

SPINNING DROPLETS - A CONSPICUOUS LAPILLI-SIZE STRUCTURE IN KAMAFUGITIC DIATREMES OF SOUTHERN GOIÁS, BRAZIL

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RESUMO *SPINNING DROPLETS - UMA ESTRUTURA TAMANHO LAPILLI, CONSPÍCUA EM DIATREMAS KAMAFUGITICOS DO SUL DE GOIAS, BRASIL* Lavas, diques e diatremas ocorrem na região de Águas Emendadas, sul do estado de Goiás, formando parte da Província Ignea Rio Verde-Ipora, de idade Cretáceo Superior. Foram reconhecidos diversos tipos de fragmentos juvenis na matriz das brechas de fácies diatrema, incluindo *armoured lapilli*, *frozen droplets* e *spinning droplets*. Este trabalho descreve os *spinning droplets* e propõe um modelo para sua geração em diatremas.

Palavras-chave: spinning droplets, kamafugito, diatrema, lapilli

ABSTRACT Kamafugitic lavas, dykes and diatremes occur in the Águas Emendadas Region, southern Goiás, forming part of the Late-Cretaceous Rio Verde-Ipora Igneous Province. A variety of lapilli-sized juvenile fragments occurring in the matrix of diatreme-facies breccias were recognised. These include *armoured lapilli*, *frozen droplets* and *spinning droplets*. This work describes the spinning droplets and proposes a model for their formation in diatreme environments.

Keywords: spinning droplets, kamafugite, diatreme, lapilli

INTRODUCTION In southern Goiás, a number of Late-Cretaceous volcanic, pyroclastic and intrusive alkaline rocks are emplaced close to the northern border of the Parana Basin. These rocks were collectively called the Rio Verde-Ipora Igneous Province (RVIIIP) by Almeida (1983). Among other petrographic types, occurrences of kamafugites in the province have been reported by Danni (1985), Danni & Caspar (1994) and Sgarbi *et al* (1998).

Diatremes, dykes and lava flows with kamafugitic affinity occur in the Águas Emendadas region, located between the towns of Amorinópolis and Montividiu (Junqueira-Brod 1998, Junqueira-Brod *et al.* 1999). The diatremes are infilled mostly by breccias, containing fragments of variable origin, shape and size (up to 3m in diameter). According to their origin these fragments can be classified as cognate, accidental, accessory and juvenile (Cas & Wright 1987). The cognate fragments range from highly porphyritic kamafugites to cumulates of pyroxene and olivine. They are non-vesicular rocks, crystallised from the magma prior to eruption (autoliths). Accessory and accidental fragments correspond to rocks from the conduit wall and diatreme roof respectively, caught by the magma during ascent and eruption (xeno-

liths and xenocrysts). They are represented by granites, gneiss, amphibolites, schists and quartzites from the Pre-Cambrian basement, sandstones from the Parana Basin and other alkaline rocks, mainly leucitites of the RVIIIP. Juvenile fragments are samples of the erupting magma and their shape and size are directly associated to the physical behaviour of the magma during ascent and eruption. They have kamafugitic composition and may be vesiculated. Such a wide variety of fragments in the breccias is the combined result of complex processes involved in the formation of the diatremes (Junqueira-Brod *et al.* 1999).

The breccia matrix consists of a polilitic lapilli tuff (Junqueira-Brod 1998) containing the same types of fragments above, together with pyroxene, olivine and alkali feldspar crystals and ash. The juvenile fragments are dominant, vary in size from ash to lapilli, and are usually rounded. Three main types of juvenile fragments are recognised (Junqueira-Brod 1998): *armoured lapilli*, *frozen droplets* and *spinning droplets* (Fig. 1). The scope of this work is to describe the spinning droplets, a peculiar lapilli-sized fragment whose origin appears to be closely linked with the magma composition and the diatreme environment.

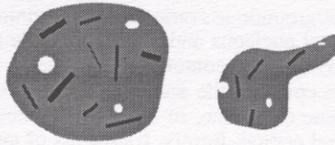
LAPILLI SIZE STRUCTURES				
structure	size	shape	description	model
armoured lapilli	lapilli	variable	presence of a core, composed of a lithic or crystal fragment (Pre-Cambrian rocks, sandstone, alkaline rocks, alkali feldspar), and a rim made of ash.	
"frozen droplets"	variable	variable	composed by microphenocrysts of pyroxene and olivine, vesicles filled with carbonate and a glassy groundmass. The shape is variable but with rounded contours.	
"spinning droplets"	lapilli	spherical	presence of a core composed of phlogopite, pyroxene, olivine or a lithic fragment. The rim comprises a microcrystalline groundmass and a great number of microphenocrysts orientated concentrically around the core.	

