# The Effect of Igneous Intrusion on the Mineral Matter in Coal, Moatize Bain, Mozambique

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## Introduction and Methods

This study investigated the mineralization trend in an Early Permian medium volatile rank coal seam approaching a Jurassic dyke that intruded the Bananeiras Seam, Moatize Basin, Mozambique (Figure 1 & Figure 2).

Four samples were selected from cores intersecting the seam at increasing horizontal distance to the dyke from 0m, 12.2m, 26.7m and 72.2m, respectively (Figure 2). In the literature, the relationship between the thickness of the dyke and its thermal effects varies, but is commonly thought to be 0.5 times the thickness of the dyke (Gurba & Weber, 2001). The width of the dolerite dyke intruding the Bananeiras Seam is approximately 26.7m (Figure 2), so the hypothesis was that the amount and diversity of epigenetic mineral species would decrease away from the dyke.

This was tested using SEM-EDS analysis to identify the mineral species and their modes of occurrence, and supported by optical microscopy analysis.

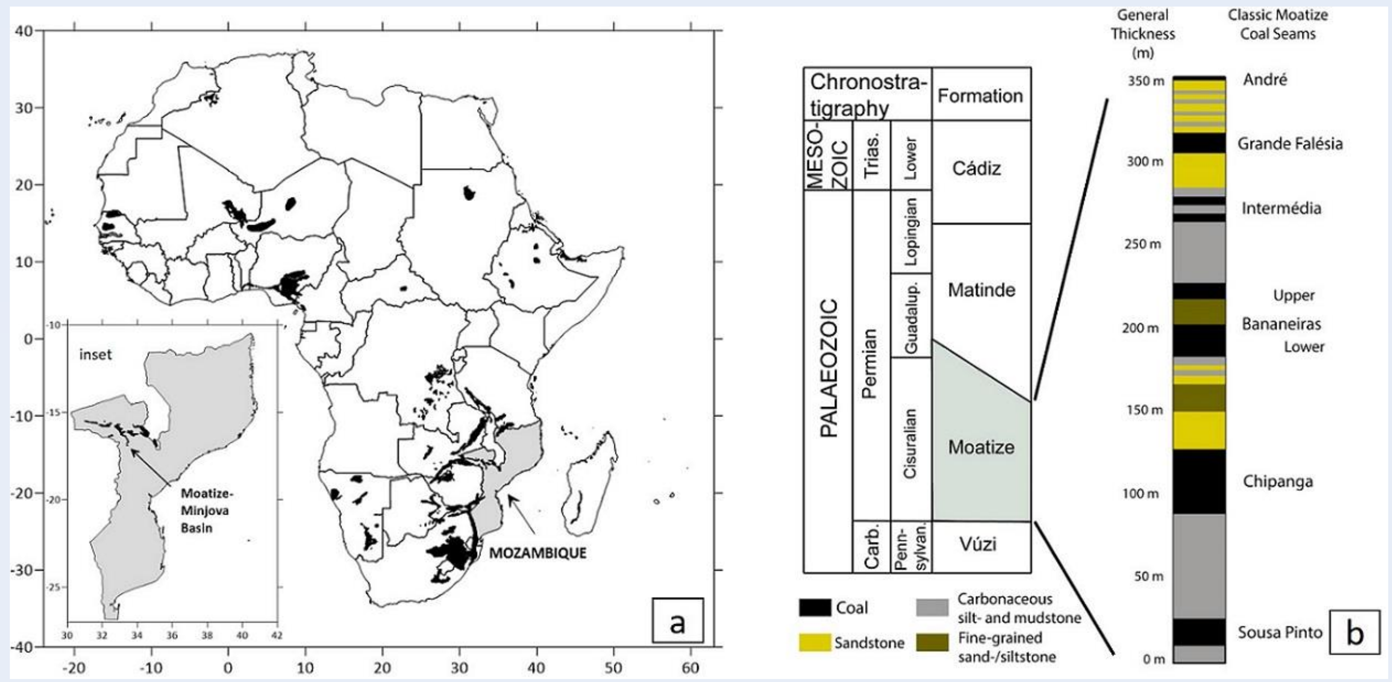


Figure 1a. The map of Africa continent and the location of Mozambique (grey), and the coal-bearing basin distribution (black). The arrow in the inset map points the site of Moatize-Minjova Basin (Merrill, & Tewalt, 2008). 1b.Stratigraphic column adapted from Lakshminarayana (2015) and Vasconcelos et al. (2014).

