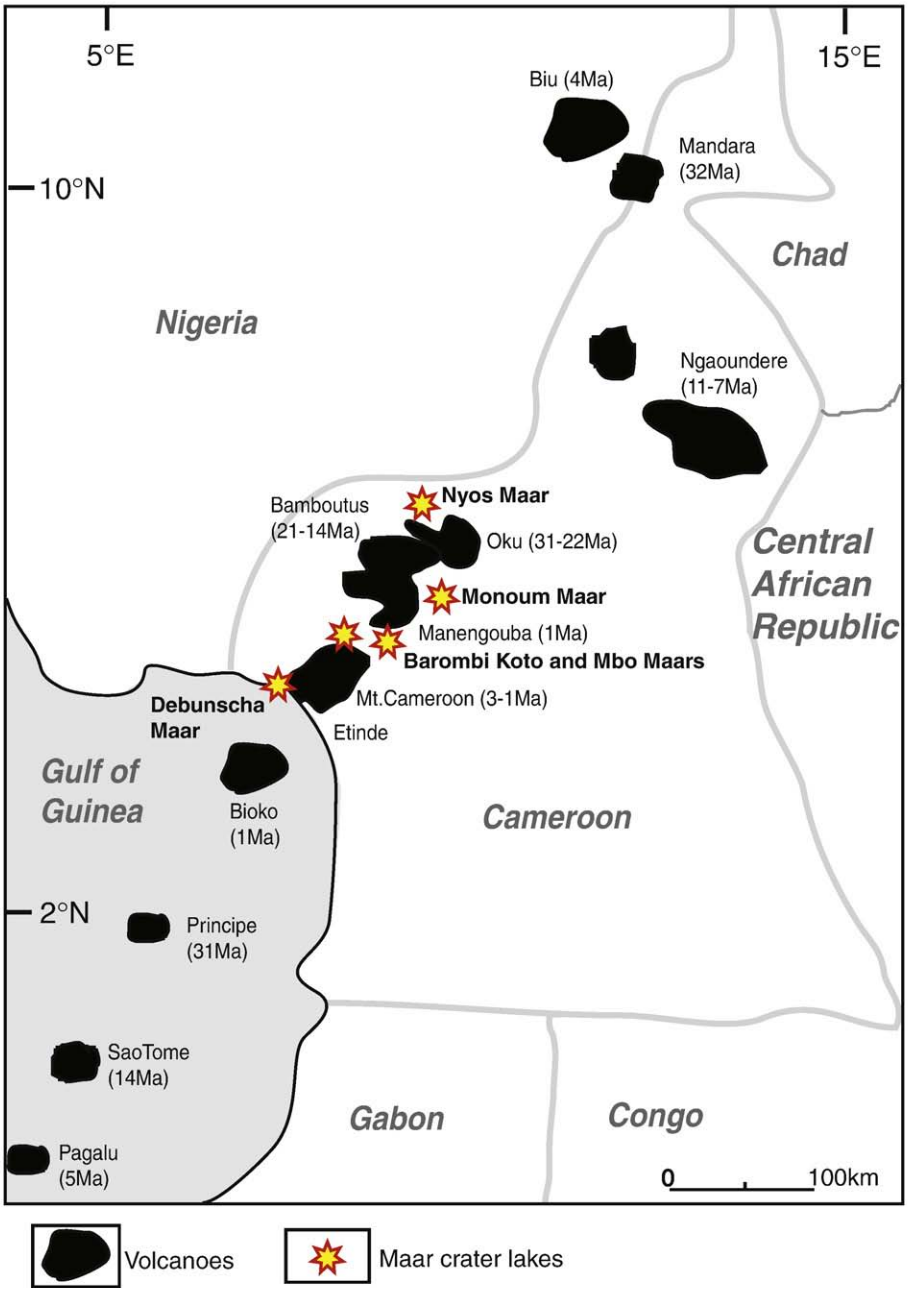

Fig. 1. Locations of the Debunscha, Barombi Mbo, Barombi Koto, Munoun and the Nyos Maars along the Cameroon volcanic line volcanoes.
Map and ages adapted from Suh et al. (2008), My = million years. Positions of lakes from Aka et al. (2008), Tamen et al. (2007), Sigurdsson et al. (1987).

released from the Monoun maar, 100 km south of Lake Nyos, caused the death of 35 people (Baxter and Kapila, 1989; Baxter, 2000; Kusakabe et al., 2003). Later, in 1986, the release of CO_2 from the 200 m deep Nyos maar crater lake caused the death of about 1700 people and countless animals (Lockwood et al., 1988; Baxter and Kapila, 1989; Freeth and Kay, 1990; Cotel, 1999; Baxter, 2000; Kusakabe et al., 2003). Presently, the Nyos maar lake still poses potential threats to the surrounding population. Firstly, Lockwood et al. (1988) have calculated that in the event that erosion causes the collapse of the lake's weak natural dam, over 50 million m^3 of lake water will cause devastating floods in inhabited areas in both Cameroon and neighbouring Nigeria. This follows from the works of Freeth and Rex (2000) that the upper 40 m of Lake Nyos is retained by a weak natural dam. Secondly, due to the CO_2 recharge rate of 0.12 ± 0.04 Gmol/yr (Kusakabe et al., 2008), the lake may explosively degas again. The past disasters and future threats posed by some of these maar lakes and their resultant pyroclastic deposits highlight the need for more systematic physical and geochemical studies of all maars along the Cameroon volcanic line. In this study we focus on the field study of the pyroclastic deposits around the Debunscha Maar in the coastal region of Mount Cameroon with the aim of documenting the nature of the tephra sequence, investigating the emplacement mechanisms, and reconstructing the stratigraphic sequence of the region below the vent area. This we hope will help in unravelling the pre-eruptive and post-eruptive stratigraphy beneath and around the maar as well as allowing deductions to be made about the eruption dynamics and tephra emplacement mechanism. This study has direct implication for hazard assessment, mitigation and possible management around the volcano.