Figure 1 - Main characteristics of the juvenile lapilli-size fragments found in the Águas Emendadas diatremes

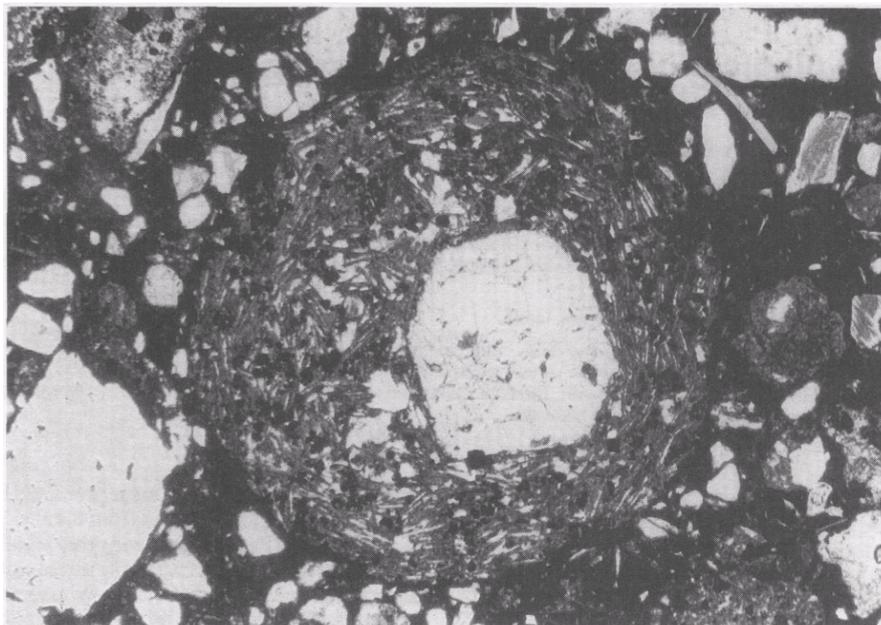


Figure 2- photomicrograph of a spinning droplet. The particle is composed of a pyroxene core and a concentrically oriented, microporphyritic rim. Field of view is 5x3.5mm. Plane-polarized light.

SPINNING DROPLETS The name "spinning droplet" was proposed by Junqueira-Brod (1998) to describe a type of spherical juvenile fragment, up to 12mm in diameter, composed by a crystal core and a densely micropo/phyritic rim with concentric-orientation structure, occurring in the Aguas Emendadas diatremes (Fig. 2).

Somewhat similar structures have been described in other alkaline rocks, such as carbonatites, kimberlites and melilitites, and have been given different names, such as: "pelletal lapilli", "spherical lapilli", "tuffisitic lapilli" and "concentrically shelled lapilli" (e.g. Clement 1973, Dawson 1980, Clement & Skinner 1985, Mitchell 1986, Keller 1989, Dawson *et al.* 1992, Stoppa & Lavecchia 1992, Stoppa & Lupini 1993, Mitchell 1995, Stachel *et al.* 1995, Stoppa 1996, Stoppa & Principe 1997, Stoppa & Woolley 1997, Kurszlaukis & Lorenz 1997, Lorenz & Kurszlaukis 1997). However, all the above classifications carry limitations derived either from the definition itself or from the misinterpretation of processes involved in the genesis of these structures. The name spinning droplets is applied exclusively on a textural sense, avoiding any size and/or origin implications (Junqueira-Brod 1998).

Macroscopically, the spinning droplets resemble armoured lapilli, but can be easily distinguished from the latter under the microscope, by the presence of a rim composed of oriented microphenocrysts plus devitrified glass, instead of ash. Furthermore, they are invariably spherical, whilst armoured lapilli can mimic the shape of their core. The third type of juvenile lapilli, frozen droplets, are distinguished by their lack of concentric orientation, a smaller microphe-nocryst/groundmass ratio than the spinning droplets, frequent absence of crystal nucleous and a more variable shape, although always outlined by rounded contours.

The cores of the spinning droplets can be made of phlogopite, pyroxene or olivine, in this order of abundance, usually as a single euhedral crystal. Rarely, fragments of cumulates are also found. Together, phlogopite and pyroxene make up the core of about 80% of the studied particles. The crystal core is situated almost invariably in centre of the particle, although some degree of eccentricity is present in rare individuals. The size of the cores is limited to less than half the diameter of the particle, in most cases.

The rim is formed by a dense aggregate of concentrically oriented prismatic microphenocrysts, immersed in a glassy groundmass. The microphenocrysts are represented by pyroxene and probably melilite, with subordinate oxides, olivine, carbonate and phlogopite.

