wear of diamond bits [3], they will wear less during drilling in solutions which produce $\zeta = 0$. As a result, they will stay sharp longer, enhancing both penetration rates and penetration.

The bit-wear reduction mechanism will be valid only if the diamonds "fail" due to blunting of their points by wear – not if they fail by massive fracture, which could result in resharpening. It should also be emphasized that the mechanism suggested does not depend on any improved cooling capacity of the water by the additive, as has been suggested previously [3], because the heat transfer coefficients of water are not significantly influenced by the small concentrations of surfactants used. The essence of the present hypothesis is that chemomechanically active media actually reduce the *amount* of heat generated at the rock–bit interface.

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Comments on "Influence of chemomechanically active fluids on diamond wear during hard rock drilling"

We were very pleased to hear of the work of Mills and Westwood, and to learn that they have confirmed the findings reported by us in an earlier letter to this journal [1]. We should like to make a few brief comments in further clarification of our views.

The effect of the environment on the rate of wear of the diamonds may now be accepted as an important, and sometimes overriding effect. How this occurs is, in our view, still not clear. In all probability, it is related to the heat generated at the cutting points by friction between rock and diamond. Mills and Westwood argue that the quantity of heat generated, and hence the wear of the diamonds, depends upon the coefficient of ploughing friction between the two materials, and that this in turn is influenced by the environment since the latter acts to harden or soften the rock.

For us, a major dilemma then lies in the resolution of the following question "If the basic parameter influencing the wear of the diamond is the variation in the hardness of the rock, why do we not observe differences in the instantaneous drilling rate when changing between environments, which are at least of similar magnitude to the observed differences in the rate of wear? In other words, if the rock is hardened or softened by the environment, why is the rate of penetration not changed?".

Our work with different additives, reported earlier [1], may be summarized as follows: (1) in granite, the rate of penetration was scarcely affected by the environment, while there were large differences in the rate of wear, and (2) in marble, neither the rate of penetration nor the rate of wear was affected (with the reservation in the latter case, as pointed out above by Mills and Westwood, that to observe differences in the rate of wear in marble, we should perhaps have had to drill for great distances). We were particularly disappointed not to have found differences in the rate of penetration of marble, since calcite is a material in which dislocation movement at room temperature is well known, and the influence of the environment on its plasticity has been documented [2–4]. We were thus unable to confirm that we had found evidence of the expected chemomechanical effect.

In our view, the wear of the diamonds is a complex phenomenon, and any complete description of the wear process should take account of at least the following contributory factors:

(1) The quantity of heat generated during drilling. Mills and Westwood refer to the coefficient of ploughing friction during rock destruction. We would entirely agree that one may reasonably hope to find an influence of the environment on the coefficient of friction through its effect on the properties of the rock.

(2) The efficiency of heat transfer from the hot diamond to the liquid cooling medium. We agree with the view expressed by Mills and Westwood above, that small additions of organic substances are not likely to change the specific heat or conductivity of the flushing liquid, but the conditions of heat transfer are extreme.

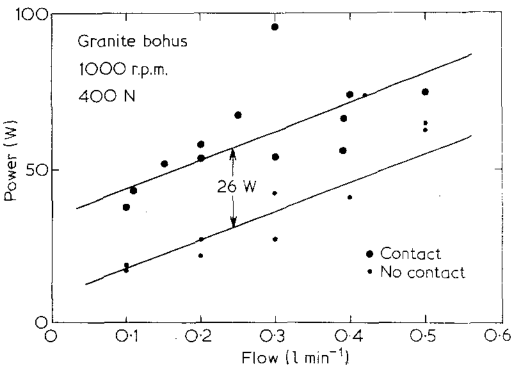

Figure 1 Apparent power generated during drilling, as deduced from the temperature change of the flushing water. Experiments were made at different flow rates, and with the bit drilling, or not quite touching the hole bottom, to identify and eliminate sources of heat generation other than those directly associated with rock destruction.