2. Volcanic setting

The Cameroon volcanic line (CVL) is a 1600 km long chain of volcanic centres that extends from the island of Pagalu (2°S) in the Atlantic Ocean, across the West African continental margin in to main land Africa (Fig. 1). The principal volcanic centres of the CVL include Pagalu, Principe, Sao Tome, Bioko, Mount Cameroon, Manegouba, Bamboutos and Oku Mountains. Suggestions that the line may extend as far south as St. Helena (Furon, 1963) or that it may be linked to the Ascension fracture zone in the mid Atlantic Ocean (Gorini and Bryan, 1976) have been made. The CVL has been widely documented in literature (Aka et al., 2004; Rankenburg et al., 2004a,b and references there in) and thus we give only a short summary in this work.

The volcanic rocks of this line are predominantly alkaline. There are also some acidic types which range from rhyolites to phonolite (Fitton, 1987; Ngounouno et al., 2004). Mount Etinde, dated at 0.65 ± 0.1 Ma (le Marechal, 1976; Dunlop, 1983; Fitton and Dunlop, 1985; Fitton, 1987) is situated on the southwestern flank Mount Cameroon and it is dominated by nephelinitic rocks. The ages of igneous rocks from the Cameroon line (Jacquemin et al., 1982) indicate that the earliest igneous activity consisting mostly of granite and syenite intrusive ring complexes that are probably the deeply eroded remnants of still older volcanoes range from 66 to 30 Ma. The oldest extrusive rocks from a ring complex at Kirawa on the Nigeria–Cameroon border have Rb–Sr whole rock ages of 51.1 Ma and 45.5 Ma, respectively (Dunlop, 1983). Younger extrusive centres give K–Ar ages of 35 Ma (Mandara) to present for Mt Cameroon (Fitton and Dunlop, 1985; Wandji et al., 2009).

Many disasters have been recorded within the Cameroon sector of the CVL during the last four decades. These hazards include landslides most of which are unrecorded except where people are killed and/or appreciable property is destroyed (Lambi, 1991; Ayonghe et al., 1999; Thierry et al., 2008). However records of historical occurrences show that between 1988 and 2001, 64 people were killed by landslides along the CVL (Ayonghe et al., 2004). Secondly there have been volcanic gas releases in some maar lakes (Lake Monuon, 1984; Lake Nyos, 1986) along the CVL where close to 2000 lives and lots of properties were destroyed (Baxter and Kapila, 1989; Baxter, 2000; Kusakabe et al., 2003). The CVL has also witnessed hazards associated to the eruptions of Mount Cameroon (4.20°N, 9.17°E), an active stratovolcano with an estimated volume of ~1200 km^3 on the ocean/continent boundary of the CVL (Fig. 1).

For example the 1999–2000 eruptions where lava consumed an enormous amount of forest (about 800 hectares) with its rich biodiversity and cut-off 83 m of a paved road. The tremors associated to these eruptions also collapsed prominent buildings and rendered many people homeless (see Suh et al., 2003; Ateba et al., 2009).

Debunscha Maar (Fig. 2) is on the southwestern flank of Mount Cameroon. Mt Cameroon is the highest peak on the CVL and has erupted at least seven times (1909, 1922, 1954, 1959, 1982, 1999, and 2000) in the last 100 years (Fig. 2). Eruptions at Mount Cameroon are both Strombolian and Hawiian. Details of these eruptions are provided in Venzke et al. (2002), Suh et al. (2003), Ateba et al. (2009) and other references cited therein. Phreatomagmatic eruptions have not been recorded in historical times. Over a hundred cinder cones are at the summit and flanks of this edifice (Suh et al., 2008). Many of the landslides recorded in the country are on the slopes of these cones. For example the June 2001 landslide where 24 people died and several buildings damaged was on a volcanic cone in Limbe, a coastal town 20 km east of Debunscha (Ayonghe et al., 2004). The present study is set against a background of recurrent natural disasters related to volcanic features along the CVL.

3. General features of the Debunscha Maar crater and clasts type distribution

The Debunscha Maar crater is at an altitude of 65 m above sea level and located at 04° 06′ 09″ N and 008° 58′ 45″ E. It is almost rectangular in shape with GPS measured long and short dimensions of 500 m by 320 m, respectively. This crater is filled with fresh water. The inner walls of the crater are very steep and rise about 20 m above the surface of the lake water. The pyroclastic tephra pile, covered with thick jungle, flanks the outer crater walls on all sides with the NW to SW flanks sloping in to the sea. No detailed topographic map of the Debunscha area is available. However the thick jungle cover on the slopes, though making photogrammetry impossible and surveying extremely difficult, suggests heavy erosion has occurred. The age of the maar is not known as no dating of eruptive products at the maar has been carried out. However, the sandstone and shale clasts within the tephra (described below) are thought to be from Cretaceous sediments of the Douala basin.

The structure and field description of various facies within the tephra pile on the outer slopes of the crater were compiled from three vertical sections at the S, SW (where exposures were quite good) and NE of the crater (Fig. 3). Exposures of the sequence could be laterally traced for hundreds of meters only in sections exposed at the S and SE. Due to thick vegetation cover, erosion, and human activities, the NE section could only be traced laterally for a few meters. Logs of representative sections that were studied and systematically sampled are shown in Fig. 4.