DISCUSSION Structures such as the spinning droplets are often found in diatremes (e.g. Clement & Skinner 1985, Mitchell 1995, Lorenz & Kurszlaukis 1997, Kurszlaukis & Lorenz 1997, Junqueira-Brod 1998). Therefore, their origin must be somehow linked with processes occurring in diatreme environments. Mitchell (1995) gives

a summary of the ideas about diatreme formation in association with kimberlitic magmatism, while Lorenz & Kurszlaukis (1997) extend the studies for carbonatite-related volcanism. The latter authors, among others, consider two possible alternative processes, relevant to the formation of diatremes: a magmatic and a phreatomagmatic model.

The magmatic model involves rapid exsolution of a volatile phase, with the particles being transported in a gas-liquid fluidized system, resulting in a "cold" emplacement. MacCallum (1985) studied fluidization experimentally and suggests that it is an important process in the formation of breccia pipes. A turbulent movement is required to produce a well-mixed system, as is the case in diatreme facies. In this context, the spinning droplets would be formed inside the conduit, during the ascent of the fluidized mixture, in a similar way as proposed by Clement (1973) and later by Dawson (1980).

The phreatomagmatic eruptions are the result of hot magma interacting explosively with a body of cold water, a process also known as fuel-coolant interaction (e.g. Sheridan & Wohletz, 1983; Cas & Wright, 1987). Authors who adopt this model to explain the formation of diatremes and associated deposits include Lorenz (1979), Zimanski *et al.* (1997), Kurszlaukis & Lorenz (1997) and Lorenz & Kurszlaukis (1997). In this model the fragmentation of the magma is not taken into consideration. The origin of the spinning droplets would have to be explained by magma adhering to a previously crystallised nucleous, due to surface tension, followed by rotation of the droplets during transport (Mitchell 1995). In the rocks that form the Aguas Emendadas diatremes there is no strong evidence of magma-water interaction. Therefore it is unlikely that a phreatomagmatic component contributed for the formation of the spinning droplets.

An alternative model for the formation of particles like the spinning droplets is presented by Stoppa (1996), but it requires, by definition, a mantle xenolith/xenocryst as a core for each lapillus and a magma with carbonatitic-melilititic affinity (Stoppa 1996, Stoppa & Woolley 1997). In this model the magma comes directly from the mantle at high velocity and the liquid adheres to a xenolith core. The cores found in lapilli from Aguas Emendadas region seem to be crystals formed an underlying the magma chamber and entrained by magma prior to the eruption. There is no evidence linking them with a mantle origin. Association with carbonatitic magma can neither be proved, nor ruled out at the present stage.

The model envisaged here for the formation of the spinning droplets in kama-fugitic diatremes is an adaptation of the process suggested by Clement (1973) and Dawson (1980), and later summarised by Mitchell (1995). It is proposed that the spinning droplets are formed by the rotation of magma droplets during ascent in a fluidized system. This mechanism requires fragmentation and high velocity of the rising magma or mixture, in order to form and spin the droplets. Most of the existing models presume fragmentation of the magma through volatile

