COOLING AND UPLIFT PATTERN OF THE LIBERTY HILL PLUTON, SOUTH CAROLINA, USA

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Abstract

The Liberty Hill pluton is one of a series of post-metamorphic plutons emplaced in the central and eastern Piedmont province of the Appalachians in the late Paleozoic. An investigation of the post-magmatic cooling and uplift pattern of the pluton utilized the $^{40}Ar/^{39}Ar$ and fission track dating techniques. Similar $^{40}Ar/^{39}Ar$ ages of 314 - 302 Ma shown by hornblende, muscovite and biotite separates as well as a previously calculated Rb/Sr whole rock date indicate the pluton cooled rapidly after emplacement in the low metamorphic grade rocks of the Carolina Slate Belt. An $^{40}Ar/^{39}Ar$ microcline age of 260 ma as well as fission track ages of 123, 97.0, 92.4, and 82.1 Ma indicate the pluton cooled slowly after reaching ambient country rock temperatures. A crystallization pressure of 4.6 ± 1 Kb from a hornblende geobarometer and an estimate of the paleogeothermal gradient permitted the construction of a depth-time curve consistent with a three stage uplift history for the Liberty Hill pluton.

Chapter 1

1.0 Introduction

The Appalachian orogen was constructed along eastern North America by a series of collisions which spanned much of the Paleozoic. Taconic (Ordovician) and Acadian (Devonian) collisions involved the accretion of island arcs while the Alleghanian (Pennsylvanian-Permian) collision of Africa and North America caused considerable crustal thickening and orogenic development (Secor et al. 1986; Hatcher, 1987). Current attempts to understand the constructional histories of this and other mountain belts throughout the world have relied on a wide variety of geological and geophysical techniques. One method of investigation involves tracing the uplift history of plutons contained within orogenic belts. Isotopic dating of coexisting minerals with different closure temperatures combined with geobarometric data provides a convenient way to reconstruct the pressure-temperature-time (P-T-t) history of a pluton. This study will use this method to investigate the cooling and uplift history of the Liberty Hill pluton, emplaced in the Southern Appalachians during the Alleghanian orogeny.

1.1 Regional Tectonic Setting

The Liberty Hill pluton is located in the South Carolina section of the Carolina Slate Belt. This belt forms the eastern section of the Appalachian Piedmont province which is bounded on the west by the hills of the Blue Ridge and on the east by the sedimentary rocks of the Coastal Plain (Figure 1). Hatcher (1978) proposed that the Carolina Slate Belt formed part of a late Precambrian volcanic island arc which collided with North America during the Acadian orogeny (~400 - 350 Ma) (Hatcher, 1987). The Alleghanian collision of

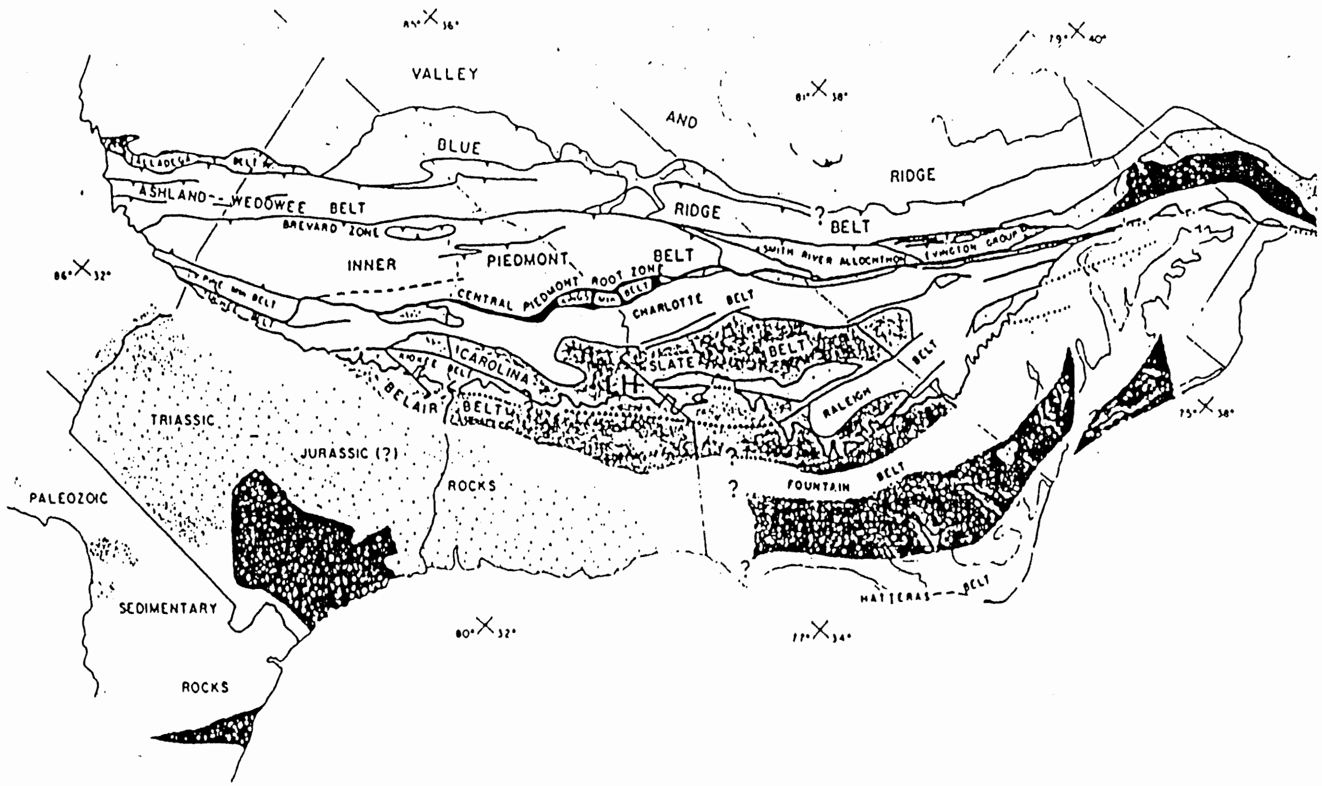


Figure 1: Generalized geologic map of the central and southern Appalachians showing location of Carolina Slate Belt. LH denotes location of Liberty Hill pluton (after: Glover et al., 1983).

North America with Africa (~300 - 245 Ma) produced a string of granitic plutons which intruded into the low-grade rocks of the Carolina Slate Belt (Figure 2). The plutons all yield emplacement ages of 325 to 265 Ma and only show signs of deformation adjacent to regional ductile deformation zones (Glover et al, 1983).

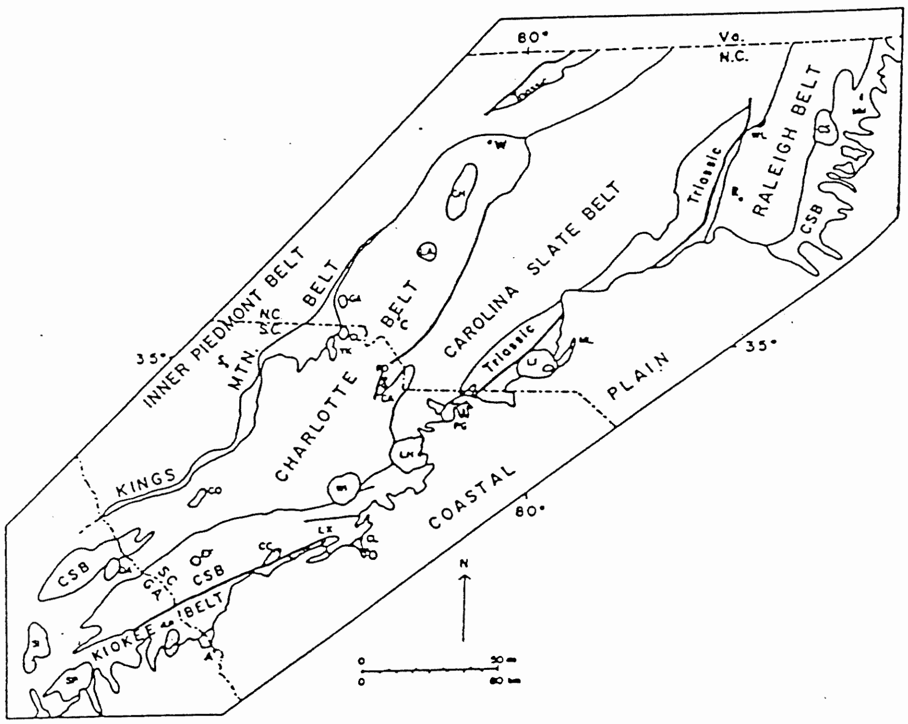


Figure 2: Generalized geologic map showing 325 to 265 Ma (Pennsylvanian-Permian) granitic plutons (stippled pattern) in the central and eastern Piedmont of North Carolina, South Carolina and Georgia. LH denotes the Liberty Hill pluton (after: Fullagar and Butler, 1979).