Three main pyroclastic ejecta (fragments, or clasts) the juvenile blocks/bombs fragments, cognate and accidental fragments (entrained lithics), the latter made of ankaramite pillow lavas, sandstones, and shale fragments (naming is according to Fisher and Schmincke, 1984) are found in the deposit. Accretionary lapilli set within a fine to coarse ash matrix in the deposit are also considered in this study as an ejecta type. A general summary of the deposit from top to bottom is as follows: the entrained lithics make up about 40–60% of fragments at the bottom, decreasing to about 25% in the middle and eventually 0–<5% at the top. The fines make up about 20% at the bottom. At the top of studied sections especially at proximal locations, all the entrained lithic fragments are completely absent and one finds juvenile ejectas embedded mostly in partially reworked weathered

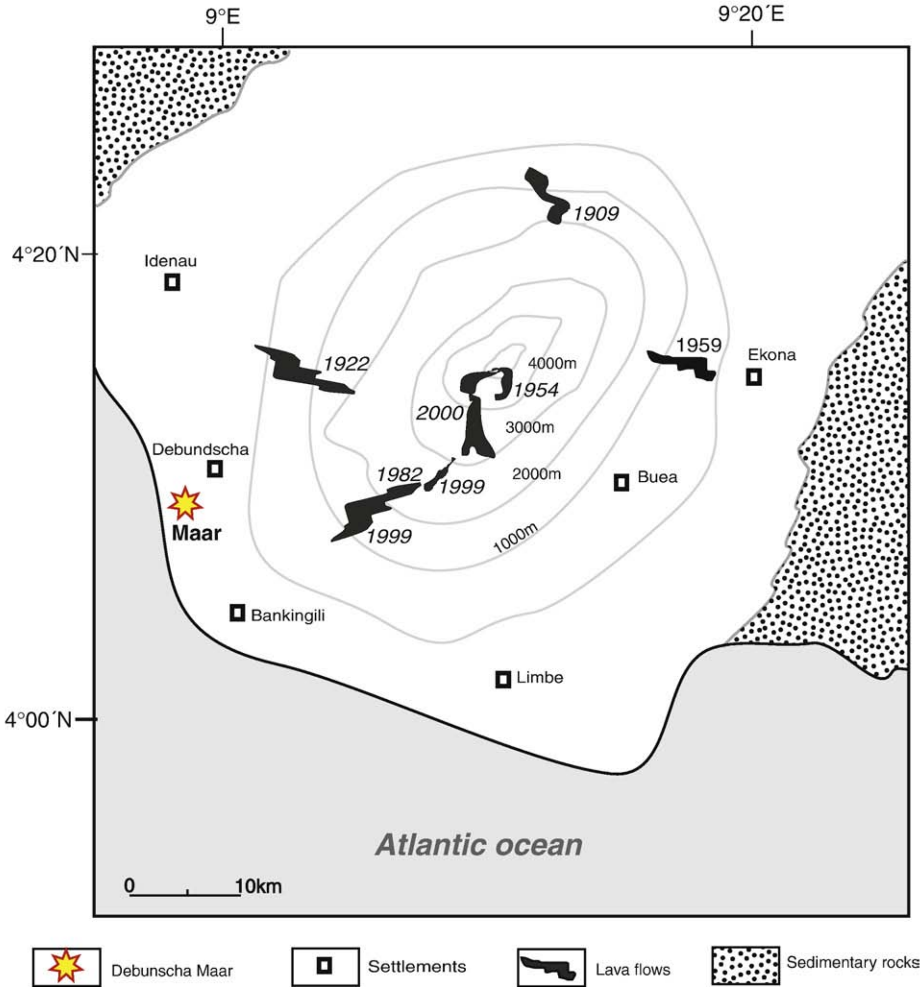

Fig. 2. Sketch map of Mount Cameroon locating the Debunscha area. Debunscha Maar crater filled with water. Recorded positions of historical eruptions of Mt Cameroon with their years, as well as major settlements around the Mountain area are also shown.
Map adapted from Suh et al. (2008).

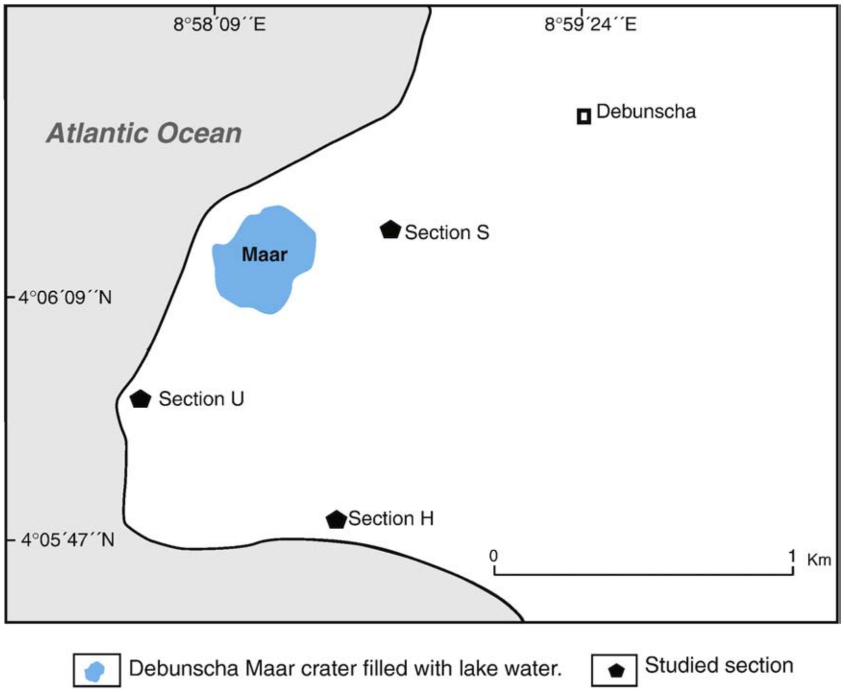

Fig. 3. Location of representative studied sections at the Debunscha pyroclastic deposit. Frame values are UTM.

