http://dx.doi.org/10.18268/BSGM2024v76n3a130224

and U4 units, but less than those in Yaxcopoil-1. In Yaxcopoil-1, the basal surges suggest collapse of the ejecta plume under turbulent conditions as proposed by Wittmann *et al.* (2007) with data on the particle shapes, lack of particle selection and their random orientations. For the Yax U3 or US units considered as a fallback ejecta a temperature gradient towards the top is indicated. The deposit for Yax U1 and U2 units, suggests less turbulence, indicated by clast selection (Wittmann *et al.*, 2007).

The vector diagrams for thermal demagnetization of samples from the upper section U2 to U3B units show single to two component magnetizations, with characteristic components. Some samples show inflection points, in 350°C and 525 °C. The AF demagnetization vector diagrams show one or two components of medium coercivity between 20 and 45mT and high coercivity from 50 to 70mT.I In some cases the component deviates from origin indicating remagnetization o incomplete separation of high coercivity components.

The upper section shows zones with fewer clasts but large sizes such as the upper part of the unit U2A, lower part of units U2B, unit U3A, and lower part of the U3B. Zones with small size clasts are the lower part of the unit U2A and upper part U2B and U3B. U3B-U2 units may have been deposited in less turbulent environmental conditions and temperatures, which correspond with the fallback suevites drilled in the Yaxcopoil-1 borehole. The U1 appears similar to the USS and LSS units from Yaxcopoil-1 borehole, interpreted as late fall back breccias, but more studies are needed.

Pilkington *et al.* (2004) reported that Fe-oxide phases comprising limonite-goethite, magnetite, and Fe-Ti oxides occur in the impactite section of Yaxcopoil-1. Magnetite, Fe-oxyhydroxides and Fe-Ti oxides are secondary minerals in the matrix, in addition of microlites, diopside, and plagioclase, vesicles associated with quartz and clay minerals, and veins with K-feldspars and albite. Planar deformation features PDFs are observed in up to three directions. Diaplectic glass mosaicism and fluidal morphologies have been documented in Tuchscherer *et al.* (2004), also in the Yaxcopoil-1 breccias.

The characteristic inclinations vary over a wide range, larger than expected from paleosecular variation effects (Figure 6). This could indicate magnetization components acquired over extended periods and incomplete removal of secondary magnetizations. Impact breccias are characterized by complex paleomagnetic records, associated with the magnetic mineralogy, high energy emplacement and alteration processes (Halls, 1979; Elmore and Dulin, 2007; Fairchild *et al.*, 2016).

Further analyses are needed to constrain the magnetization components in the breccias and the relations to emplacement mode. The Santa Elena polymictic breccias are highly heterogeneous, with clasts of melt, basement and carbonates in a melt rich or carbonate rich matrix. Different emplacement conditions were involved, from high temperature basal surges to fall back breccias and reworking (Stoeffler *et al.*, 2004; Tuchscherer *et al.*, 2004; Kring *et al.*, 2004; Wittmann *et al.*, 2007). The remanent magnetization is probably a thermochemical or chemical magnetization, acquired after breccia emplacement. Studies of the geomagnetic field in the Mesozoic have documented an interval of constant polarity during the Cretaceous normal polarity superchron. Recent studies have focused on the paleointensity record during the superchron and extended to the K/Pg boundary interval (Goguitchaichvili *et al.*, 2004, 2023). Studies have analyzed the relationships among the frequency of reversals, secular variation and the intensity of the magnetic field. In the period before the K/Pg boundary the reversal frequency increased to around a reversal per million years.

The studies with high resolution magnetostratigraphy at the K/Pg boundary consider the paleosecular variation changes and strength of the field, in addition to the polarity changes (Zhu *et al.*, 2003; Goguitchaichvili *et al.*, 2004).

The characteristic magnetizations with upward inclinations are carried by magnetite and Ti-poor titanomagnetites, with low-intermediate coercivities and distributed 300o-600o C unblocking temperatures. Pilkington *et al.* (2004) analyzed the magnetic mineralogy of the breccia section in the Yaxcopoil-1 borehole, showing that the dominant magnetic phase is magnetite formed by low temperature <150o C alteration. The secondary magnetite is associated with quartz and clays and in fine plagioclase-diopside aggregates in the melt. This association is observed for the Fe-Ti oxides and Fe-oxyhydroxides. Rock magnetic properties indicate magnetite and Ti-poor titanomagnetites (Urrutia-Fucugauchi *et al.*, 2014). Hysteresis loops for melt-rich breccias show saturation at low applied fields indicating low coercivity magnetic minerals. In the magnetization-coercivity ratio plot samples fall in the pseudo-single and multidomain fields. Curves of magnetic susceptibility as a function of temperature show irreversible behavior, with magnetic phases formed after heating to 700o C. Well defined Hopkinson peaks are observed between 500o and 570o C. Samples subjected to a second heating run to 700o C showed similar cooling/heating curves, with reduction of magnetic susceptibility.

The remanent magnetizations carried by the secondary magnetite are likely chemical remanent magnetizations, acquired after emplacement of the breccias. The hydrothermal activity, with hot fluids circulating through the fractured porous breccias might have resulted in secondary overprints acquired over an extended period, which accounts for the multicomponent and mixed polarity magnetizations in the Yaxcopoil-1 section (Urrutia-Fucugauchi *et al.*, 2004; Pilkington *et al.*, 2004; Velasco-Villarreal *et al.*, 2011).

5. Conclusions

Results of a study in the Santa Elena borehole are used to investigate the paleomagnetic record of the impact breccias. The impact breccias cored between 332 and 504 m depth are formed by melt, basement and carbonate clasts in carbonate-rich and melt-basement-rich matrix. Thermal and alternating field demagnetization show univectorial and two-component magnetizations, with upward inclinations and few downward inclinations. The dominantly upward magnetization inclinations in the breccia sequence are interpreted in terms of reverse polarity thermoremanent magnetizations acquired during the reverse polarity ch29r chron. Magnetic susceptibility varies from 5 to 5000 10^{-6} SI, with most between 5 to 2000 10^{-6} SI. The upper section has low susceptibilities, while the lower section shows higher susceptibilities. NRM intensity log shows similar trends, with intensities between 0 to 0.5A/m, mostly between 0 to 0.15A/m. The trends correlate with the lithological and mineralogical composition, with the textural and clasts and matrix composition, with melt and basement rich in the upper section and less abundant melt particles in the lower section.

The magnetic susceptibility and remanent magnetization intensity variations throughout the upper section suggest emplacement as a fall air deposit in relatively less turbulent conditions. The trend for magnetic susceptibility and NRM in the lower unit, clast composition and petrography suggest a high temperature gas emplacement as a basal surge deposit. Analysis of thermal and AF demagnetization vector diagrams and coercivity and unblocking temperature spectra support that the upper unit is a fallback suevite and the lower unit a high temperature basal surge.

Mineralogical and chemical analyses show hydrothermal alterations that vary with location in the crater and surroundings. This resulted in formation of secondary magnetic minerals. Additional studies are needed to analyze the secondary overprints and the magnetization acquisition mechanisms.

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Conflict of interest

Authors confirm that there are no known conflicts of interest.

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