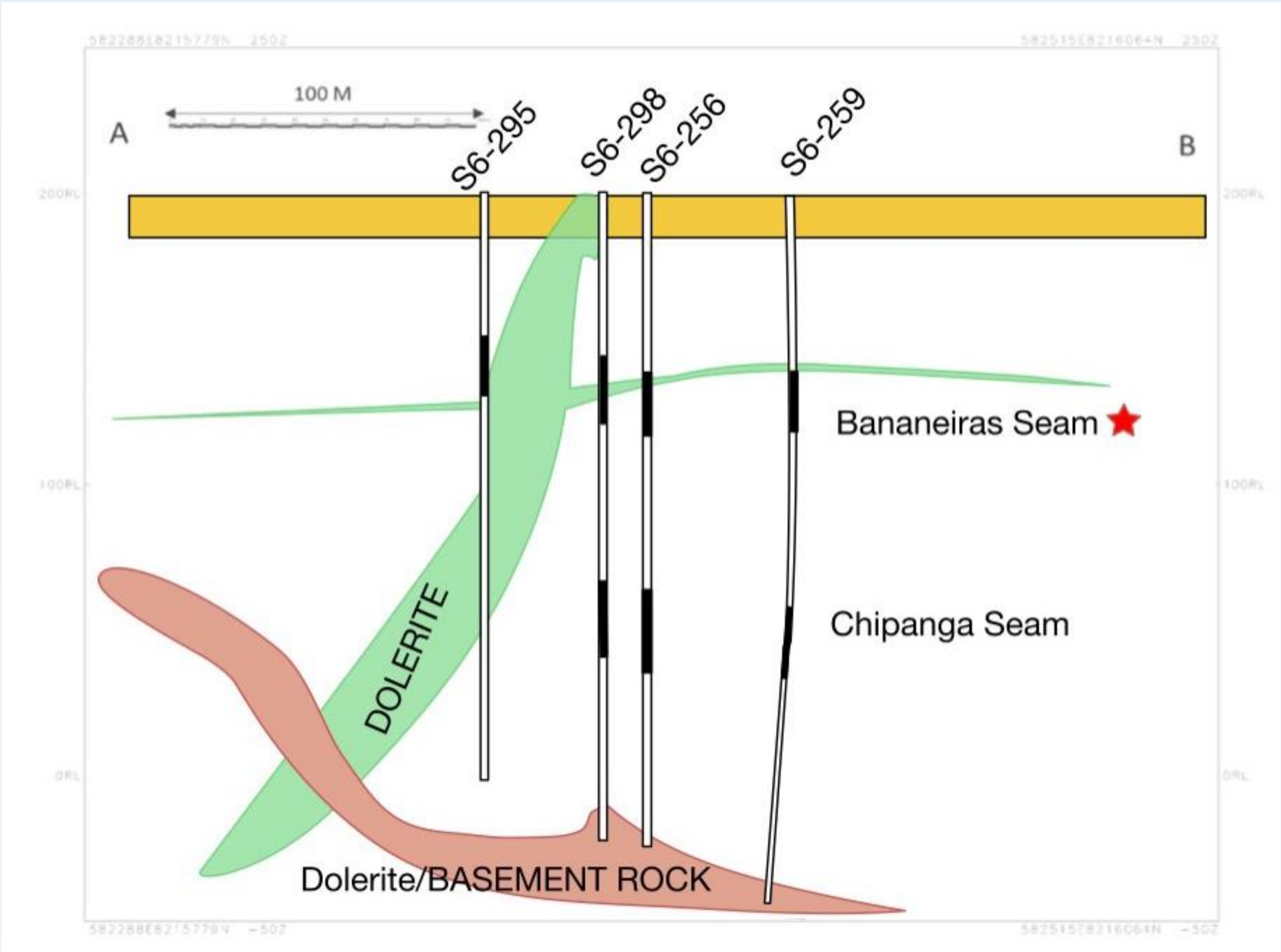


Figure 2. The conceptual cross-section of locations of samples (Bananeiras Seam) against the dyke.

