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Fossil gas explosions?

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ABSTRACT

A volcanic breccia cross-cutting the tuff layers of a cinder cone near Langeac, France, contains abundant fragments of the Carboniferous rocks directly beneath the volcano. Unlike the Carboniferous sediments in situ, which are mainly black due to finely dispersed organic matter, the fragments included in the tuff are light-medium brown, except for a thin but continuous black rim around each fragment. It is argued that methane was generated in the coaly sediments by the heat from the volcanic edifice. The methane came into contact with oxygenated groundwater, and this explosive mixture was ignited by basaltic dikes, which postdate the main volcanic activity. After ejection, the pores of the sedimentary fragments were still filled with methane. The gas composition in the hot basaltic tuffs in which they became embedded is inferred to have been a normal steam–CO_2 mixture, which is incompatible with methane: where the two gases met, in the rims of the fragments, carbon precipitated.

The Massif Central in France is well known for its variety of volcanic manifestations in the form of basalt flows, cinder cones, as well as several large stratovolcanic edifices. Broadly speaking the whole Massif Central consists of crystalline basement rocks, locally cut by grabens filled with Upper Carboniferous coal-bearing sediments. One such graben filled with coal-bearing Carboniferous rocks is located near the town of Langeac (Marchand et al., 1989). Immediately south of the town, on top of the underlying Carboniferous, there is a tuff cone which was quarried until recently, as the tuff forms a reasonably well consolidated material suitable for building purposes. Figure 1 shows a simplified geological map of the area and the location of the quarry. Most of the rocks in the quarry are well-stratified and well-sorted tuffs, full of small fragments of basaltic rocks which gently slope away from the eruption point. In one of the quarry faces they terminate abruptly at a knife-sharp and steep boundary separating them from a rather chaotic and much more poorly sorted and stratified tuff. This line represents the boundary of a steep funnel-shaped explosion pipe, which was backfilled with erupted material, including coarser blocks, up to several tens of centimeters in size. The sides of this pipe were sandblasted and almost polished by the explosive activity, with the exception of an occasional basalt fragment sticking out from the wall of the original tuff. Within the pipe are several steep and sharp planes, separating one chaotic tuff breccia from another, testifying to the fact that similar blow-outs have repeatedly taken place. From the geometrical relations in the quarry one can deduce that the diameter of the explosion pipe was of the order of 15–20 m only (see Fig. 2).

It is interesting to note that abundant fragments of Carboniferous sand- and siltstone are found exclusively in this cross-cutting pipe. A closer inspection of the many large and small Carboniferous inclusions shows that they are

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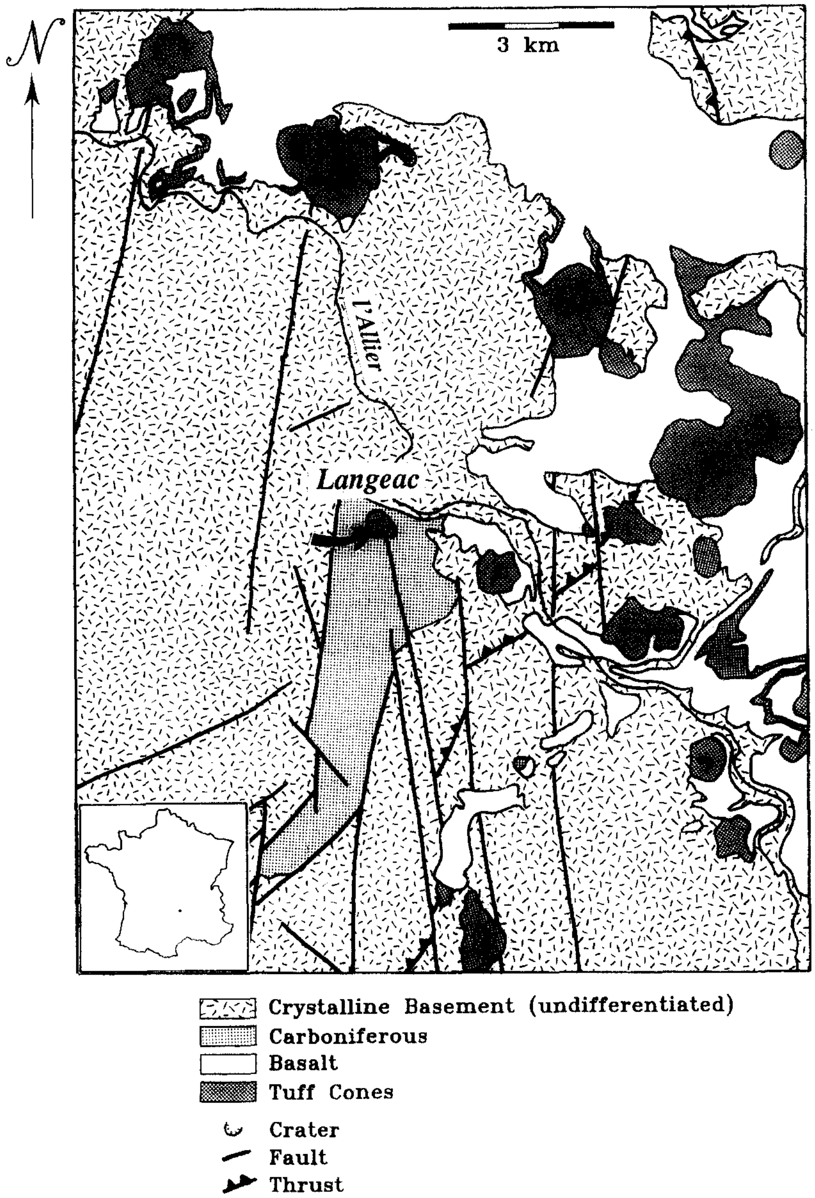
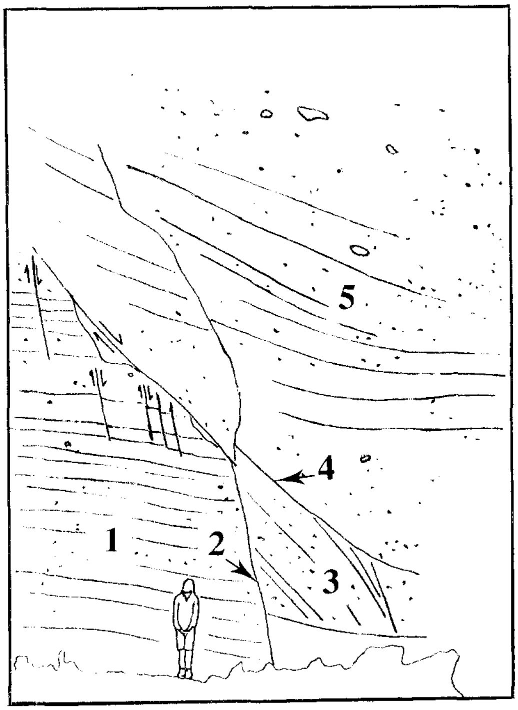