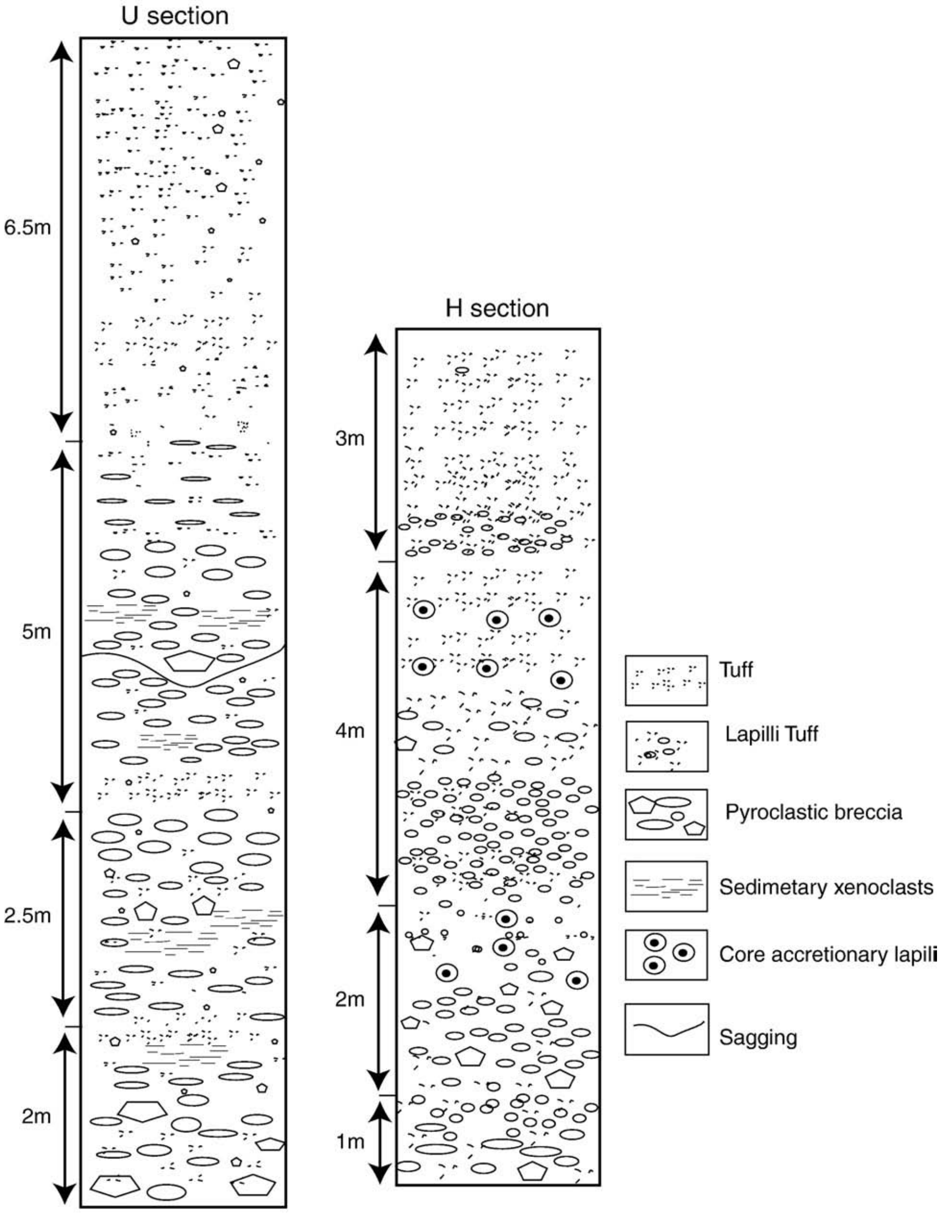

Fig. 4. Representative type sections of pyroclastic pile at Debunscha Maar showing facies variations and syndepositional features (depositional features and clasts sizes are not drawn to scale).

regolith. Accretionary lapillis, although observed in the middle of the section at the SE (section H), occur mostly on the surface at the very distal locations away from the crater.

4. Tephra characteristics and depositional features

Using the classification scheme of Schmid (1981), the pyroclastic tephra at Debunscha comprises tuff, lapilli-tuff and pyroclastic breccia. The tuff units made of ejecta with particle sizes ≤2 mm (Fig. 5a) dominate at the top of the deposit and at distal locations. The depositional features common in the tuff units are internal planar lamination and millimeter cross laminations. Pinch out, dunes as well as bomb sag depositional features are also present. The cognate and juvenile blocks were responsible for the formation of the impact sags. The frequency of such sags decreases laterally away from the crater and vertically from the bottom to the top of the tephra sequence. The dunes observed in the DM tephra sequence are asymmetrical and are classed type b according to Cole (1991) and type III structures according to Schmincke et al. (1973). Other soft sediment deformation structures like contoured laminae or undulating bedding that are related to cohesive fine ash deformation also occur.

