Modern Geology
1970, Vol. 1, pp. 211–217

DETECTION OF STRAIN IN ROCKS USING AN INTRINSIC "SEMI-INSULATOR" CHARACTERISTIC OF SOME MINERALS

G. DOUGLAS, M. MORENCY AND D. J. McDOUGALL

Department of Geotechnical Sciences, Loyola College, Montreal, Canada

Abstract—Strain induced by impact or static loading will cause changes in some of the solid-state characteristics of minerals. Although exact relationships have not yet been demonstrated, thermoluminescence provides one means of obtaining a *relative* indication of these changes.

Data from investigations of suites of rocks from the vicinity of the Gaspe Copper "A" fault; the Charlevoix, Holleford and Brent "meteorite" craters; and the Sedan nuclear event, are used to illustrate some of the variations of strain-induced thermoluminescence. The results of artificial static loading of high-purity limestone from Bedford, Quebec, and of crushing and grinding of several rock types are also described.

An idealized thermoluminescence vs load relationship is suggested as a partial explanation of the changes in "semi-insulator" characteristics due to deformation.

Strain-induced lattice defects may produce marked changes in the solid state characteristics of some minerals. One method of investigating strain effects has been the observation of x-ray defraction line broadening or the blurring of Laue patterns (Johnson and Daniels, 1961; Roach, 1961, 1968; Aitken, 1965; Myner, 1967). A second line of investigation has been based on the observation of variations of a solid state characteristic such as: the formation of *F*-centers due to translational gliding in calcite and halite (Handin *et al.*, 1957; Agullo-Lopez and Levy, 1964); the increase in the number of etch pits in Iceland spar (Keith and Gilman, 1960; Kolantsova *et al.*, 1962; Thomas and Renshaw, 1967; d'Albissin and Fornaca-Rinaldi, 1968); measurement of the electronic charge on lattice dislocations in NaCl (Turner and Whitworth, 1968); and the strain-induced thermoluminescence of carbonate minerals, feldspars, and quartz. Exact relationships have not yet been demonstrated, but since many of the principles involved are similar to those for silicon whisker semi-conductor strain gauges, these "semi-insulator" phenomena in minerals may ultimately provide a means of measuring the amount of strain to which a rock has been subjected. For the present, where permament deformation has occured, a comparison of strained and unstrained samples may provide a relative indication of the amount of deformation.

Strain-induced thermoluminescence can be defined as thermoluminescence due solely to physical deformation and not to ionizing radiation. A number of investigators have previously reported studies of strain-induced thermoluminescence by: (i) uniaxial and triaxial loading (Zeller *et al.*, 1955; Lewis *et al.*, 1956; Handin *et al.*, 1957; d'Albissin, 1963; Ovchinnikov and Maxsenkov, 1963; Angino, 1964; Morency and McDougall, 1964; Morency, 1968; d'Albissin and Fornaca-Rinaldi, 1968); (ii) projectile impact (Roach *et al.*, 1961); and (iii) grinding (Debenidetti, 1958; Johnson and Daniels, 1961; Fornaca-Rinaldi, and Tongiorgi, 1961; Lewis, 1968). Field studies of natural strain-induced thermoluminescence have included investigations in the vicinity of alpine nappes (d'Albissin *et al.*, 1962, d'Albissin, 1963); meteorite craters (Roach *et al.*, 1962; Fuex, 1967); underground nuclear events (Dickey, 1960; Fuex, 1967; Roach, 1968); and faults (McDougall, 1968a, 1968b).

There appears to be some disagreement in the literature, but the *initial* effect of increasing strain is usually reported as a change in amplitude of one or more glow curve peaks and an increase in the total emission. Still greater strain usually results in a decrease in thermoluminescence. In some cases, strain may cause either the appearance or disappearance of certain glow curve peaks. The causes of changes in thermoluminescence due to strain are not well understood, but, in part at least, appear to be due to variations in the free energy of the crystal (McDougall, 1968b) which in turn is related to the formation and annihilation of lattice dislocations. Over some ranges of increasing deformation, thermoluminescence varies uniformly with strain, but over greater ranges, this simple relationship is not always apparent.