1.2 Geology of the Liberty Hill Region

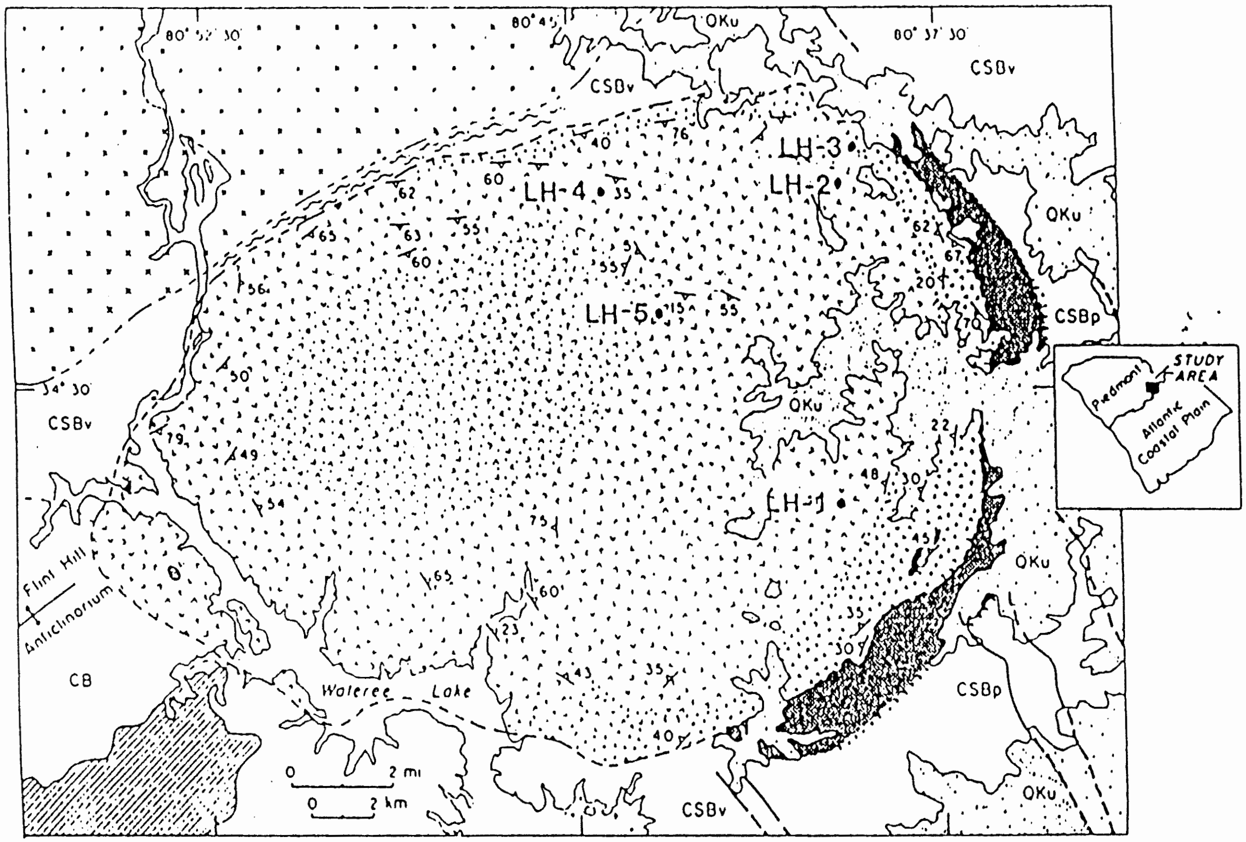
The Carolina Slate Belt is predominantly late Precambrian to early Paleozoic pyroclastic and epiclastic volcanic rocks with a small percentage of lava flows and pelitic rocks (Fullagar and Butler, 1979).

The Liberty Hill pluton was emplaced in metamorphosed hypabyassal, pyroclastic and epiclastic rocks (Speer, 1981). Pelitic rocks on the eastern margin of the pluton have preserved a well-developed contact aureole, that--superimposed on the regional Precambrian greenschist facies metamorphic assemblage of minerals--indicates ambient country rock temperatures of 300°C - 400°C.

The Liberty Hill Pluton is a roughly elliptical, steep-sided intrusion with a single root (Bell and Popenoe, 1976). It covers approximately 360 km^2 in Kershaw, Lancaster and Fairfield Counties in north-central South Carolina. The pluton consists of three texturally and mineralogically distinct facies (Figure 3). The predominant facies is a central coarse-grained amphibole-biotite granite which grades to a coarse-grained biotite granite at the margins. A fine-to-medium-grained biotite granite co-exists with the coarse-grained granites particularly in the west-central regional. Compositional similarity and the manner in which one granite grades into another have ruled out multiple intrusions (Speer, 1987).

The pluton was first isotopically dated by Overstreet and Bell (1965) using a zircon separate which yielded a lead-alpha age of 245 ma. A subsequent Rb-Sr whole-rock age of 299+ 8 Ma was determined by Fullagar (1971).

Spear (1981) estimated a contact metamorphic temperature of 725°C for the central granitoids, 647°C for the marginal rocks and an emplacement pressure



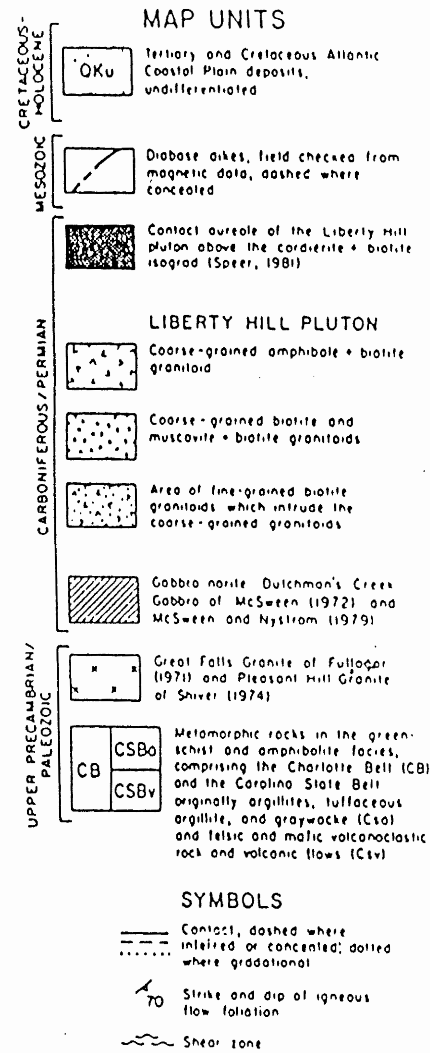


Figure 3: Geologic map of the Liberty Hill pluton showing sample location (after: Speer, 1987).

of 4.5 to 5.1 Kb. after examining the contact aureole. This pressure estimate is dependent on the choice of the aluminosilicate triple point; the point suggested by Richardson et al. (1969) gives a pressure of 4.5 to 5.1 Kb while that of Holdaway (1971) would yield a pressure estimate of 2.0 - 3.5 Kb. Dr. Casey Ravenhurst collected samples of the coarse-grained amphibole-biotite granite (LH-1, -2, and -5) and the fine-grained biotite granite (LH-3, -4) in December 1986 (location map, Figure 3). $^{40}Ar/^{39}Ar$ and fission track dating of minerals from these samples as well as the use of a hornblende geobarometer allow the calculation of the emplacement and cooling history of the pluton. With an estimate of the paleogeothermal gradient, the temperature-time history can be converted into a depth-time history allowing estimation of the uplift of the Liberty Hill pluton.

Chapter 2: $^{40}Ar/^{39}Ar$ Dating Technique

2.0 Introduction

The Rb/Sr whole rock date of 299±8 (Fullagar, 1979) constrains the crystallization age of the Liberty Hill pluton. Dating the subsequent cooling history of the pluton requires isotopic systems with lower closure temperatures, such as $^{40}Ar/^{39}Ar$. The $^{40}Ar/^{39}Ar$ dating technique is a modification of the K-Ar technique. It is based on the radioactive decay of K to Ar. At high temperatures any Ar produced by this decay is lost to the environment. However, at the closure temperature Ar becomes immobile and begins to accumulate within a mineral. The temperature at which Ar becomes immobile varies from mineral to mineral; therefore, dating a set of coexisting minerals will reveal a time-temperature history. Current experimental difficulties in quantifying the parameters that affect closure temperatures have led to large errors in their estimates. In this chapter the theoretical basis of $^{40}Ar/^{39}Ar$ dating, laboratory procedure and results from the Liberty Hill samples will be examined.

2.1 $^{40}Ar/^{39}Ar$ Dating Theory

The $^{40}Ar/^{39}Ar$ dating technique is a variant of K-Ar dating. Both systems depend on the accumulation of radiogenic ^{40}Ar ($^{40}Ar*$) from decay of ^{40}K. In the K-Ar method $^{40}Ar*$ and ^{40}K are measured on separate aliquots of a sample, the ratio of the two yielding the age. The $^{40}Ar/^{39}Ar$ technique involves conversion of ^{39}K atoms to ^{39}Ar by irradiation with fast neutrons. The amount of ^{39}Ar produced via this reaction is proportional to the total amount of ^{40}K, since the ratio of ^{40}K to ^{39}K is essentially constant. Thus the ratio of

$^{40*}Ar/^{39}Ar$ gives a measure of the $^{40}Ar^{*}/^{40}K$ ratio and the age of the sample.

