FIFTY YEARS OF COLLECTING ANTARCTIC METEORITES: A THERMOLUMINESCENCE REVIEW AND UPDATE. Derek W. G. Sears and Alexander Sehlke, Bay Area Environmental Research Institute and NASA Ames Research Center, Moffett Field, CA 94035. DerekWGSears@gmail.com.

Introduction: Thermoluminescence (TL), literally light emission caused by heating, is a widely used and widely studied process in dosimetry, dating and various industries. Ionizing radiations passing through crystalline materials cause electrons to be energized and "trapped" where they can be stable for minutes to billions of years [1]. Heating releases these electrons so the light emitted is a function of past radiation and thermal history. On the other hand, the TL that can be induced by artificial irradiation in a crystal whose natural TL has been removed depends on the physical and compositional properties of the crystal (in silicate rocks it is normally feldspar) which, for meteorites, usually amounts to its metamorphic or shock history [2]. There has now been about sixty years of research on the TL properties of meteorites with Antarctic meteorites playing a large part in that history.

Thermal and Radiation History: *The Natural TL Survey of Antarctic Meteorites:* Walker and Sutton originally proposed that natural TL (NTL) measurements be included in the preliminary examination of Antarctic meteorites as a means of locating ordinary meteorites with unusual histories [3]. After a blind test [4], data for $\geq$1000 meteorites were published in the Antarctic Meteorite Newsletter over a 14 year period [5].

Orbits and Terrestrial Age. Close passages by the Sun and long terrestrial ages result in a decrease in natural TL levels [6,7]. The systematics of natural TL levels are well-known so a quantitative evaluation can often distinguish between low NTL due to small perihelion and large terrestrial age. Sometimes orbit or terrestrial age are known and the other can be determined. Because NTL is a "low energy" (i.e. ionization) product, shielding has a relatively small effect on NTL levels although variations due to shielding have been measured in several cores and slabs [e.g., 8]. Several technical studies have been published on the TL properties of meteorites from various Antarctic sites addressing, among other topics, implications for ice movements [9, 10, 11].

An Antarctic Meteorite with an Anomalous Orbital History. About fifty paired fragments of ALH 88017 that were freshly weathered out of the ice were found to have much higher NTL levels (a factor of two or more) than freshly fallen meteorites. It is unlikely that terrestrial processes (e.g. burial in the ice) would increase NTL levels so Benoit et al. argued that this meteorite had only recently (within 10^5 years) been placed on an Earth-crossing orbit [12].

Heat Penetration During Atmospheric Passage. The drainage of NTL by heat penetration during atmospheric passage can be detected within ~6 mm of the fusion crust. The NTL profile can be measured and "calibrated" by laboratory experiments to yield a temperature profile and ablation rate and, as expected, higher ablation rates are associated with steeper temperature gradients [13]. These data have value in understanding the behavior of meteoroids' passing through the atmosphere and thus mitigating the effects of asteroid impact [14].

Pairing. Since NTL levels can vary over five orders of magnitude its measurement is one of the better techniques for identifying pairing (meteorites that were part of the same mass when it entered the atmosphere) [15].

The Destructive Nature of CT-scanners. The heavy doses applied during CT scanning, increasingly used as part of the initial screening of extraterrestrial materials, overwhelms the natural dose and makes any estimation of the natural dose by TL or any other technique impossible. The destruction of evidence for the samples' natural radiation history should be borne in mind when the risk-benefit analysis of placing a sample in a CT scanner is performed [16,17].

Metamorphic History: The Induced TL of Antarctic Meteorites: The induced TL of meteorites shows five orders of magnitude range in intensity due mostly to metamorphic effects. This has made it uniquely valuable in petrographic classification, especially the unequilibrated (type 3) ordinary chondrites (UOC) which were subdivided into types 3.0-3.9 [18]. Since the change in induced TL is due to the phase transformation of feldspathic glass to feldspar, the various criticisms of Bonal et al [19] are erroneous. One of the major contributions of the Antarctic meteorite program is the discovery of large numbers of UOC so that once rare materials are now available in sufficient amounts that almost any study is possible.

Paleothermometry. In addition to the level of induced TL providing a precise quantitative indication of metamorphic intensity experienced, the temperatures at which TL is emitted provides a crude geothermometer. UOC of type 3.0-3.2 have nondescript induced TL emitted over a broad range of temperatures. Over this metamorphic range TL is produced by calcic glass, sodic plagioclase, and possibly forsterite. Meteorites of type 3.3-3.5 have induced TL emitted over a narrow range at heating temperatures around ~100°C by plagioclase in the ordered structural form. Meteorites of type >3.5 have induced TL over a relatively broad temperature range at heating temperatures around 200°C due to plagioclase in the disordered structural form. Since we know the order-disorder transformation occurs at ~500°C, we have a unique paleothermometer for the UOC where the lack of equilibration makes geothermometry based on mineral pairs difficult to impossible [20].

Weathering. All studies of Antarctic meteorites have to take into account the effects of weathering, which is often considerable. Benoit et al suggests that weathering lowered TL values by a factor of 10, but this is doubtful as their results were affected by the removal of small grains during acid washing [21]. Weathering has the potential of lowering TL by coating the grains with Fe oxides and lowering their albedo. However, NTL measurements are made on a monolayer of grains and albedo effects should not be important. Further studies of the effect of acid-washing need to be made.

Pairing. Like NTL, induced TL intensities vary over a 10^5-fold range and are also well-suited to identifying pairing within a group of meteorites found locally.

Induced TL Emission Characteristics and Streaming from the H chondrite Parent Body. It is possible to capture the geothermometry information for ordinary chondrites by plotting the heating temperature at which induced TL emission is at a maximum against the range of temperatures over which the TL is emitted. These parameters are usually referred to as peak temperature and peak width (more precisely, full-width-at-half-maximum). These data for H chondrites from Allan Hills are very different from those of observed falls, suggesting a significant difference in the metamorphic history of meteorites falling 40,000 years ago and those currently falling (or falling within the last 250 years). Furthermore, Antarctic ice fields of intermediate ages have plots that appear to be transitionary between the plots for Allan Hills and observed falls. Clearly, the change with time of the fragments reaching Earth reflects differences in the internal structure of the H chondrite parent body [22,23].

HED meteorites from Vesta. The induced TL of eucrites increases by a factor of 100 as pyroxenes homogenize since both are the result of parent body metamorphism. However, in this case, and unlike UOC, it is the loss of incompatibles (in particular Fe) from the feldspar that causes the increase. The induced TL of howardites is a result of mixing luminescent eucrites with non-luminescent diogenites [24].

Enstatite chondrites. The TL systematics of enstatite chondrites are very different from those of the ordinary chondrites because the mineral involved is enstatite rather than feldspar. Structural and compositional changes in the pyroxene affect the luminescence properties so there is a relationship between luminescence and petrographic type [25]. Most notable are the major differences between EH and EL chondrites that reflect major differences in thermal history identified some time ago from sulfide compositions [26].

Cathodoluminescence. Cathodoluminescence (CL) is a powerful bridge between the bulk powder TL measurements and the plethora of techniques that can be applied to polished thin sections. Many interpretations of the TL process, and more besides, have been made possible by a combined use of TL and CL. [27]

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