The lapilli-tuff is made of fragments that are ≥2 mm (generally 2–10 mm) and vary from juvenile to lithic clasts. The clasts here are mostly angular and sub angular to sub rounded with the juvenile clasts having quenched surfaces, cracked and curved margins, and being almost non-vesicular. The lapilli-tuff is the most frequent type of tephra in the Debunscha pyroclastic deposit. The accretionary lapilli (Fig. 6b) are predominantly oval to spherical in shape measuring between 1 and 3 mm in diameter. At very distal locations especially at the Debunscha settlement areas (see map), armoured or mantle (Waters and Fisher, 1971; Fisher and Schmincke, 1984) or rim type (Schumacher and Schmincke, 1991) accretionary lapilli fragments are dominant in the tuff. Core type (Schumacher and Schmincke, 1991) accretionary lapilli appear at the middle of the pyroclastic section at the SE location (section H). The most conspicuous depositional feature shown by the lapilli-tuff is millimeter to centimeter planar layering

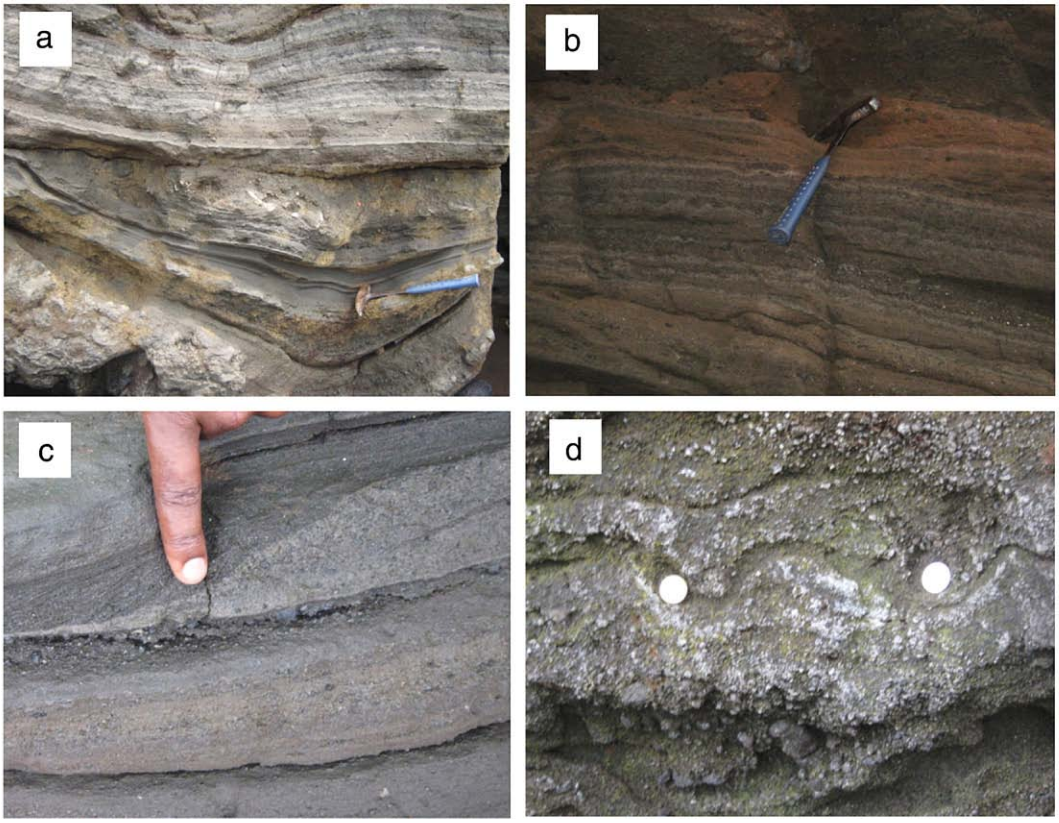

Fig. 5. Representative photographs of (a) general view of the tuff units. Note that the very fine tuffs are being eroded away faster (b) general view of the Lapilli-tuff showing some planar laminations. (c) Lithic lapilli rich lens that fine out (d) contoured laminae.

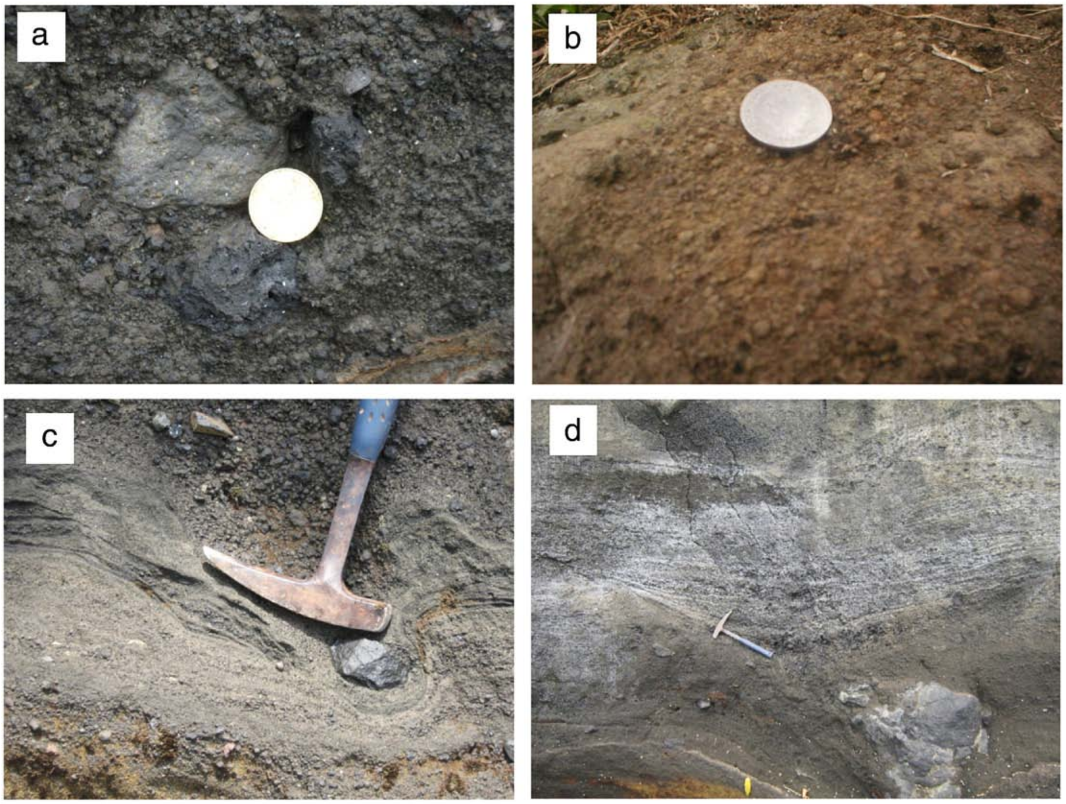

Fig. 6. Representative photographs of a) the pyroclastic breccia unit (b) armored accretionary lapilli, (c) impact sags caused by block (d) small channel structure that is filled mostly by tuff.