The amount of ^{39}Ar produced via the nuclear reaction ^{39}K (n,p) ^{39}Ar is given by the equation:

$$^{39}Ar = {}^{39}K \, \Delta T \int \phi(\varepsilon) \, \sigma(\varepsilon) \, d\varepsilon \quad \ldots (3)$$

where, ^{39}K - is the number of ^{39}K isotope atoms

ΔT - is the length of the irradiation in seconds

$\phi(\varepsilon)$ is the neutron flux with energy ε

$\sigma(\varepsilon)$- cross section for the reaction ^{39}K (n,p) ^{39}Ar at energy ε

The number of radiogenic ^{40}Ar atoms due to decay of ^{40}K is given by the equation:

$$^{40}Ar^{*} = \frac{\lambda_e}{\lambda} \, {}^{40}K \, (e^{\lambda t} - 1) \quad \ldots (4)$$

where; λ = the total decay constant for ^{40}K

λ_e = the decay constant of 40K for electron capture

t = the age of the sample

After irradiation of a sample the ratio of $^{40}Ar^{*}/^{39}Ar$ is given by the equation:

$$\frac{^{40}Ar^{*}}{^{39}Ar} = \frac{\lambda_e}{\lambda} \, \frac{^{40}K}{^{39}K} \, \frac{1}{\Delta T} \, \frac{e^{\lambda t} - 1}{\int \phi(\varepsilon) \, \sigma(\varepsilon) \, d\varepsilon} \quad \ldots (5)$$

The value of $\int \phi(\varepsilon) \sigma(\varepsilon) d\varepsilon$ is difficult to evaluate accurately. This has led to a system of age calculation in which samples of known age (flux monitors) are interspersed with unknown samples in an irradiation canister. Then, using the J parameter which is defined as:

$$J = \frac{\lambda}{\lambda_e} \, \frac{^{39}K}{^{40}K} \, \frac{1}{\Delta T} \, \frac{e^{\lambda t} - 1}{\int \phi(\varepsilon) \, \sigma(\varepsilon) \, d\varepsilon} \quad \ldots (6)$$

and substituting this into equation 5 we obtain:

$$J = \frac{e^{\lambda t} - 1}{{}^{40}Ar^{*}/{}^{39}Ar} \quad \ldots (7)$$

The J parameter for a canister uses the known age of the standard samples and their $^{40}Ar/^{39}Ar$ ratio measured in the mass spectrometer. A simple graph of J value versus canister position allows interpolation of a J value for the unknowns. The age of the unknowns is calculated using the equation:

$$t = \frac{1}{\lambda} \ln \left[\left(\frac{{}^{40}Ar^{*}}{{}^{39}Ar} \right) J + 1 \right] \quad \ldots (8)$$

The estimated analytical error of the age t is given by:

$$\sigma_t \simeq \left[\frac{J^2 F^2 (\sigma_F^2 + \sigma_J^2)}{t^2 \lambda^2 (1 + FJ)^2} \right. \quad \ldots (9)$$

where; $F = {}^{40}Ar^{*}/{}^{39}Ar$

σ_F^2 and σ_J^2 - are variance of F and J expressed in percent (Faure, 1977)

2.2 $^{40}Ar/^{39}Ar$ Lab Procedure

The samples used in the $^{40}Ar/^{39}Ar$ dating technique were crushed using a hydraulic press and a tungsten-carbide shatterbox, sieved and washed to obtain the 70 to 120 mesh size fraction. A Frantz magnetic separator sorted the samples according to their magnetic susceptibilities. The fractions containing large quantities of biotite or muscovite were paper panned and handpicked to obtain very pure samples. The magnetic fractions containing hornblende were placed in a methylene iodide heavy liquid solution yielding a hornblende separate. This hornblende separate was handpicked to eliminate biotite contamination. The potassium feldspar rich fraction was purified in a sodium polytungstate solution (density ~2.6 g/cm^3).

Aliquots of approximately 100 mg of biotite and muscovite, 200 mg of potassium feldspar and 500 mg of hornblende, wrapped in aluminum foil inside an irradiation canister were irradiated at McMaster University nuclear reactor for approximately 10 hours. After being returned to Dalhousie and allowed to "cool", samples from the canister were placed in a quartz tube in a Lindberg extraction furnace. Gradual heating in a step-wise fashion extracted the argon gas.

A typical heating step consisted of:

1) Heating the furnace up by a 50°C interval and allowing the sample to outgas for one hour. (Extraction system shown in Figure 4.)
2) Lowering the charcoal finger temperature to -196°C by immersion in liquid nitrogen, resulting in absorption of the gas onto the charcoal.
3) Isolating the system by closing the valve to the furnace.
4) Cleaning the surface of the titanium "getter" by heating it to 800°C for 10 minutes while it is being pumped.
5) Cleaning the sample by allowing it to interact with the titanium "getter" for twenty minutes. Volatile gases bind to the titanium surface leaving a relatively pure sample of argon gas.

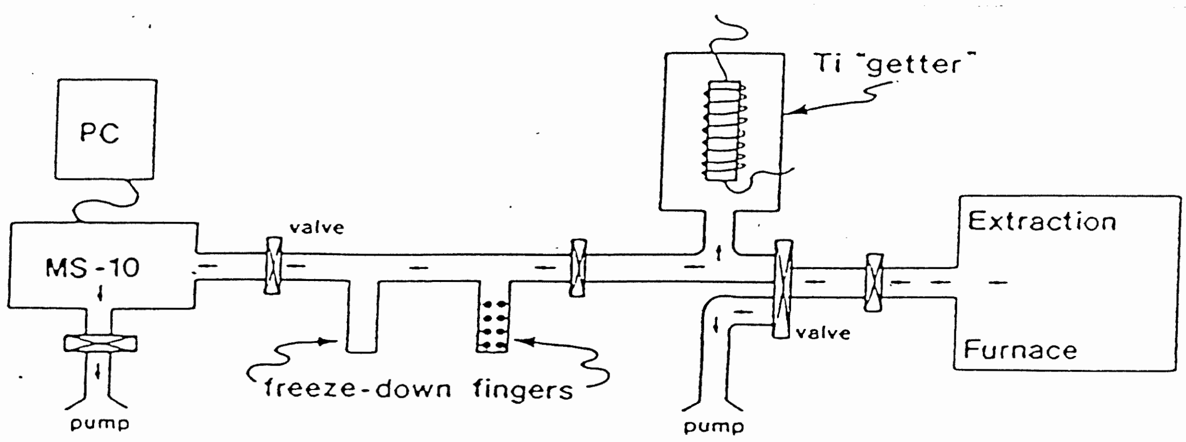


Figure 4: Argon extraction system. The Ti "getter" chemically buries reactive impurities in its surface. The freeze-down fingers are immersed in liquid nitrogen. One finger contains activated charcoal to condense argon, the other condenses out gases not absorbed by the Ti getter (after: Grist, 1986).

6) The empty freeze-down finger was then immersed in liquid nitrogen in order to condense out the gases not absorbed by the titanium "getter".

7) The argon gas was slowly admitted to the MS-10 mass spectrometer where it was analyzed for quantities of the various isotopes of argon. Measured isotope ratios were corrected for:

    1) mass spectrometer discrimination

    2) atmospheric argon contamination

    3) interfering isotopes of argon (^{36}Ar, ^{39}Ar) produced by irradiation of calcium-containing minerals.

The apparent age corresponding to each heating step, calculated from the corrected argon isotope ratios and plotted as a function of the percentage of ^{39}Ar released, produced an age spectrum for each mineral.

2.3 Results

The age spectra obtained from the biotite, muscovite and microcline of sample LH-4 and hornblende and biotite of LH-2 are shown in Figure 5. A crystal description of each of these phases is shown in Table 1.

Three of the spectra show relatively concordant ages, in which over 80% of the gas fractions released have approximately the same age.

The LH-2 hornblende spectrum shows a distinct six-step plateau representing 85% of the gas released. A weighted average of these six steps, based on the percentage of the spectrum each represents, gives an age of 303 ± 3 Ma. The LH-2 biotite spectrum also has a well-defined plateau consisting of seven heating steps representing 80% of the gas released. The weighted average of this plateau yields an age of 302 Ma $\pm$ 3. The LH-4 biotite spectrum has a plateau which represents nearly 90% of the gas released. The

TABLE 1

CRYSTALLINE NATURE OF SAMPLES USED IN $^{40}Ar/^{39}Ar$ DATING

SAMPLE	MINERAL	GRAIN SIZE	COMMENTS
LH-2	Hornblende	Up to 4mm	- Euhedral to subhedral - Pleochroic - yellow green to dark green - Some intergrown with biotite - Little alteration
LH-2	Biotite	Up to 5mm	- Euhedral to subhedral - Pleochroic - yellow to green-black - Little alteration
LH-4	Biotite	Up to 0.5mm Fine grained	- As above
LH-4	Muscovite	Up to 0.25mm	- Subhedral to anhedral grains - Intergrown with biotite, but predominantly as discrete grains
LH-4	Alkali-Feldspar (Microcline)	Up to 1.5mm	- Sub-to anhedral grains - Shows slight alteration to white mica (less than 10%)
LH-4	Orthoclase	Up to 1.5mm	- Shows 10-90% alteration to white mica - Microprobe revealed perthitic lamallea although not generally visible in thin section

small step with the anomalously high age represents 5% of the total gas released and is therefore significant. This plateau yields an age of 309 Ma ± 3.