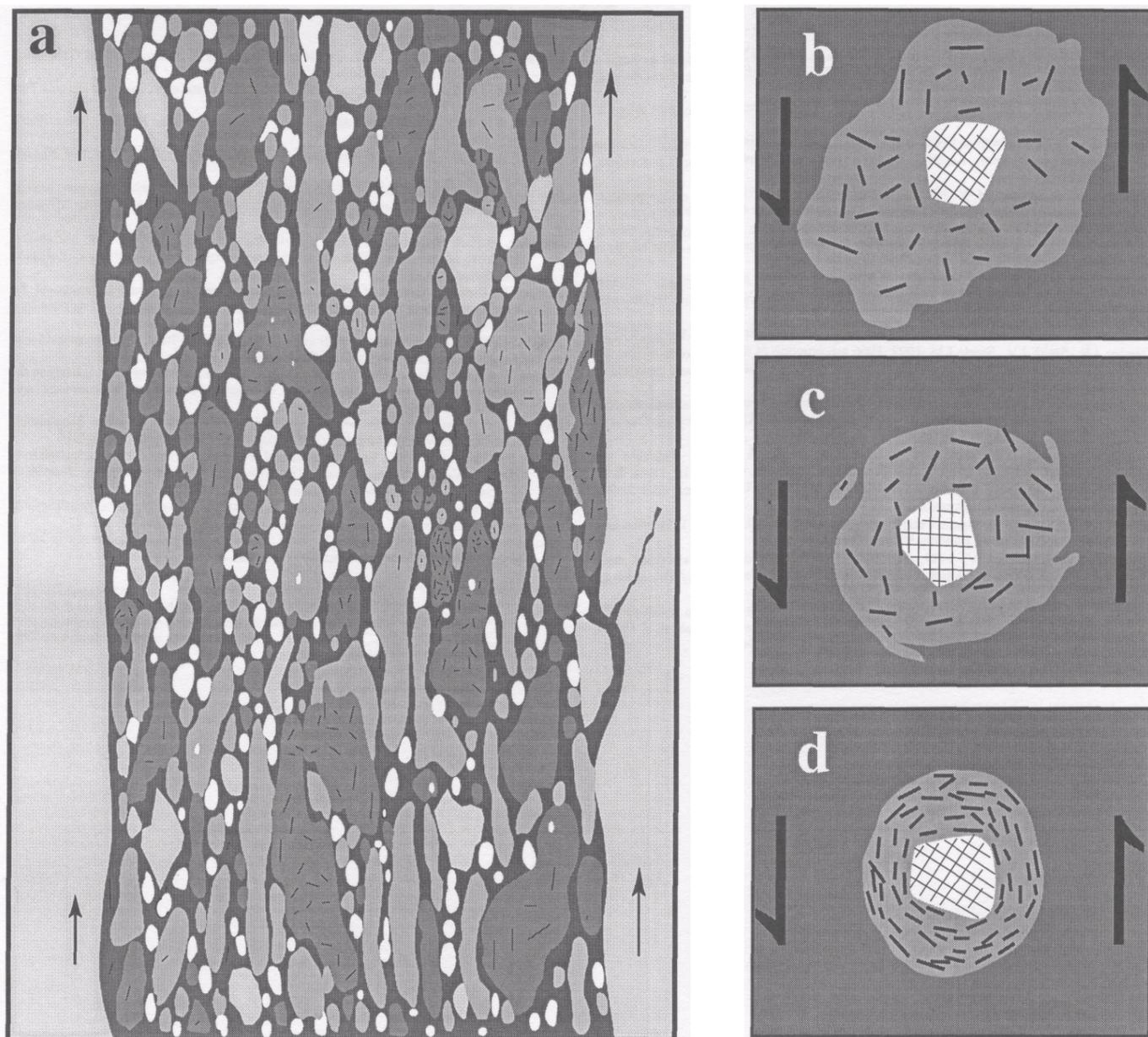


Figure 3 - Schematic model for the processes involved in the formation of spinning droplets. The microporphyritic magma droplets spin in the conduit, during the ascent of a fluidized mixture, orienting the microphenocrysts around the crystal core and becoming spherical in shape, a) detail of the rising fluidized mixture in the conduit, it is important to notice the high degree of fragmentation of the mixture, b) first stage of the spinning droplets formation, a magma droplet starts to spin, c) while spinning, the droplet loses part of the liquid fraction concentrating microphenocrysts. d) the rotation, combined with the increment in the microphenocrysts/groundmass ratio, result in the final, spherical, concentric particle.

exsolution and/or interaction with cold water during rapid ascent from the mantle source to the surface. However, field, petrographic and chemical evidence from Aguas Emendadas suggests that a number of magma chamber processes occurred during magma evolution (Junqueira-Brod 1998). These include fractionation, with the formation of cumulates, and mixing of at least two different magmas. It is suggested here that magma fragmentation was triggered within the magma chamber, by magma mixing, volatile exsolution (high vesiculation), liquid immiscibility or a combination of two or more of these processes. In this scenario, the mixture rising from the chamber to surface would consist of several phases of contrasting composition and density, including droplets of partially crystallised magma. The density contrast during the rise of the fluidized mixture at high velocity, would result in relative movement between the different phases, favouring the rotation of the magma droplets in localised domains (Fig. 3). During rotation there must be the concomitant action of two processes: a) the liquid phase within the spinning droplets must be fluid enough

to allow the phenocrysts to be concentrically oriented, b) some of this liquid fraction must be lost, probably by a spinning-induced filter pressing process, to explain the much higher microphenocryst/groundmass ratio of the spinning droplets, in comparison with the frozen droplets. The combined action of rotation and partial loss of liquid would favour the achievement of the nearly-spherical shapes (see Fig. 3b to d). When they reach the surface the droplets are already shaped. Particles such as the frozen droplets are likely to represent the non-spun equivalents of spinning droplets, generated in a lower energy, late-stage eruption.

A detailed study of the spinning droplets, including experimental modelling and further comparison with similar spherical structures elsewhere is required, in order to achieve a full understanding of their origin.

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