defined by grain size variations or matrix content, normal and reverse grading in some beds, lapilli-filled lens, and channel structures filled in most cases by sparse clast-supported materials.

The third group of tephra comprises those that are larger than the coarse ash and lapilli which we refer to generally as pyroclastic breccia (mostly bombs and blocks). Generally, these units are most common in the lowermost parts of the exposed pyroclastic pile where mixed country-rock clast populations consisting of weathered and unweathered pillow ankaramite lava pieces, lens-shaped shale clasts measuring between 20 and 50 cm long and lithified sandstones (Fig. 7a–c) occur either together in the same horizon or successively in different horizons. The lithified sandstone clasts, some measuring up to 40 cm long, have well preserved primary planar bedding. Two particularly notable features of the ankaramite pillow lava is that most show gradational changes in vesicle size and density from the interior to the quenched glassy surfaces and also they occur only mostly at the base of the deposit. The juvenile populations are fresh volcanic bombs with some measuring up to 14 cm. Clast sizes and rock type variability decrease both vertically and away from the crater. In the distal zone, moderate and very fine sequences occur at the top of the sections although in very rare cases isolated bombs are also found. The beds in this tephra unit are generally massive with some beds showing faint internal stratifications.

5. Interpretation

The juvenile olivine basalt clasts have low to almost no vesicularity and quenched surfaces. They are often fragmented, angular with sharp edges. Low vesicularity of juvenile blocks in such a deposit is an indication that the explosive release of magmatic volatiles played only a limited role in eruptive behaviour and that much of the energy for explosions came from conversion of external water to steam (Schmincke, 1977; Befus et al., 2008). Quenched surfaces of juvenile bombs also imply quenching and granulation at magma–water contacts at depth, minor degassing and steam explosion (Schmincke, 1977).

Accretionary lapilli, which are strong evidence of abundant water in a transporting system during phreatomagmatic eruptions (Crowe and Fisher, 1973; Lorenz, 1974; Schmincke, 1977; Lorenz, 1985; Wohletz, 1998; Nemeth et al., 2001) are also widely spread laterally in the study area especially at distal locations from the crater. Accretionary lapilli, impact sags, dunes, cross and planar laminations indicate the presence of water at the surface during the emplacement of the tephra sequence. Impact sags indicate the abundance of moisture and wetness (Crowe and Fisher, 1973; Lorenz, 1974, 1985; Wohletz, 1998; Nemeth et al., 2001) although impact sags on the other hand are also indicative of the plastic deformations of beds underneath the blocks (Lorenz, 1985) as well as the energy of ejection. Cross bedding and contoured laminae in the tuff units signify lateral density current transport of the tephra by turbulent base surges (Fisher and Waters, 1970; Waters and Fisher, 1971; Druitt 1998; Wohletz, 1998). The presence of both juvenile as well as cognate ejecta notably at the base of the sequence, is a result of the explosive contact between magma and ground water (Stearns and Vaksvik, 1935).

The coarse-grained units with no grading or poor stratification at the base of the deposit are interpreted as products of high grain concentration surge pyroclastic density currents after emplacement of pyroclastic material from the eruption column. Reverse grading or a coarsening upward sequence encountered in some beds at the Debunscha phreatomagmatic deposit points to the development of high particle concentration traction carpets in the basal parts of these surges (Sohn, 1997).

As explained by Houghton and Smith (1993) a mixture of a variety of clasts from a phreatomagmatic deposit points probably to explosive releases of heterogenous batches of magma coupled with the recycling of clasts during repeated phreatomagmatic eruptions.