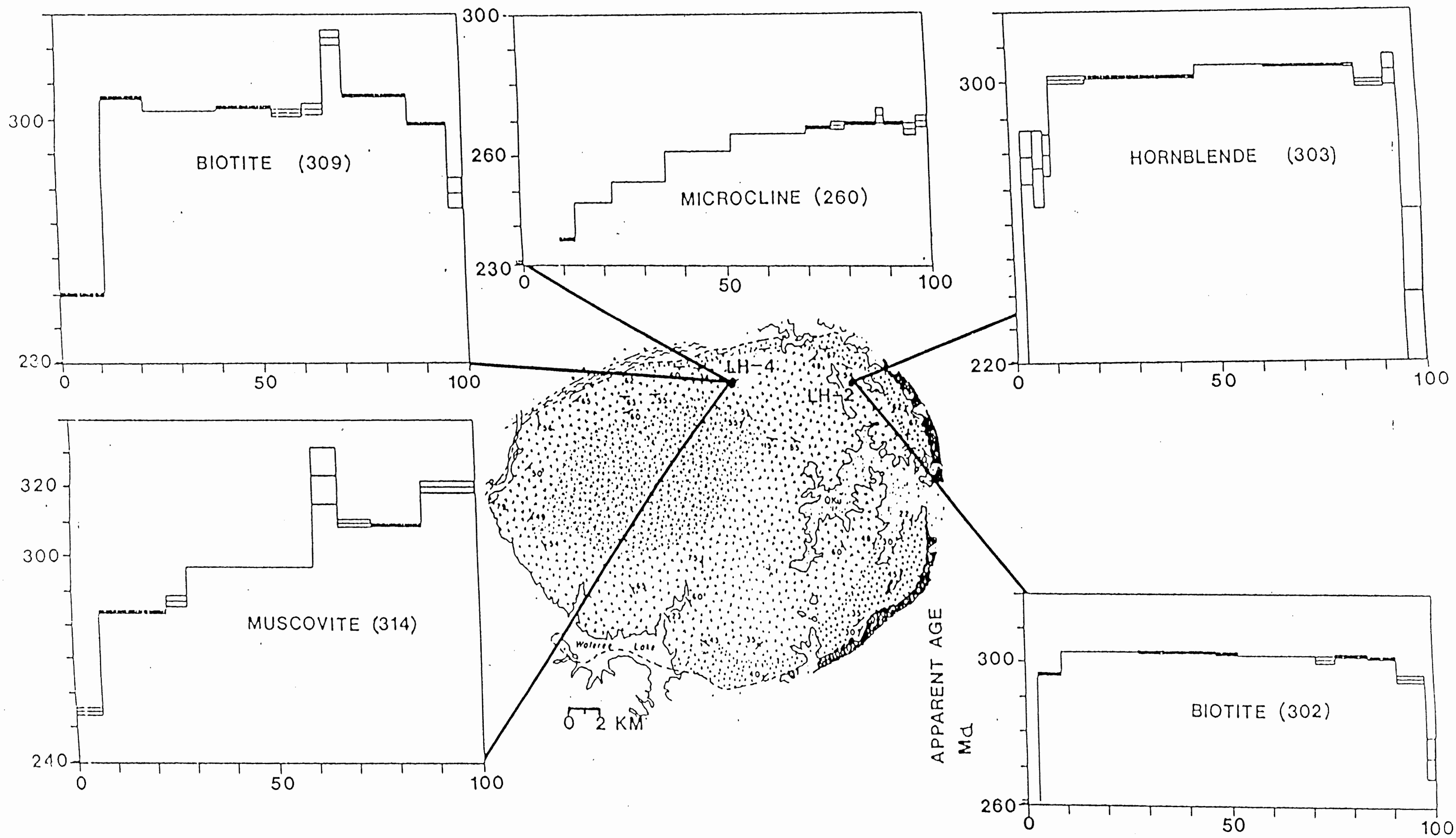


Figure 5: Age Spectrum plots for the Liberty Hill pluton showing sample locations. Calculated ages are given in parentheses. (See text for details.)

The final two spectra are discordant, that is, they fail to form an age plateau representing a large percentage of the gas released. At some point in the history of these samples they have been partially outgassed. The LH-4 muscovite produced an unusual spectrum in that it yielded insignificantly small quantities of gas above 850^{o}C. The low temperature steps show the staircase pattern typical of a partially outgassed sample. The best estimate of an age for this spectrum is 314$\pm$3 Ma as represented by the small plateau of the three high temperature steps.

The microcline separates were shown to be intermediate to maximum microcline, using the Wright (1986) method X-ray diffraction "3" peak measurement (diffraction spectra in back pocket). The age spectrum of the microcline shows a steplike pattern of increasing age with increasing temperature, leveling off to a plateau for the high temperature steps. This common shape for microcline spectra (Harrison and Be, 1983) results from either a partial loss of gas due to a reheating event, or from slow cooling through the closure temperature, allowing some escape of gas. Lack of geological evidence for a reheating event in this region, as constrained by the lower greenschist facies nature of the country rock, suggests the sample shape resulted from gas lost during passage of the feldspar through the closure temperature. In this case, the 260$\pm$3 Ma age was calculated by means of a weighted average of the total gas released.

Chapter 3: Theoretical Background and Analytical Methods
Fission Track Analysis

3.0 Introduction

The $^{40}Ar/^{39}Ar$ technique provides temperature-time (T-t) data spanning the range of 550° to 150°C. The fission track dating technique allows T-t constraints below this level. The apparent fission track age as well as the distribution of track lengths within crystals reveal important aspects of the thermal history. This chapter examines the theory, lab procedure and results of fission track analysis of apatite crystals from the Liberty Hill pluton.

3.1 Fission Track Dating Theory

The fission track dating technique depends upon the natural spontaneous fission of ^{238}U. As fission products travel through a crystal lattice they have a damage track. These damage tracks are typically a few Å wide and 10-20 long (Figure 6).

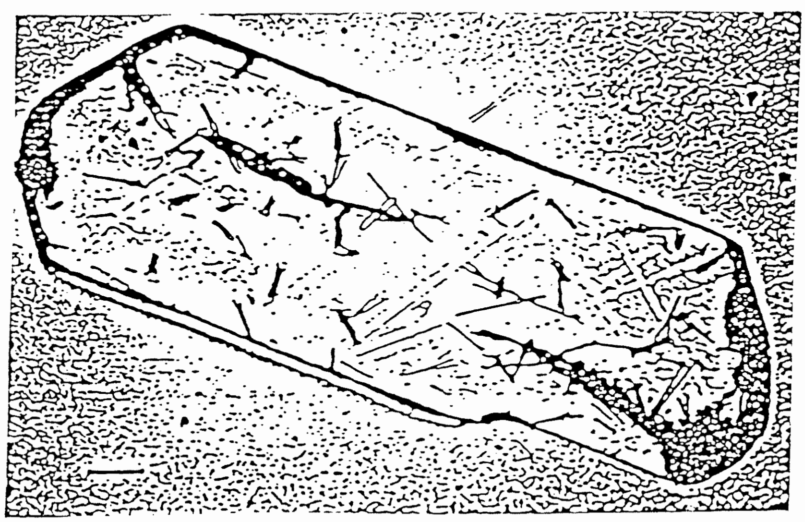


Figure 6: Photomicrograph of an etched apatite crystal showing fossil fission tracks. The scale bar is 10 (after: Gleadow, 1983).

Treatment fo the host crystal with a chemical etchant allows the fission tracks to be observed with a petrographic microscope. Fission tracks are stable for long periods of time at room temperature; however, at elevated temperatures the damage zones gradually anneal rendering the tracks invisible. Fission tracks are completely retained in apatite crystals when formed below the annealing (closure) temperature range of 70°-120°C (Harrison and McDougall, 1980).

The use of fission tracks as a dating technique is based on the assumption that in a system where there is no loss or gain of ^{238}U and the amount of time the system has been cooler than the closure temperature.

This study uses the "zeta calibration" age calculation technique outlined by Hurford and Green (1982). The age, t, is determined from the equation:

$$t = \frac{1}{\lambda_D} \ln \left[1 + \lambda_D Z (\rho_s / \rho_i) g \rho_D \right] \quad \ldots (1)$$

where Z (zeta) = $$\frac{\exp(\lambda_D t_{STD})^{-1}}{\lambda_D (\rho_s/\rho_i)_{STD}\, g \rho_D} \quad \ldots (2)$$

λ_D = total decay constant of ^{238}U (1.555125×10^{-10}/yr)

ρ_s = spontaneous track density

ρ_i = induced track density

ρ_D = track density of glass dosimeters

t_{STD} = age of standard (Fish Canyon apatite, 27.8 0.2 Ma)

g = geometry factor (0.5)

The zeta parameter is evaluated using glass dosimeters and age standards. This allows the calculation of an apparent age for unknowns without having to measure the thermal neutron flux in the reactor, as well as other poorly known parameters. Individual determinations of zeta may contain large unexplained errors (Hurford and Green, 1983). It is therefore more precise to use an average value of zeta calibrated from many capsule runs. The zeta used in this study is the laboratory average described in Section 3.2.

3.2 Fission Track Laboratory Procedure

The samples used for fission track dating were crushed using a hydraulic press and a tungsten-carbide shatterbox. The samples were washed and sieved to obtain the 70 to 120 mesh size fraction. The separation of apatite grains was initiated by removing the magnetic fraction using a Frantz-magnetic separator. The sample was further purified using a sodium polytungstate solution (density ~3.0 g/cm^3) and a methylene iodide solution (density ~3.3 g/cm^3). Approximately 150 apatite crystals, hand-picked from each separate, were mounted in araldite epoxy resin.

All grain mounts were polished using a Polimet polisher, starting with a 600 grit paper and then continuing with a 15, 9, 3, and 1/4 diamond paste.

Spontaneous tracks were revealed by etching the grain mounts in 7% HNO_3 for 40 seconds. The grain mounts were covered with a freshly cleaved flake of low uranium mica (Brazilian Ruby Clear) to record induced tracks produced in the reactor. Apatite grain mounts of known age (Fish Canyon Standards) and SRM-614 uranium dosimeter glasses (from the National Bureau of Standards) were also covered with mica detectors. The grain mounts and dosimeters were placed in an irradiation canister, sent to McMaster University nuclear reactor and irradiated in site 9D for 555 seconds.

Upon return of the capsule the mica detectors and glass dosimeters were removed and etched in 48% HF for 30 seconds. The micas were carefully washed in distilled water and heated on a hot plate eliminating remaining HF. The number of tracks per grid was counted at 400 X magnification with a microscope in which a 5 x 5 graticule in one ocular served as a grid. Approximately 250 grid fields were counted for each dosimeter. The mica detectors for the standards and unknowns were etched in 48% HF for 13 minutes and placed in bilateral symmetry with the grain mount on a glass slide. The density of spontaneous tracks, counted in the grain mounts, and of induced tracks, counted in the portion of the mica detector directly above the grain, was counted at 1000 x magnification. The glass dosimeter track density and the ratio of spontaneous to induced track density from the standards were used to calculate a zeta parameter using equation 2 (Section 3.1). This parameter, averaged with zetas from previous capsule runs, gives a value of $11.4 \pm 0.4 \times 10^3$. The ratio of spontaneous to induced track density, determined for fewer than 50 grains for each unknown, is independent of the concentration of uranium and should therefore show similar values, subject to the variation allowed by a Poissonian distribution. However, there are several sources of error which can conspire to make the distribution larger than Poissonian. According to the statistical method developed by Green (1981) if the $\rho s/\rho i$ data pass a chi-square statistical distribution it is analyzed in a conventional Poissonian manner (the ratio $= \Sigma \rho_s / \Sigma \rho_i$). However, if the data fail the chi-square distribution test a mean track density ratio ($\Sigma \rho_s / \rho_i$) is calculated and a standard error of the mean assigned to that quantity.