## Results and Discussion

In all samples, epigenetic minerals are the major mode of occurrence, regardless of distance to the dyke, and detrital and syngenetic minerals occur in lower abundances. Quartz occurs as a detrital mineral, but is also found as euhedral crystals that developed in the devolatilization pores (Figure 3B and 3C), suggesting precipitation from hydrothermal fluids (Ward, 2016; Chen et al., 2014; Dai et al., 2014). Chamosite, illite, and K-bearing clay are the main clay minerals found in the samples, with minor amounts of kaolinite (Table 1). Clays do occur as detrital grains, but the main mode of occurrence is infilling in fractures and devolatilization pores, which suggests later stages of precipitation (Figure 3A and 3B). Chamosite is interpreted to have precipitated from Fe-Mg-rich siliceous fluids (Li et al., 2019; Rodrigues et al., 2020). Chamosite has also seen to surround apatite crystals in devolatilization pores (Figure 3A). This suggests that fluorapatite precipitated before the chamosite from Ca-rich fluids, then chamosite from Fe-Mg-rich siliceous fluids precipitated later (Ward, 2016; Permana et al., 2013; Rodrigues et al., 2020). Siderite is interpreted as both syngenetic and epigenetic from the second sample which is 12.2m away from the dyke (Table 1; Figure 3D and 3E). Siderite precipitated first at the borders of fractures, followed by ferroan dolomite precipitating towards the centre of fracture at a later stage. Syngenetic nodular siderite has been observed partially replaced by ankerite and chamosite (Figure 3D). Finkelman et al. (1998) suggested that $CO_2$ or CO from the heated coals can react with high Ca, Mg and Fe-rich fluids to form ankerite and chamosite. Pyrite is another abundant epigenetic mineral that also occurs as fracture and pore infillings in all samples (Figure 3F). Epigenetic pyrite is also commonly developed from high Fe and S fluid from igneous intrusion (Ward, 2016) and it is observed that epigenetic pyrite filled the spare spaces between other minerals which are already there, thus suggesting the S and Fe fluid precipitated in the last stage (Rodrigues et al., 2020).

The mineral occurrences in fractures and devolatilization pores (associated with thermal alteration) infillings suggest that the main reason for the formation of the epigenetic minerals in the coal is the precipitation from hydrothermal fluids related with igneous intrusions. The Si-rich fluids delivered epigenetic quartz, and Ca-, Mg-, Fe-rich fluids to form carbonates and clay minerals, and the late fluid rich in Fe and S deposited pyrite in fracture and devolatilization pores. The fluids also removed elements from minerals; e.g. siderite was altered and Fe ions were removed, and was replaced by ankerite or ferroan dolomite.