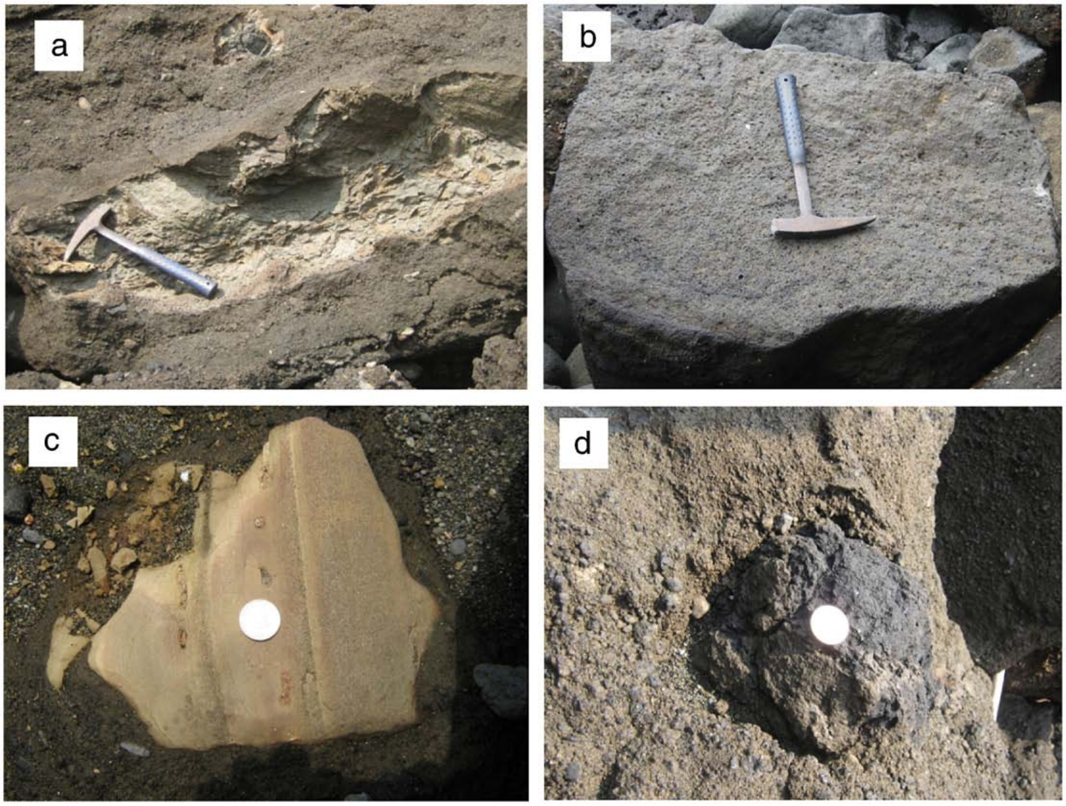

Fig. 7. Representative photographs of ejecta types (a) entrained lithic shale (b) entrained lithic lava with vesicle gradation (c) sandstone with planar lamination and (d) Juvenile basaltic bomb.

In the Debunscha tephra sequence, we have intermixture of lithics (ankaramite pillow lavas, sandstones, shale) and juvenile basaltic ejecta. The population of these clasts decreases both laterally away from the crater and vertically up the deposit. This suggests that the initial high-energy 'throat-clearing' events caused by the interaction of the ascending magma with ground water was explosive resulting in the ejection of large numbers of non-juvenile clasts. As the eruption progressed, water availability in the conduit decreased and the eruption became progressively more Strombolian, emitting more fines. The abundance of lithic ejecta in the deposit also implies significant quarrying of the vent zone (Nemeth, 2003) as a result of high-energy phreatomagmatic explosion (Zimanowski, 1998) and indicates a complex fragmentation regime (White and Schmincke 1999).

6. Discussion

The observed depositional features at DM, including dunes, channel structures, impact bomb sags underneath blocks and bombs and lateral thinning of the deposit away from the crater are typical, for maar tephra (Lorenz, 1985; Gençalioğlu-Kascu et al., 2007) and by direct fallout from eruption columns during pulsatory phreatomagmatic eruptions (Befus et al., 2008).

As in many other subaerial phreatomagmatic eruptions that form maars, we infer from the lithology (entrained lithics and juvenile clasts) and the above textural characteristics found in the Debunscha pyroclastic deposit that there was an interaction of water and rising magma during this eruption. There is however no evidence of standing bodies of surface water prior to or during this eruption and the non-vesicular juvenile magma appears volatile-poor, so we infer that the only likely source of water to fuel this eruption was ground water (Lehman, 1985; Bohanan, 1987; White, 1991, 1996; Hanson and Elliot, 1996; Lorenz, 2003a,b; McClintock and White, 2006; Ross and White, 2006). Phreatomagmatic activity possibly was initiated by simple rise of magma through a single vertical conduit from greater depth and interacting with groundwater. As the eruption progressed, the conduit was steadily cleared of lithics and its walls sealed by a chilled margin such that in the waning stages of the eruption, entrained lithics plucked from the walls of the conduit decreased. Chilled margins prevented further groundwater flux to the conduit