3.3 Track Length Distribution

The variation of the length of confined fission tracks yields important information about thermal histories. As figure 7 shows, confined fission tracks do not intersect the polished surface of a crystal.

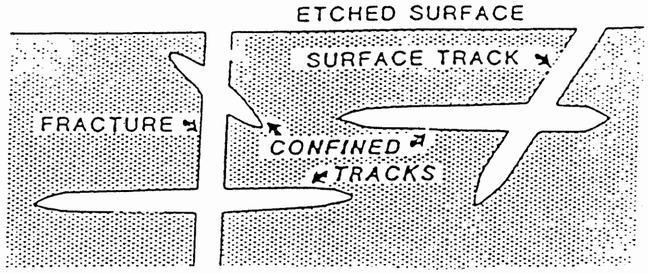


Figure 7: Diagram showing the etching of confined fission tracks used to measure track lengths (after: Gleadow et al., 1983).

Instead they intersect other features such as cracks or surface tracks which act as conduits of etchant to the confined tracks. When freshly formed, fission tracks in apatite have a fairly constant mean length of about 16.3$\pm$0.9 (Gleadow et al., 1983). New tracks are continuously formed throughout the history of a sample. Therefore each track will spend a different amount of time in the annealing temperature range and show a different degree of shortening. The overall track length distribution therefore represents a compilation of the temperature history of each track. A narrow distribution of long tracks (Figure 8a) represents a relatively short residence time within the partial annealing zone, whereas a broad distribution of tracks with a shorter mean length (Figure 8b) indicates a longer time in the annealing zone.

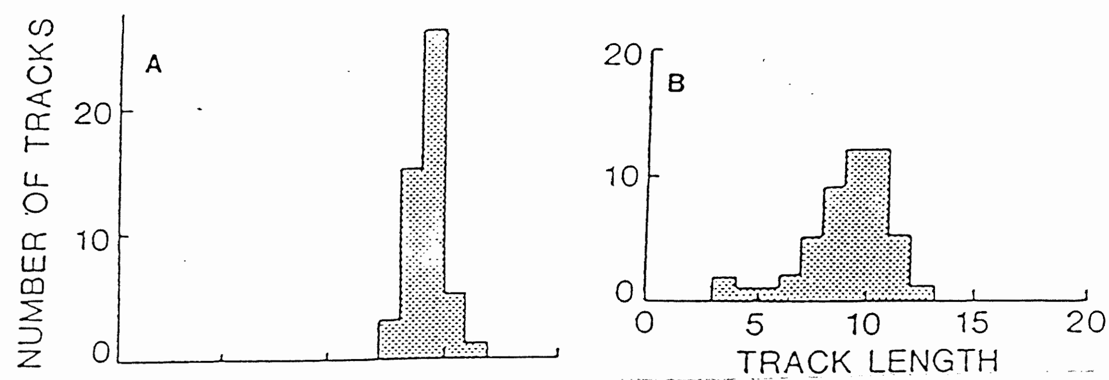


Figure 8: Variation in the distribution of track length. (See text for details)

3.4 Track Length Laboratory Procedure

The measurement of track lengths, restricted to confined tracks horizontal or sub-horizontal to the viewing surface, ensured that a real, not an apparent, length was measured. These tracks were measured with a digitizing tablet linked to a microcomputer. The tablet cursor was fitted with a light emitting diode (LED) visible through the microscope via a drawing tube. The track lengths, measured by placing the LED image at either end of a selected track and energizing the cursor, were computed with reference to a previously entered calibrated distance presented as a histogram.

3.5 Results

The results of the analysis of apatite mounts from four samples of the pluton are shown in Table 2. Samples LH-1, -2, and -5 show similar ages (82.1, 97.0, 92.4 Ma), while the age of LH-3 seems anomalously old (123 Ma). The reason for this discrepancy is not fully understood, although it was noted that the apatite grains from sample LH-3 were small and anhedral compared to the larger euhedral crystals obtained from the other three samples. There also exists an elevation range of 100m between the highest (LH-3) and lowest (LH-5) samples. At an uplift rate of .05mm/year this would pass LH-3 through the annealing zone 2 x 10^6 years before LH-5.

The distribution of confined fission track lengths is shown in Figure 9. The pattern of this length distribution is diagnostic of the cooling history of a sample (Hurford, 1986). A steady slow cooling history will produce a broad, asymmetric, unimodal distribution of track lengths (Hurford, 1986). Hurford (1986) also found that 150 slowly cooled plutonic rocks had mean track lengths that lay within the range of 12-14 . The samples LH-5, -2, and -1

TABLE 2

SAMPLE	# GRAINS				U ppm	AGE (Ma)
LH-1	24	6.29	7.13	1.94	12	97.0 ± 7.5
LH-2	19	3.31	4.03	1.98	7	92.4 ± 8.9
LH-3	28	6.47	5.86	1.98	10	123 ± 9.4
LH-5	30	5.53	7.42	1.94	13	82.1 ± 6.0

Ages calculated using a laboratory zeta factor of 1142.0 ± 380.0; neutron flux monitored using standard glass SRM 614; error calculated using the Poissonian Statistical Method (Green, 1981) and reported to 10.

show unimodal distributions, with mean track lengths between 12.8 and 13.5 . Sample LH-3 has a mean track length within the slow cooling range; however, the frequency distribution shows a slightly bimodal population. Bimodal distributions usually result from a subsequent heating event after initial cooling. The proximity of this sample to the perimeter of the pluton may have left it susceptible to reheating from hydrothermal fluids. However, mineral alteration within the samples does not provide conclusive evidence for this assertion. The overall pattern of the track length distributions and mean lengths suggests slow steady cooling.

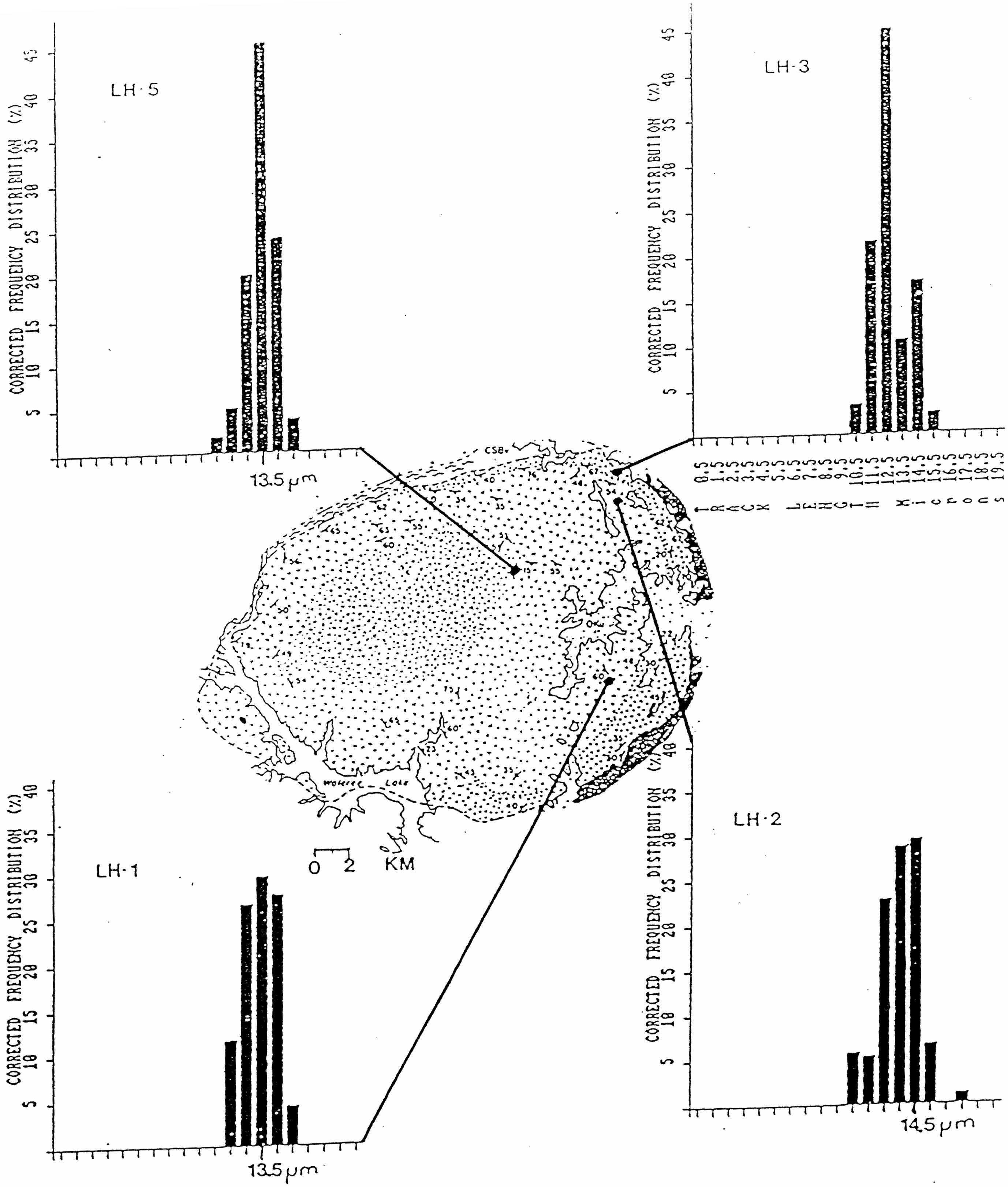


Figure 9: Distributions and mean values of confined fission track lengths and sample locations.

