

with my, MANC-JW 70-0142
Revised manuscript

THERMAL ACTIVATION ENERGY OF
SHOCKED AND STRAINED
QUARTZ

BY

JOHN W. MANCONI AND DAVID J. McDOUGALL

Reprinted from American Mineralogist
55: 398-402 (1970)

DEC 15 1970

THERMAL ACTIVATION ENERGY OF SHOCKED AND STRAINED QUARTZ

JOHN W. MANCONI¹ AND DAVID J. MCDUGALL,
Loyola College, Montreal, Canada

ABSTRACT

The thermal activation energy calculated by the initial rise method appears to be an indication of the state of deformation in quartz from shocked and strained quartzites. The data suggests that undeformed material from two widely separated sources have approximately equal eV values.

On the basis of preliminary data similar results can probably be obtained from other rock types.

Shock effects in the vicinity of meteorite impact craters and underground nuclear blasts have been shown to cause modifications in the physical, optical and crystallographic characteristics of quartz (cracking cleavage, isotropism and formation of the high pressure polymorphs, coeite and stishovite) (Short, 1966). In addition, it has been demonstrated that some of the electronic characteristics of calcite and other minerals as reflected in their thermoluminescence, can also be modified by shock and static loading (Douglas, *et al.*, 1969). However, application of the relative change in thermoluminescence to the investigation of shock and strain effects has been restricted by the knowledge that other factors may produce similar results. Such complicating factors include: variations in natural and artificial radioactivity; the state of saturation of the electron "traps," including draining of "traps" by thermal energy generated during the event which caused the shock or strain; or natural variations in lattice defects (trace elements, vacancies, dislocations).

This paper presents the results of an investigation of some of the electronic characteristics of shocked and strained quartz. Diamond drill core samples of quartzites from the sources of a) the Sedan underground nuclear event, Nevada test site; and b) the Nordic mine, Elliot Lake, Ontario, were used. Brief descriptions of the amount of shock or static loading are given in Tables I and II. Each sample was crushed in a jaw crusher and the 100 mesh size was used in the experiments. The thermoluminescence reader is a modified version of equipment developed at the University of Rome (Bettinali, Ferraresso, Gottardi, 1966 and Bettinali, Ferraresso, Manconi, 1967), with the thermoluminescence emission observed with a RCA 5819 photomultiplier having a S-11 type response.

To enable the sample (approximately one grain thick) to adhere evenly

¹ Present address: Laboratoire de Geologie Dynamique, Faculté des Science, Université de Paris, France.

TABLE 1. NEVADA TEST SITE: THERMOLUMINESCENCE IN CAMBRIAN AND PENNSYLVANIAN ROCKS

Shock (arb. scale)	Description ^a	Thermoluminescence				Activation Energy	
		Peak A		Peak B		Peak A	Peak B
		nat	X-ray	nat	X-ray	X-ray	X-ray
0	Unshocked	—	10.5	6.0	3.8	0.42	0.78
1	Mildly shocked (cracked)	—	5.0	2.8	3.2	0.69	1.03
2	Moderately shocked	—	2.2	1.0	2.0	1.37	1.51
3	Strongly shocked (partly isotropized quartz)	—	1.4	—	0.8	.91	1.86
4	Very strongly shocked (nearly all quartz isotropized)	—	0.8	—	—	—	—
5	Very strongly shocked (isotropized, glassy)	—	0.6	—	—	—	—
6	State of shock unknown (assumed to be very high on basis of TL data)	—	0.4	—	—	—	—

^a Personal communication, N. M. Short, National Aeronautics and Space Administration. (U.S.)

to the heater plate, the heater was first coated with a thin layer of silicone grease. The samples were heated to about 300°C at a rate of 15°C per minute. For each sample, glow curves were obtained for a) the natural thermoluminescence and b) the thermoluminescence induced by 3.3×10^8 R/hr X-rays. The X-ray excited peaks at circa 40°C and circa 100°C

TABLE 2. THERMOLUMINESCENCE IN URANIUM-BEARING MISSISSAGI QUARTZITES FROM THE NORDIC MINE, ELLIOT LAKE, ONTARIO

Stress (estimated) ^a psi	Strength (Compressive) ^a psi	Thermoluminescence				Activation Energy	
		Peak A		Peak B		Peak A	Peak B
		nat	X-ray	nat	X-ray	X-ray	X-ray
3,000	b	—	1.8	1.0	1.1	0.61	—
4,000	b	—	1.5	0.5	0.8	0.65	—
6,000	b	—	1.6	0.5	1.15	0.79	—
10,000	29,000	—	2.2	1.0	1.1	1.02	—
14,000	30,000	—	1.6	1.45	1.15	1.92	—

^a Personal communication, T. S. Cochrane, Mines Branch, Dept. Energy, Mines and Resources. (Can.)