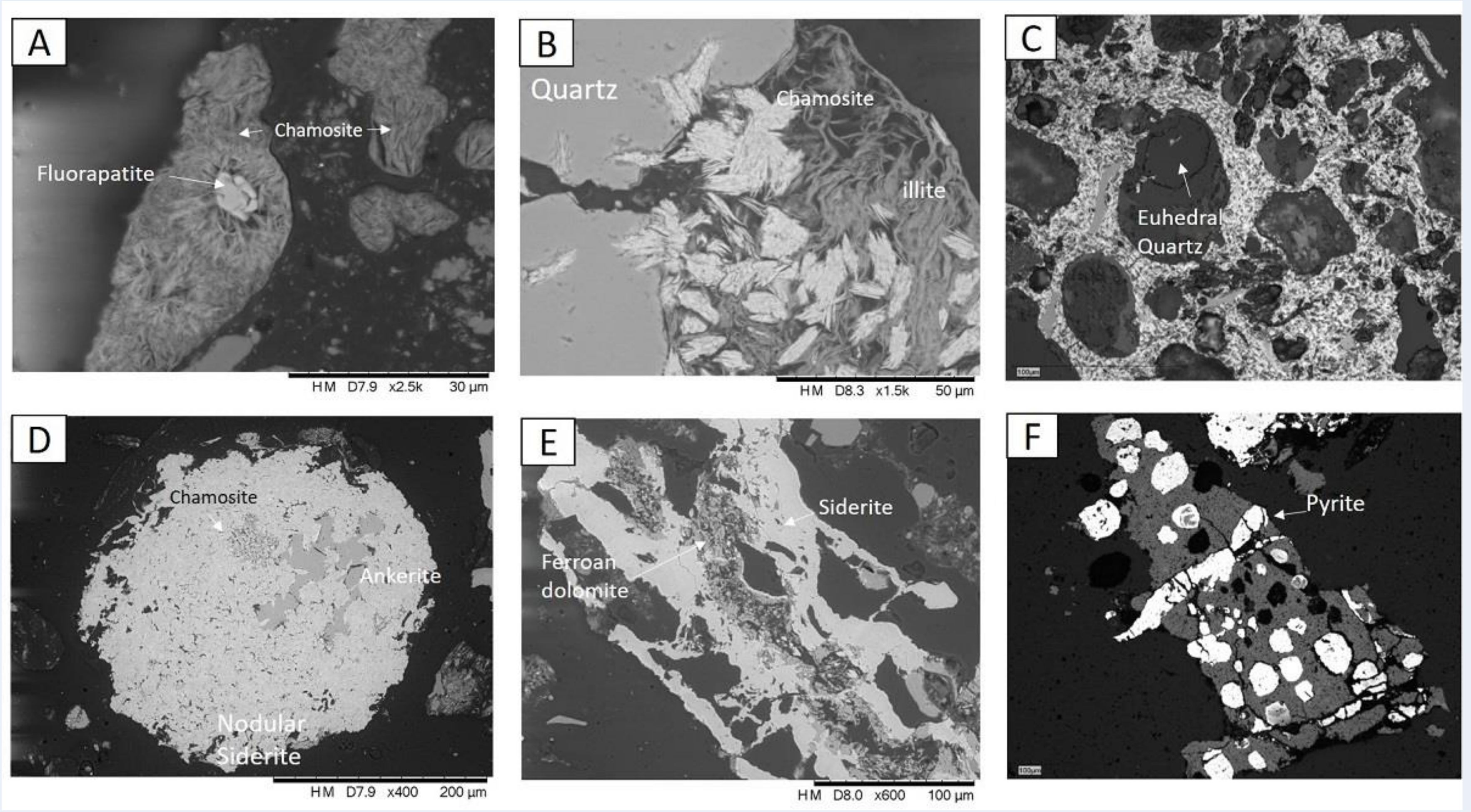


Figure 3A) SEM image showing chamosite and fluorapatite filled in devolatilization pores ; 3B) SEM image displaying quartz, chamosite and illite filled in the fracture system; 3C) optical microscopy image of euhedral quartz filled in the pores; 3D) SEM image showing nodular siderite is partially replaced by chamosite and ankerite; 3E) SEM image exhibiting siderite (outer) and ferroan dolomite (centre) filled in a fracture; 3F) optical microscopy image of epigenetic pyrite filled in the fractures and devolatilization pores.

Table 1. Minerals found in the samples and their distances to the dyke.

| | S6-295-002 | S6-298-002 | S6-256-002 | S6-259-004 |
|---|---|---|---|---|
| Approximate distance to the dyke (m) | 0 | 12.2 | 26.7 | 72.2 |
| Quartz | × | × | × | × |
| Pyrite | × | × | × | × |
| Sulfate | | × | | |
| Dolomite | × | | | |
| Ferroan dolomite | × | | × | × |
| Ankerite | | × | × | |
| Siderite | | × | × | |
| Siderite (altered) | | | × | × |
| Chamosite | × | × | × | × |
| Chlorite | × | | | |
| Kaolinite | | × | × | × |
| Illite | × | × | × | × |
| K-clay | × | × | × | |
| Mg-rich clay | | × | | |
| K-Fe-rich clay | × | | | |
| Fe-rich clay | × | | | |
| K-Feldspar | | × | × | × |
| Fluorapatite | × | × | × | × |
| Apatite | × | × | × | |
| Rutile | × | × | × | × |
| Zircon | | × | × | |
| Silver-bearing mineral | | | × | |

## Conclusion

The resulting analyses showed that the minerals in all samples were related to igneous activity however no trend was observed with the distance to the dyke. The reason interpreted for the lack of trend in the expected mineralogy is that the samples follow an offshoot of the dyke, a very thin sill that follows the roof of the seam, which contributed high temperature and hydrothermal fluids and this affected the mineralogy in the coal (Finkelman et al., 1998).

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