Chapter 4: Hornblende Geobarometer

4.0 Introduction

Calculating the uplift history of a pluton necessitates an estimate of the depth at which it crystallized and thus stopped moving upward relative to the host country rock. Geobarometers are available which allow a calculation of the ambient pressure at the time of crystallization. This study used a hornblende geobarometer to calculate crystallization pressure and thus yield the starting point on the depth-time profile of the Liberty Hill pluton.

4.1 Hornblende Geobarometer Theory

Hammerstrom and Zen (1986) proposed an empirical correlation between the estimated pressures of crystallization of calc-alkaline plutons and the total Al content of hornblende. In common rocks, there are usually too many thermodynamic degrees of freedom to constrain amphibole-bearing systems enough to use compositional parameters to determine pressure. However, in calc-alkaline magma systems there are sufficient constraints to correlate the Al content of hornblende to the pressure of solidification (Hollister et al, 1987).

According to the phase rule, at a specific temperature and pressure the number of degrees of freedom of a system is determined by the number of phases subtracted from the minimum number of chemical components (F = C-P+2; "Phase Rule"). A calc-alkaline rock may be described by the 10 major oxides as well as seven solid phases. Assuming that melt and an H_2O-bearing vapour phase are present at the end of crystallization, the system has a variance of 3: P, T and one compositional degree of freedom. This variance is lowered to one by the observation that in most calc-alkaline plutons the rim composition of plagioclase is nearly uniform and the temperature range of solidification of hornblende is only approximately 100°C for pressures above 2 Kb (Hollister et al., 1987). The final degree of freedom is accounted for by variation in the Al content of hornblende.

To use the geobarometer, the following four conditions must be met:

1) The phases quartz, plagioclase, hornblende, biotite, orthoclase, titanite and magnatite must have crystallized together form the melt.

2) Only rim compositions of the hornblende should be analyzed.

3) The pressure should be above 2 Kb.

4) The rim plagioclase composition should be between An_{23} and An_{35} (Hollister et al., 1987).

If these conditions are met then the pressure P is given by the equation: P ($\pm$ 1 Kb) = -4.76 + 5.64 Al_t . . . (10)

where; Al_t is the total number of cations of Al per formula unit based on 23 oxygens. The Liberty Hill pluton meets these conditions.

4.2 Results

Eight hornblende crystals from samples LH-5 and LH-2 were analyzed on the JEOL-733 Microprobe operating at 15KV and 5 nanno amps. Both samples contained euhedral to subhedral dark yellow-green hornblende crystals up to 4 mm in size. As suggested by Hollister et al. (1987) only crystal rim analyses were used in pressure calculations. A list of the total number of aluminum cations per formula unit based on 23 oxygens and the calculated pressures are presented in Table 3.

TABLE 3

(Complete data in Appendix.)

SAMPLE	#	AL	PRESSURE (Kb ± 1)
LH-2	1	1.6948	4.80
	2	1.6670	4.64
	3	1.6750	4.69
	"	1.7195	4.94
	4	1.6808	4.72
LH-5	5	1.9122	6.02
	"	1.6017	4.27
	6	1.4784	3.58
	7	1.6348	4.46
	"	1.6372	4.47
	8	1.55546	4.01
	"	1.5574	4.14

The average pressure of these results if 4.6 ± 1 Kb (standard error estimate for this technique). This is comparable to values of 3.1 to 4.7 Kb estimated by Speer (1987) using the same geobarometer.

5.0 Temperature-Time

In principle, different cooling ages measured on coexisting minerals should allow construction of a cooling history for the Liberty Hill pluton. However, in practice there are limitations on the development of a temperature-time history because of variability of closure temperatures. Closure temperatures are sensitive to a number of variables, among which cooling rate and effective grain size are the most important (Cliff, 1985). At present, difficulty in determining the precise effective grain size of diffusive gas loss has led to closure temperatures with significant errors. The closure temperatures chosen for this study and the ages obtained are presented in Table 4.

Table 4

MINERAL	ISOTOPIC SYSTEM	CLOSURE TEMPERATURE	AGE (MA)
Hornblende	$^{40}Ar/^{39}Ar$	$530 \pm 40^{o}C$*	303 ± 3
Muscovite	$^{40}Ar/^{39}Ar$	$350 \pm 25^{o}C$**	314 ± 3
Biotite	$^{40}Ar/^{39}Ar$	$280 \pm 40^{o}C$*	302 ± 3 309 ± 3
Microcline	$^{40}Ar/^{39}Ar$	$150 \pm 30^{o}C$*	206 ± 3 200 ± 3 ?
Apatite	Fission Track	$105 \pm 10^{o}C$*	123 ± 9.4 97.0 ± 7.5 92.4 ± 8.9 82.1 ± 6.0

* (Harrison and McDougall, 1980)
** (Dallmeyer et al., 1981)

The data in Table 4 is open to a number of interpretations. With additional information it may be possible to further constrain the post-magmatic cooling pattern of the Liberty Hill pluton. The simplest interpretation of current data follows:

A. ~300 Ma - The Liberty Hill pluton was emplaced at a depth of approximately 15km, corresponding to 4.6 Kb of pressure, with a central temperature of approximately 725°C (Speer, 1987). Similar cooling ages for hornblende, muscovite and biotite suggest the pluton cooled rapidly through the closure temperature of these minerals to the ambient temperature of the host Carolina Slate Belt, after which both followed similar cooling histories.

B. ~260 Ma - The pluton cooled through the temperature required for retention of argon in microcline (~150°C).

C. ~100 Ma to present - The pluton cooled through ~150°C allowing fission tracks to accumulate in apatite, after which the temperature stayed below this level.

These data are presented in the T - t (temperature - time) graph shown in Figure 10. The initial portion of the curve shows rapid cooling from 700°C to 300°C.

An attempt was made to estimate the amount of time a body of magma of this size would take to cool by conduction from 700°C to 300°C. Jaeger (1967) developed simple cooling models of magma suddenly emplaced at a uniform temperature and cooled by conduction into country rocks with the same thermal properties as the magma. This cooling model ignores the affects of latent heat, convection and differentiation within the magma, and thus gives only an order of magnitude estimates of the cooling time. Jaeger (1967) determined

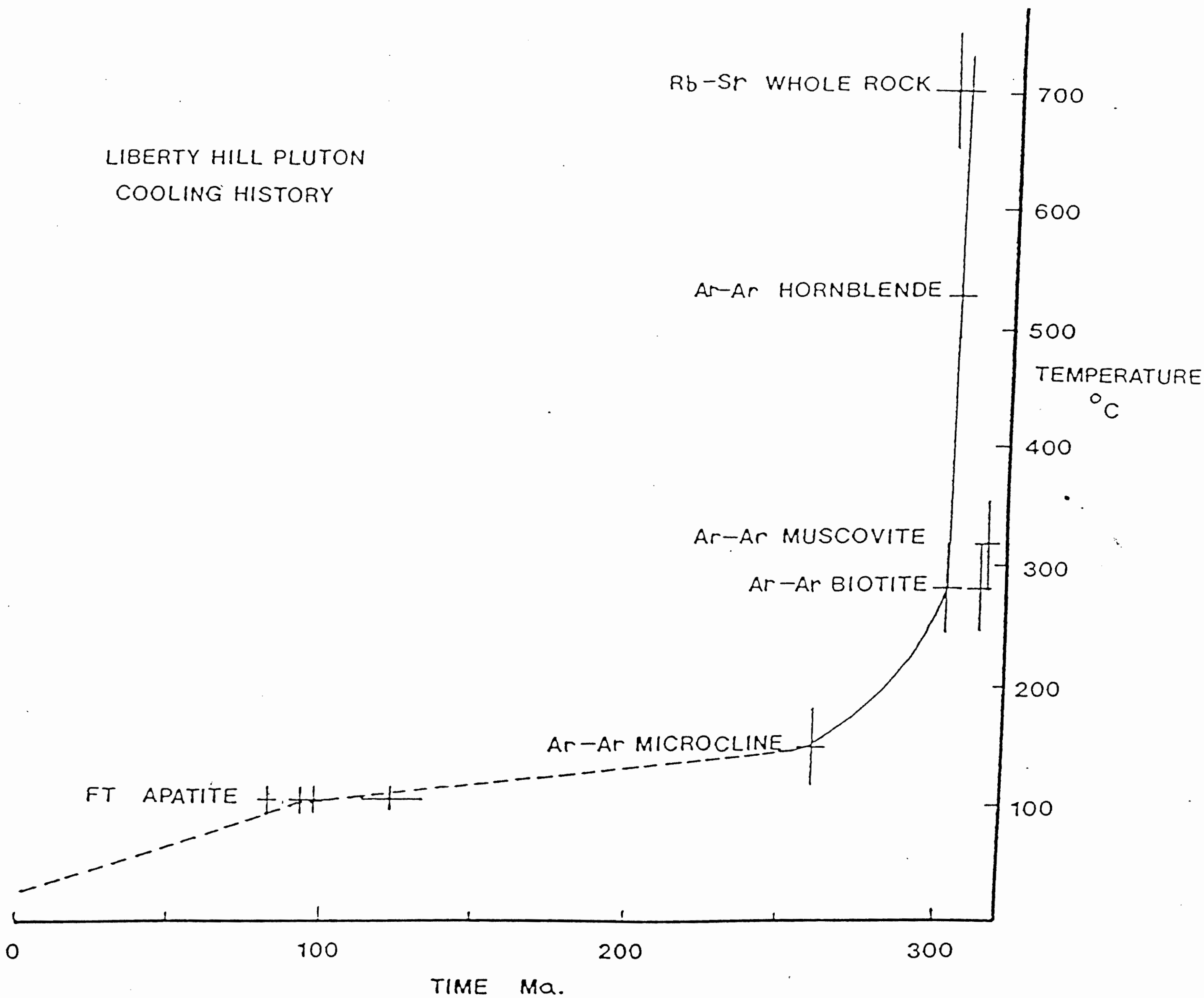


Figure 10: Simplest interpretation of the cooling history of the Liberty Hill pluton, plotted from measured mineral ages against preferred system closure temperatures.

that the sizes, positions and conductivities of cooling bodies is expressed in a family of curves which relate ξ and τ where:

$\xi = \frac{x}{a}$; x is a position co-ordinate and a is the linear dimension (radius or half thickness) and

$\tau = \frac{kt}{a^2}$. t is time and k is thermal diffusivity.