Fig. 1. Simplified geological map of the Langeac area (after Marchand et al., 1989), and location of the quarry.

all, without exception, light-medium brownish, apart from a continuous black rim, a few mm thick, which contains of the order of 10% carbon (Fig. 3).

Most Carboniferous rocks in this area are black, however, as a result of finely divided organic material. According to Peterlongo (1978), the Carboniferous sediments at Langeac are mainly represented by black micaceous shales and siltstones. Apparently, some process caused the organic material to be removed from the internal parts of the inclusions in the tuff. The problem of the origin of the black rims must also be addressed. The rims follow very faithfully the outline of the present fragments. One must conclude that they have formed in the fragments in their present location, where they reached their present form, as



1. Regularly stratified tuffs with basaltic fragments.
2. First blow-out structure.
3. Fall-back sediments, tuffs with fragments of basalt and carboniferous sediments).
4. Second blow-out structure.
5. Backfilled sediments, poorer sorted tuffs with fragments of basalt and carboniferous sediments.

Fig. 2. Sketch of the geological relations in the quarry face.

they were continuously abraded before their final emplacement.

Contrary to the origin of the regularly stratified tuffs that make up the main body of the cinder cone, and that contain some fragments of crystalline basement rocks, the explosive activity leading to the formation of the pipe must have had a shallow origin (no more than a few hundred meters), as indicated by the overabundance of Carboniferous fragments; one could interpret this as just a minor phreatomagmatic explosion, but such blow-out features have not been observed in the many other cinder cones of the area that are located on the crystalline basement. We therefore envisage another explanation. The evidence that fairly large amounts of organic material have been removed from Carboniferous rocks in conjunction with volcanic activity is convincing. The Carboniferous, at shallow depth under the tuff cone and in close proximity to the volcanic conduit, must have been heated, assisted by the heat from basaltic dykes that crosscut the tuffs. The first effect of heating the organic substance in the Carboniferous sediments must have been the generation of methane, as the coals are bituminous to sub-bituminous, containing between 20 and 26% of volatile matter, and the old coal mines were reputed to have been methane-rich; if steam was involved, some carbon monoxide and hydrogen may have formed in addition. When these explosive gases mix with superheated oxygenated groundwater, the exothermic reactions will quickly accelerate into an underground explosion, blasting its way through the overlying tuff masses. Self-ignition would require temperatures of more than 500°C (Braker and Mossman, 1980), which could have been provided by the intrusion of basaltic dykes, which postdate the regular, main explosive activity. As new reservoirs of organic-rich Carboniferous were heated and tapped, the explosive activity repeated itself. The fragments of sedimentary rock were still saturated with reducing gases in their pores when they were ejected and emplaced in the hot material of the blow-out pipes. Contact of this outwardly diffusing methane with inwardly diffusing mixtures of water vapour and CO_2 from the surrounding tuffs produced unstable compositions, resulting in the precipitation of carbon in the zone of mixing in the rim of the fragments. Figure 4 gives a graphical presentation of the behaviour of methane when it reacts with a steam–CO_2 mixture. Under realistic conditions of a total pressure of 20 bar and a temperature of 400°C, carbon starts to precipitate as soon as the methane comes in contact with a CO_2–H_2O mixture. Calculation of this diagram was done on the basis of data by Holloway (1977) and Flowers (1979). One could also invoke the reaction of $2CO \rightarrow C + CO_2$, which proceeds very