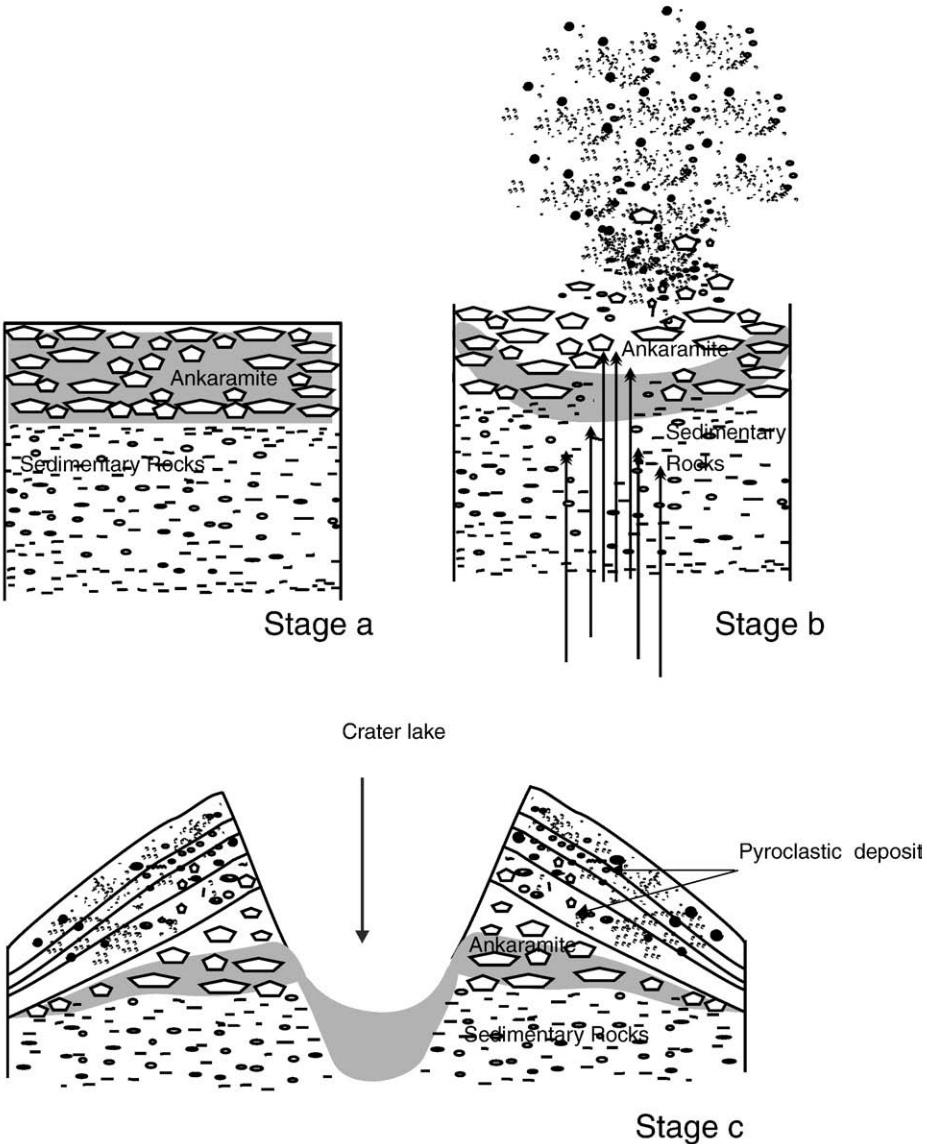

Fig. 8. Constructed model for the eruption (a) pre-eruptive stratigraphy with the porous ankaramite pillow lavas hosting the water (b) ascend of the hot magma through the sedimentary formation and then to the groundwater aquifer (c) resulting stratigraphy with the sedimentary formation at base followed by the porous ankaramite formation and lastly the pyroclastic deposit at the top. Crater resulting crater filled with water.

with an attendant decrease in violent explosions. The possibility that water supply was also simply depleted cannot however be overlooked but is more difficult to visualize in this setting. If phreatomagmatic activity at DM involved the emplacement of dykes at shallow depths (therefore more than one conduit), phreatic pipes (Elliot et al., 2007) arising from the vaporization of groundwater would have been preserved. Also, phreatomagmatic activity wherein magma ascended through multiple conduits usually results in the formation of a vent complex or nest of diatremes (McClintock and White, 2006; Ross and White, 2006) characterized by steeply dipping contacts between various volcaniclastic rocks of contrasting lithology. This has not been observed at DM.

The occurrence of lithic clasts where population decreases both laterally away from the crater and vertically from bottom to the top of the deposit as well as the absence of an advanced erosional surface or paleosol suggests monogenetic activity at Debunscha. When the phreatomagmatic explosions of a maar volcano finally come to an end, the crater typically fills with water. Lavas erupted subsequently into lakes impounded within maars are generally characterized by pillow lavas, peperite and hyaloclastites. At DM, pillow lavas are restricted to the base of the tephra deposits suggesting that since the lake was impounded within the maar, lava has not been erupted into it. This provides further support for the monogenetic nature of the maar.

Unlike other phreatomagmatic eruptions where soft sedimentary rocks have acted as the aquifers for the groundwater (Lehman, 1985, 1991; Bohanan, 1987; White, 1991, 1996; Befus et al., 2008), the lithified sandstones and shales at the Debunscha deposit are unlikely to have either the porosity (inherent water content) or the permeability (to transport water to the site of eruption in sufficient quantities) to provide the water necessary to drive such phreatomagmatic activity. Pillow lava, on the other hand, is known from the seafloor to have porosities of 10–30% and bulk permeabilities as high as 10^{-9} m^2 (Fisher, 1998), one to two orders of magnitude above those in uncemented sandstones (Bear, 1972). We assume this formation provided the water to fuel the phreatomagmatic activity, an assumption in accordance with the predominance of ankaramite blocks in the lowermost (and hence initial) tephra deposits. We suggest that particularly the weathered ankaramite blocks, some of which are found at the base of the deposit, were at the (submarine?) Earth's surface and thus suffered weathering prior to the onset of the phreatomagmatic eruptions. As the eruption progressed the crater excavation continued, leading to the incorporation of sedimentary clasts from the formations below the pillow lavas (Fig. 8a–c).

7. Conclusions

This contribution throws light on the field characteristics of the deposit at the Debunscha Maar (DM). The observed depositional characteristics such as the internal plan lamination, millimetric cross bedding in some cases, pinch and swell along sections showing micro dune, channel structures, impact sags are all typical for maar eruptions. The variability of clast populations, from lithics to juvenile occurring together in the deposit signifies complex fragmentation processes during the eruption. Abundance of the lithic fragments equally signifies quarrying of the vent zone. Evidence from entrained lithics, juvenile clasts and especially accretionary lapilli point to the fact that water played a role during the eruption at the Debunscha. Evidence from the entrained country rocks and their stratigraphic distribution within the maar deposits shows that (1) the area is underlain by indurated sedimentary formations and (2) pillow lava flows presumably from Mt Cameroon provided the aquifer necessary for the phreatomagmatic maar activity.

However, further studies on the relationship between the DM volcanic activity and tectonic features such as the Douala basin to the SE and the Rio del Rey basin to W of Mt Cameroon are necessary to shade more light on the possibility that this activity postdated the Cretaceous sedimentation phase in these basins and actually resulted in the separation of what was once a single basin into these two basins. Compositional and textural variations in ejecta along the profiles are also necessary to test the hypothesis of chilled margin preventing water to reach the conduit at some stage. These will also elucidate conduit processes operational during the DM eruption. As long as the age of this maar remains unknown, its relations to eruptions of the broader Mt Cameroon will remain also elusive.

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