^b Average compressive strength: 31,000 psi.

are indicated in the Tables as Peak A and Peak B respectively. The symbols "nat" and "X-ray" in Tables I and II serve to distinguish between natural and X-ray induced thermoluminescence. The thermal activation energies in electron volts (eV) were calculated by the initial rise method (Halperin, Braner, and Kristianpoller, 1960 and Bettinali, Ferrareso and Manconi, 1969) for the X-ray excited peaks of the shocked and strained samples. The experimental data: Thermoluminescence (in relative units) and Activation Energy (in eV), is summarized in Table 1 for the shocked samples and in Table 2 for the strained samples. These data are also shown graphically in Figures 1 and 2. The tables are incomplete because in many cases the intensity of the emitted light was too low to provide meaningful results.

In Figure 1, the decrease in both the natural and X-ray excited thermoluminescence with increasing shock is similar to the effects observed in calcareous rocks from the vicinity of some Canadian meteorite craters (unpublished data). It has been observed that in general, the amount of thermoluminescence emitted from rock samples which have previously failed as the result of natural or artificial causes, is markedly less than that from unfailed specimens (Douglas, *et al.*, 1969). In Figure 2, the stress for each sample is an estimated figure for the amount actually

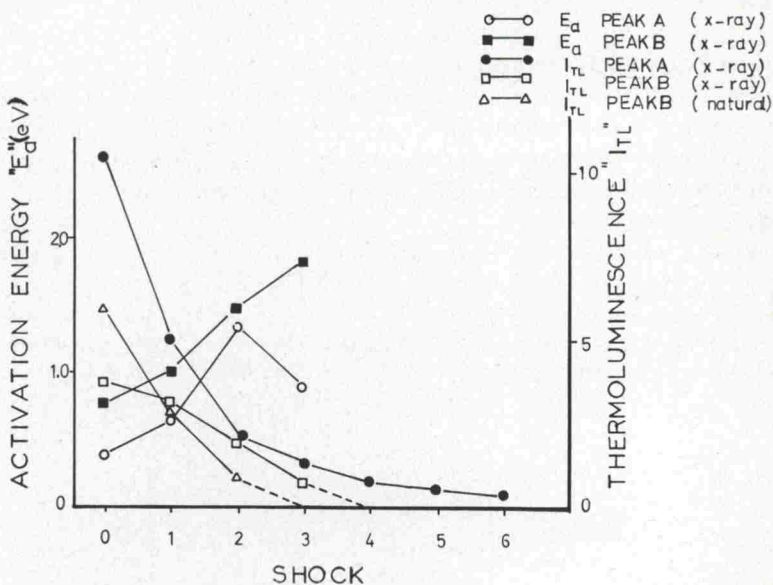


FIG. 1. Activation energy and thermoluminescence vs increasing shock for natural and X-ray excited quartzites from the Nevada Test Site. (See Table 1 for description of amount of shock.)

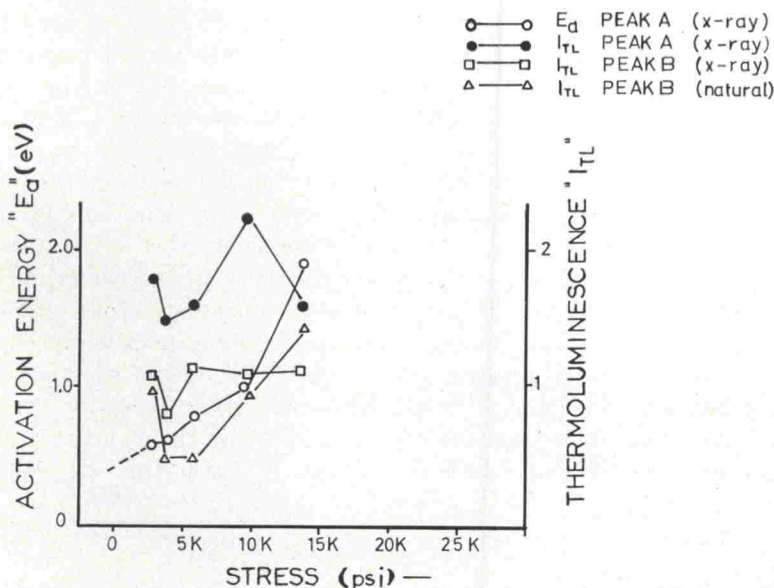


FIG. 2. Activation energy and thermoluminescence vs increasing stress (estimated) for natural and X-ray excited uranium-bearing Missisagi quartzites. (See Table 2 and text for details.)

sustained by the mine pillars from which the samples were obtained (personal communication, T. S. Cochrane). Information on the amount of strain is not available to the writers, but the loading can be considered to be essentially uniaxial. It will be noted that both the natural and artificial thermoluminescence do not vary uniformly with increasing stress. Rather similar "cyclical" thermoluminescence has been reported for samples of limestone and syenite which were artificially strained while confined by a hydrostatic load and then subsequently tested for thermoluminescence (Morency, 1968). However, one portion of the natural thermoluminescence curve (from about 4000 to 14,000 psi) indicates a general increase in thermoluminescence with increasing load. This type of increase may be considered to correspond to a strain-induced increase in thermoluminescence towards (but not into) fault zones (McDougall, 1968).

In Figures 1 and 2, the thermal activation energy tends to increase with both increasing shock and static loading. Two features of the thermal activation energy curves for the X-ray excited peak A require comment:—a) in Figure 2, the curve can be extrapolated (dashed line) to about the same value at zero stress as the unshocked sample in