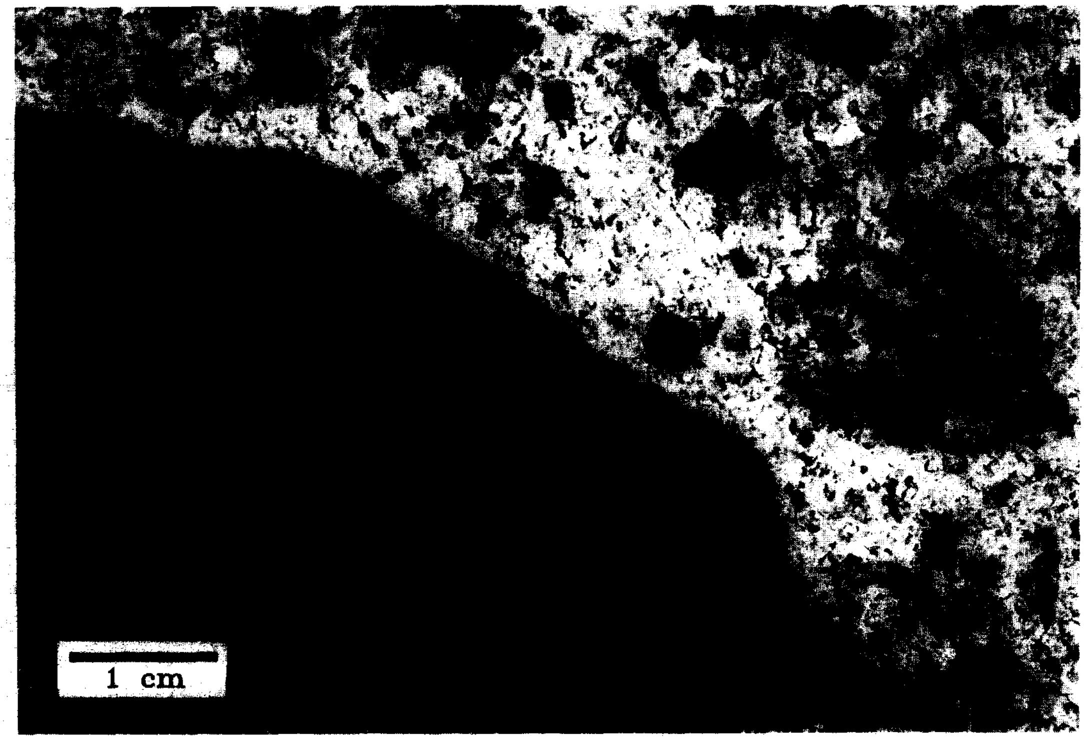


Fig. 3. Carboniferous inclusion in tuff, showing black reaction rim.

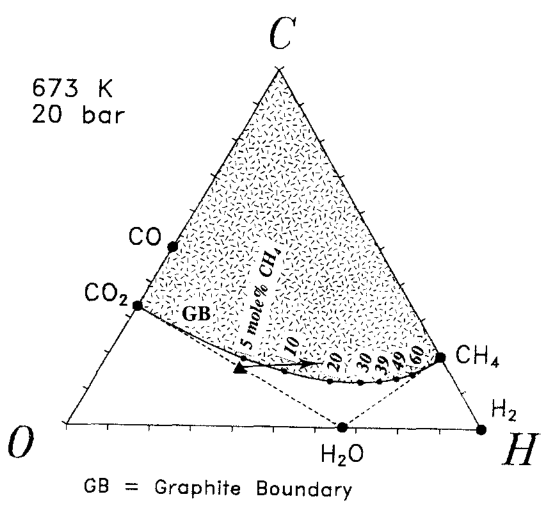


Fig. 4. Phase relations in the system COH, and precipitation of graphite upon addition of steam–carbon dioxide mixtures to methane.

fast at temperatures around 400–500°C, but it is difficult to see why this would result in a rimlike precipitation of carbon around the edges of the fragments. It is more likely that the carbon formed at the place where two incompatible gas mixtures met, and its formation can essentially be described by the reaction $CO_2 + CH_4 \rightarrow 2C + 2H_2O$.

Conclusions

Fossil gas explosions provide a consistent explanation for the observations in the blowout structures of a volcanic cone at Langeac. The gas was generated from the coaly substance in the Carboniferous sediments directly below the volcano, which provided the required heat. The gases may have been ignited by intruding basalt dykes. When, after the blow-out, the sediment fragments cooled in a tuff mass, precipitation of carbon occurred in their rims where two incompatible gas compositions mixed.

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