Using the k value of granite (0.01 cm^2/sec) τ equals:

$\tau \simeq 31.5t/a^2$

where: t is time in years and is a linear dimension in meters.

At this stage determination of the time at which the temperature at the center of an intrusion reaches a specified value K of the initial temperature is possible. In this case:

$K = 300^oC/700^oC = .0428$

Approximating the pluton as a cubic intrusion, the time for this much cooling is given by the function:

$\phi(0,\tau) = K^{1/3}$ ($K^{1/3} = .754$)

From Table 2 (Jaeger, 1967) for K = .754, τ is .04. Therefore for the Liberty Hill pluton, which has a half width of 13,000m the cooling time is given by:

$t = (13{,}000)^2 \; (0.4)/31.5 = 2.2 \times 10^6$ years

A cooling time of less than 5 x 10^6 years is within the error of the ages obtained for this portion of the curve.

5.1 Depth-Time

There are three time points to constrain in order to interpret a depth-time path; the 300 Ma age of emplacement, the 260 Ma age given by the microline, and the 98 Ma average of the fission track ages.

Two independent pressure indicators, the hornblende geobarometer and the metamorphic mineral assemblage of the contact aureoloe, agree that the emplacement pressure was ~4.5 kb giving a depth of about 15 km. The Rb/Sr whole rock the hornblende, muscovite and biotite $^{40}Ar/^{39}Ar$ ages all of 300 Ma indicate that the pluton cooled rapidly to a temperature of about 300°C. This is consistent with the metamorphic mineral assemblage of the surrounding country rock. The presence of metamorphic vermiculite in this assemblage suggests a maximum ambient temperature of 400°C (Veld, 1978). Thus at 15 km depth the upper temperature limit of the host rock if 400°C, while the lower limit is 300°C, as supplied by the cooling history. This yields a geothermal gradient between 26°C/km and 20°C/km. Assuming the paleogeothermal gradient decayed in a linear fashion to the present day Liberty Hill geothermal gradient of 14.9 01°C/km (Costain et al., 1986) the depth of the 150°C + 30°C microcline temperature is between 5 and 9 km. The 105 10°C closure temperature of the fission track dates yields a depth range of 5 to 7 km. The final point of the curve is the surface where the Liberty Hill pluton is exposed today (summarized in Figure 11).

The initial rapid uplift of the pluton (~0.2 mm/year) between 300 Ma and 280 Ma corresponds well to uplift rates determined elsewhere in the Piedmont Belt during this period of time (Dallmeyer et al., 1986). From 280 Ma to 100 Ma the uplift rate of the pluton appears slower (0.01mm/year). Possible regional events which affected this uplift are late Triassic-early Jurassic (205 to 190 Ma) systems of basins which opened up along the length of the Appalachians in response to the opening of the Atlantic Ocean (Swanson, 1986). During this time the Crowburg and Wadesboro basins developed north of the Liberty Hill pluton. The large fault that activated these basins is in

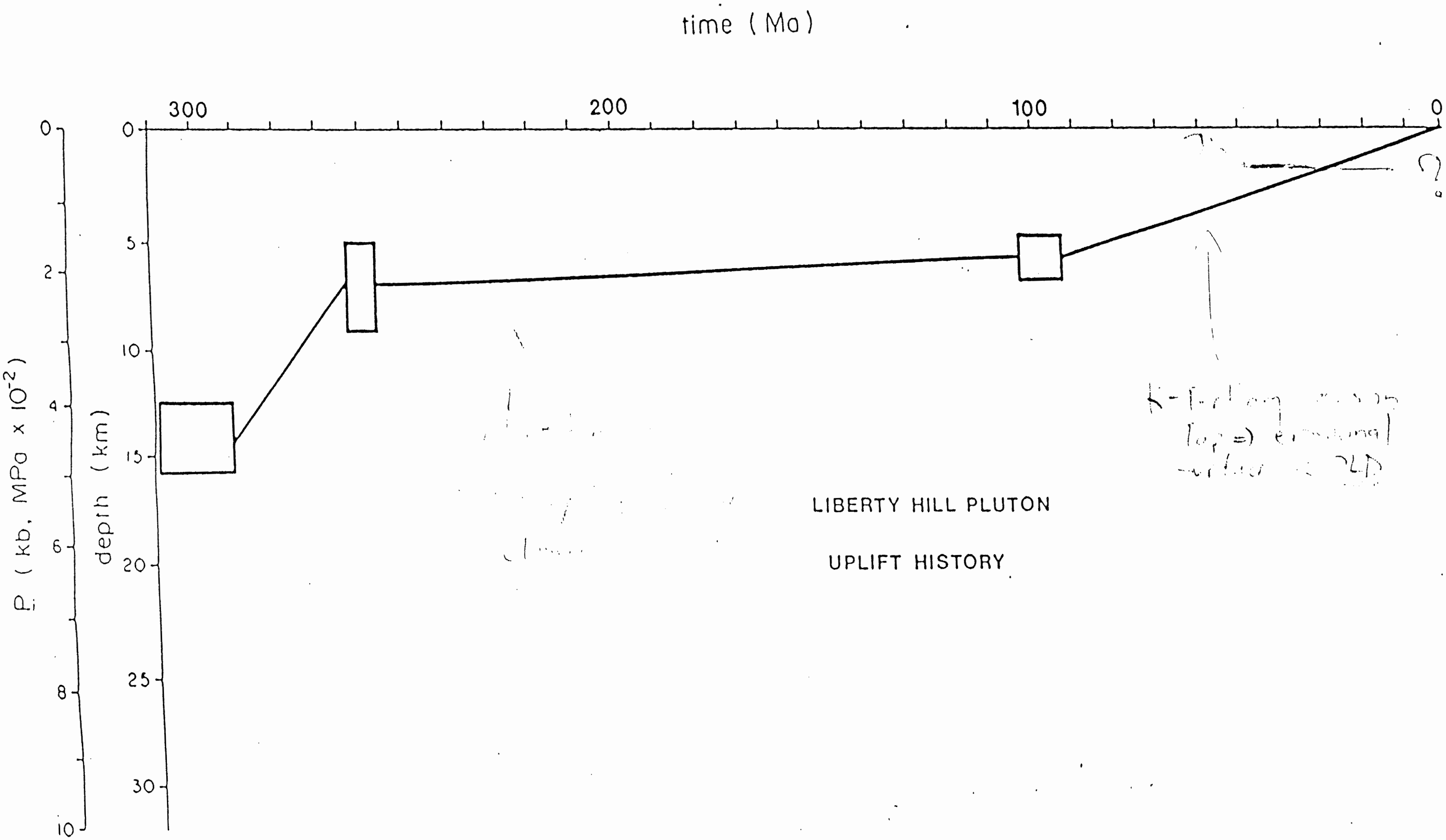


Figure 11: Depth (P) - time plot for the Liberty Hill pluton.

contact with the northwestern edge of the pluton, dipping in along the pluton edge at an angle of approximately 40^{o} (Bell and Popenoe, 1976). The pluton lies on the uplifted side of the fault. If significant upward movement occurred along the fault the assumption of a continuous slow uplift may be invalid. However, as there is such a narrow closure temperature range between the microcline and apatite ($50^{o}C$), had significant uplift occurred the fission tracks would record an age much closer to that of the microcline. The rate of uplift from 100 Ma until the present appears to increase ($\tilde{}$.05 mm/year). A study of the nature of the sediments of the nearby Coastal Plain (Owens, 1970) suggests that the Southern Appalachians has undergone a period of gentle uplift since Cretaceous times, except for a mid-Tertiary hiatus. The gentle uplift trend of the Southern Appalachians is consistent with the uplift data from the Liberty Hill pluton.

Chapter 6: Conclusions

The main conclusions of this study are as follows:

1) The LH-4 hornblende, muscovite and biotite plateau ages are 303 ± 3 Ma, and 309 ± 3 Ma respectively.

2) The LH-2 biotite yields a plateau age of 302 ± 3 Ma while the LH-2 microcline total gas age is 260 ± 3 Ma.

3) The fission track ages for apatites from samples LH-1, -2, -3 and -5 are 97.0 7.5, 92.4 8.9, 123 9.4, and 82.1 6.0 respectively.

4) The hornblende geobarometer gives a crystallization pressure of 4.6 ± 1 kb.

5) The shape of the track length distributions of unconfined tracks suggests slow steady uplift through the apatite annealing temperature range.

6) Conversion of the T-t data to depth-time data reveals a composite uplift pattern, involving initial rapid uplift of .02 mm/year (during the Alleghanian orogeny). The uplift rate slows to ~0.01 mm/year between 280 and 100 Ma, and speeds up again to ~0.5 mm/year from 100 Ma until the present.

Further work involving forward modeling of the fission track distribution may help constrain the most recent portion of the uplift history of the Liberty Hill pluton. Also fission track dates from zircon crystals would be useful to obtain as these have approximately the same closure temperature as $^{40}Ar/^{39}Ar$ dating the microcline.

The depth and time of emplacement is known for relatively few plutons in the central and southern Appalachians; the subsequent cooling and uplift history for even fewer. The variety of uplift patterns for the studied plutons indicates a complex constructional variability across the Appalachians. Investigating cooling histories of other plutons in this region will aid in our understanding of the uplift history of the southern-central Appalachians.