The studies reported below include; (a) investigations of rocks in which varying amounts of strain are either obvious or can be inferred; and (b) material which has been artificially strained in the laboratory. In them, the total emission (kE), natural glow curve peak heights (Pk_1, Pk_2) and peak height ratios (Pk_2/Pk_1) (all in arbitrary units) have been used to try to relate thermoluminescence to strain. In addition, in order to combine information on the amplitude of the peaks and total emission, the following relationship has been devised by one of the authors (G. D.)

$$\frac{kE}{(Pk_2/Pk_1) + 1}$$

FAULTS

One of the authors has previously reported examples of increased thermoluminescence in the vicinity of faults (McDougall, 1968a, 1968b). In the earlier discussions it was uncertain as to what extent the rocks might have been affected by post-faulting metamorphism or metasomatism. However, the Gaspe Copper "A" fault appears to be a case where the faulting has not been affected by more recent events. This fault is a well defined normal fault on which the north side has moved up. At the outcrop surface the fault intersects Grande Greve (Devonian) calcareous siltstones, including a portion which is within the metamorphic aureole surrounding the ore zones of the Gaspe Copper mine. During detailed geological mapping of the region surrounding the mine, the presence of a nearby body of the younger York Lake sandstone was thought to be due to graben-like faulting, and two additional faults ("C" and "D") have been postulated (Brummer, 1966). However, other than the presence of sandstone, there does not appear to be any real evidence for these two faults.

Figure 1 illustrates several thermoluminescence parameters of Grande Greve outcrop samples along a section approximately at right angles to the strike of the "A" fault. The two samples approximately 500 feet north and 800 feet south of the fault have been projected into the section from points about 1000 feet to the east.

The samples within and north of the fault are inside the alteration aureole, and the most northerly sample is at the southern edge of the Needle Mountain ore zone. In the direction of the fault, the thermoluminescence parameters kE (total emission), $kE/[(Pk_2/Pk_1 + 1)]$, Pk_1 (amplitude of first peak), Pk_2 (amplitude of second peak), all show a distinct increase, and the ratio Pk_2/Pk_1, shows a distinct decrease. All these changes are believed to have resulted from increased strain in the direction of the fault. The lack of similar effects near the postulated "C" and "D" faults suggest that they probably do not exist. In this general connection it may be noted that, the thermoluminescence of the alteration aureole is always distinctly higher than that of the unaltered rocks, and that samples taken elsewhere along the fault may have peak height ratios as low as zero.

METEORITE CRATERS

Shock effects have been shown to modify the thermoluminescence of rocks in the vicinity of meteorite craters (Roach *et al.*, 1962). Some aspects of the thermoluminescence response from samples taken from the vicinity of three Canadian "craters" are described below.

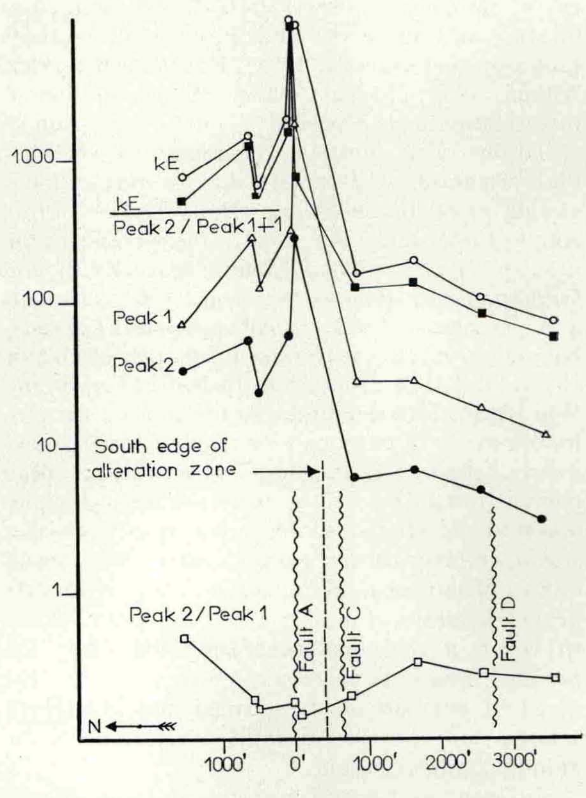

FIG. 1. Variations in thermoluminescence parameters in the vicinity of faults and zone of recrystallization (alteration zone).