Fig. 1 shows results we have obtained during measurements of the heat generated during drilling in granite with a 10 mm o.d., 8 mm i.d. core bit. The apparent power dissipated was deduced from the temperature rise of the cooling water at a variety of flow rates with the bit either drilling, or in place and rotating, but not quite touching the rock. One can see that between these two conditions, there is a fairly constant 26 W or so dissipated which can be attributed to the heat generated in rock destruction. The projected area of our drill was 28.3 mm^2, and the diamond content 19 vol%. Thus, supposing the heat to have been dissipated over the apparent area of diamond on the face of the bit, we obtain a value of $26/28.3 \times 0.19 = 4.8\ \text{MW m}^{-2}$. This is a crude calculation: some parts of each diamond will be in contact with the rock, and will not be efficiently cooled, and some of the heat will soak away into the metal matrix of the bit. Nonetheless, the calculated value is still a very high heat flux to be carried across a solid–liquid interface. We *speculate* that under these conditions, the temperature of the diamonds may easily exceed 100° C, and boiling heat transfer may have to be considered in any realistic analysis. Under these conditions, a possible role of the surfactant may be to influence the transition from nucleate to film boiling, with consequent dramatic effects on

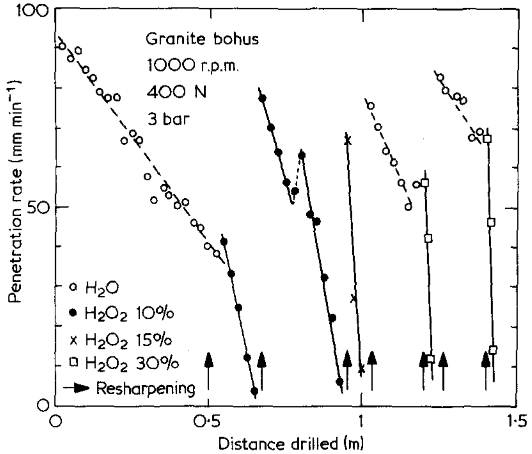

Figure 2 Effect of water, or various concentrations of hydrogen peroxide on the rate of performance loss of diamond impregnated drill bits. Vertical arrows indicate periodical redressing of the bit.

the efficiency of heat transfer and the temperature of the diamond. To achieve such an effect would not require the additive to be present in large quantities. Rhodes and Bridges [5] boiled water on the surface of a tube through which was flowing hot mercury. They found that film boiling is promoted by making the surface less wettable by, for instance, coating it with a film of wax or by adding very small quantities of oleic acid or mineral oil to the water. By contrast, the addition of sodium carbonate or sodium chloride restored nucleate boiling. The two latter chemicals *inter alia* have been said by Rehbinder [6] to improve the rate of penetration when rock drilling.

(3) Finally, the chemical nature of the additive should not be ignored insofar as it can directly influence the degradation of the diamond. Fig. 2 shows some results we have obtained using hydrogen peroxide as a drilling additive. Here, the disastrous effects of this powerful oxidizing agent are quite clear, and it is not necessary to look further for the cause of the loss in drill performance (in fact, we did consider the possibility that the oxygen bubbles liberated during drilling could have interfered with the heat transfer process: we are grateful to Professor Nabarro for a suggestion to drill with soda-water, which showed this effect to be insignificant).

In conclusion, therefore, we feel that while the effect of the environment on the performance of the drill is well established, the precise factors which influence the blunting of the diamonds are less clear. We have suggested three possible independent ways in which the environment could affect the wear of the diamonds, and others will no doubt emerge in time. Which of the mechanisms will be dominant in any given situation must depend on the conditions and additives employed.

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Velocity measurement by ultrasonic fractography for cracks in glassy polymers

Although high speed photography seems to have been most widely employed to determine the velocity of cracks (v_f) running in solids, its spatial resolution is not high enough to locate the exact position of narrow crack tips. The use of resistance grid methods [1, 2] makes it possible to measure v_f electrically. In this case, however, there still remains the doubt as to whether the electric signal generated really coincides with the crack tip arrival at the designated point.

Kerkhof [3, 4] showed that the ultrasonic fractography technique he developed is superior to the methods stated above both in spatial