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Appexindix 1

$^{40}Ar/^{39}Ar$ gas output and age for individual heating steps.

LH-4 Microcline

Temp Step (^{o}C)	Age (Ma)		MV ^{39}Ar
200 - 500	0		.05
500 - 550	236.25	.654	.023
550 - 600	246.23	.480	.050
600 - 650	252.27	.217	.071
650 - 700	261.28	.184	.087
700 - 750	266.16	.246	.064
750 - 800	265.81	.481	.036
800 - 850	267.50	.780	.034
850 - 900	268.33	1.14	.017
900 - 950	268.90	.558	.043
950 - 1000	271.17	2.51	.009
1000 - 1050	268.81	.951	.027
1050 - 1100	266.87	1.70	.015
1100 - 1140	269.54	1.65	.015

LH-2 Hornblende

Temp Step (^oC)	Age (Ma)		% ^{39}Ar
200 - 650	194.50	7.90	.009
650 - 725	278.97	7.67	.010
725 - 800	275.94	11.13	.008
800 - 850	279.71	6.46	.007
850 - 900	300.88	1.18	.030
900 - 925	301.04	.571	.091
925 - 950	304.38	.309	.074
950 - 975	304.68	.399	.056
975 - 1000	299.16	1.36	.023
1000 - 1050	302.92	4.49	.010
1050 - 1125	240.37	23.71	.015

LH -4 Muscovite

Temp Step (^oC)	Age (Ma)		MV ^{39}Ar
200 - 500	254.17	1.12	.016
500 - 600	283.80	.758	.039
600 - 650	287.27	1.92	.012
650 - 700	296.87	.240	.072
700 - 750	323.47	8.16	.014
750 - 800	309.92	1.41	.019
800 - 850	309.55	.936	.029
850 - 900	320.01	1.66	.031
900 - 950			
950 - 1000			
1000 - 1050			

LH-2 Biotite

Temp Step (^{o}C)	Age (Ma)		MV ^{39}Ar
200 - 500	145.40	5.22	.013
500 - 600	296.58	1.05	.025
600 - 650	302.91	.539	.056
650 - 700	302.91	.303	.101
700 - 750	302.12	.908	.023
750 - 800	301.54	.451	.079
800 - 850	300.58	1.34	.020
850 - 900	301.84	.660	.033
900 - 950	301.48	.668	.030
950 - 1000	295.30	1.13	.028
1000 - 1050	272.33	6.36	.009

LH-4 Biotite

Temp Step (^oC)	Age (Ma)		MV ^{39}Ar
200 - 550	249.89	.716	.045
550 - 600	306.62	.567	.041
600 - 650	302.58	.536	.070
650 - 700	303.50	.579	.053
700 - 750	302.03	1.11	.028
750 - 800	303.25	2.05	.020
800 - 850	323.19	2.52	.019
850 - 900	307.05	.624	.061
900 - 950	298.91	1.02	.037
950 - 1000	278.58	4.45	.014

- Glass dosimeter = SRM612
- ND counted = 1225
- RHOD D for glass = 1.959E+01 ± 0.560E+03
- Area of 1 QUAD = 1.21E-06
- Pooled NS/NI = 0.883 ± 0.029
- Mean NS/NI = 0.889 ± 0.089

98.0 ± 5.4 MA

MEAN AGE =

98.7 ± 10.8 MA

APPENDIX 4

Raw data from track length distributions

SAMPLE LOCATION (OR STD)...LIBERTY HILL,SOUTH CAROLINA
DATE OF ANALYSIS...........18/01/88
LAB IDENTIFICATION CODE....LIBH-001
IRRADIATION CODE...........
DISKETTE...................A:
DATAFILE...................LIBHJ001.A1L
MINERAL ANALYZED...........APATITE
ANALYSIS BY................JM

FT LENGTH DATA POINTS IN MICRONS

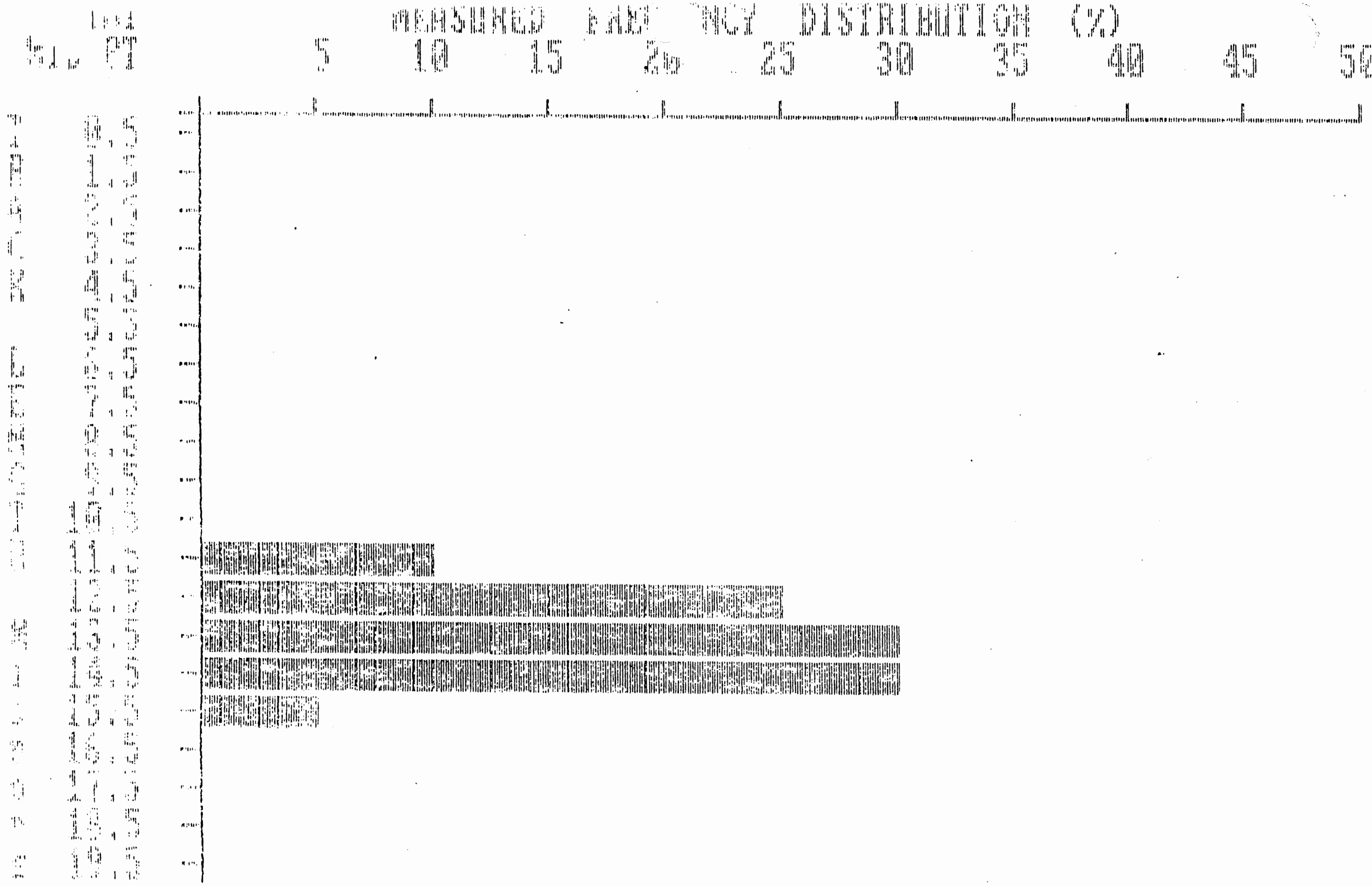
[illegible]	[illegible]	14.34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SUMMARY OF MEASURED STATISTICS

	20 FT LENGTHS MEASURED
THE MEAN IS	13.495
THE STD DEV IS	0.979
THE STD ERROR IS	0.225
THE SKEWNESS IS	-0.024
THE KURTOSIS IS	-0.877

MEASURED FREQUENCY TABLE

INTERVAL RANGE FROM TO	INT. MID. POINT	FREQUENCY VALUE	CUMULATIVE FREQUENCY	%
0.000- 1.000	0.500	0	0	0.0
1.000- 2.000	1.500	0	0	0.0
2.000- 3.000	2.500	0	0	0.0
3.000- 4.000	3.500	0	0	0.0
4.000- 5.000	4.500	0	0	0.0
5.000- 6.000	5.500	0	0	0.0
6.000- 7.000	6.500	0	0	0.0
7.000- 8.000	7.500	0	0	0.0
8.000- 9.000	8.500	0	0	0.0
9.000-10.000	9.500	0	0	0.0
10.000-11.000	10.500	0	0	0.0
11.000-12.000	11.500	2	2	10.0
12.000-13.000	12.500	5	7	25.0
13.000-14.000	13.500	6	13	30.0
14.000-15.000	14.500	6	19	30.0
15.000-16.000	15.500	1	20	5.0
16.000-17.000	16.500	0	20	0.0
17.000-18.000	17.500	0	20	0.0
18.000-19.000	18.500	0	20	0.0
19.000-20.000	19.500	0	20	0.0



PRESS (PrtSc) or (RETURN)?

SAMPLE LOCATION (OR STD)...LIBERTY HILL,SOUTH CAROLINA
DATE OF ANALYSIS...........18/01/88
LAB IDENTIFICATION CODE....LIBH-001
IRRADIATION CODE...........
DISKETTE...................A:
DATAFILE...................LIBHJ001.A1L
MINERAL ANALYZED...........APATITE
ANALYSIS BY................JM

FT LENGTH DATA POINTS IN MICRONS

[illegible]

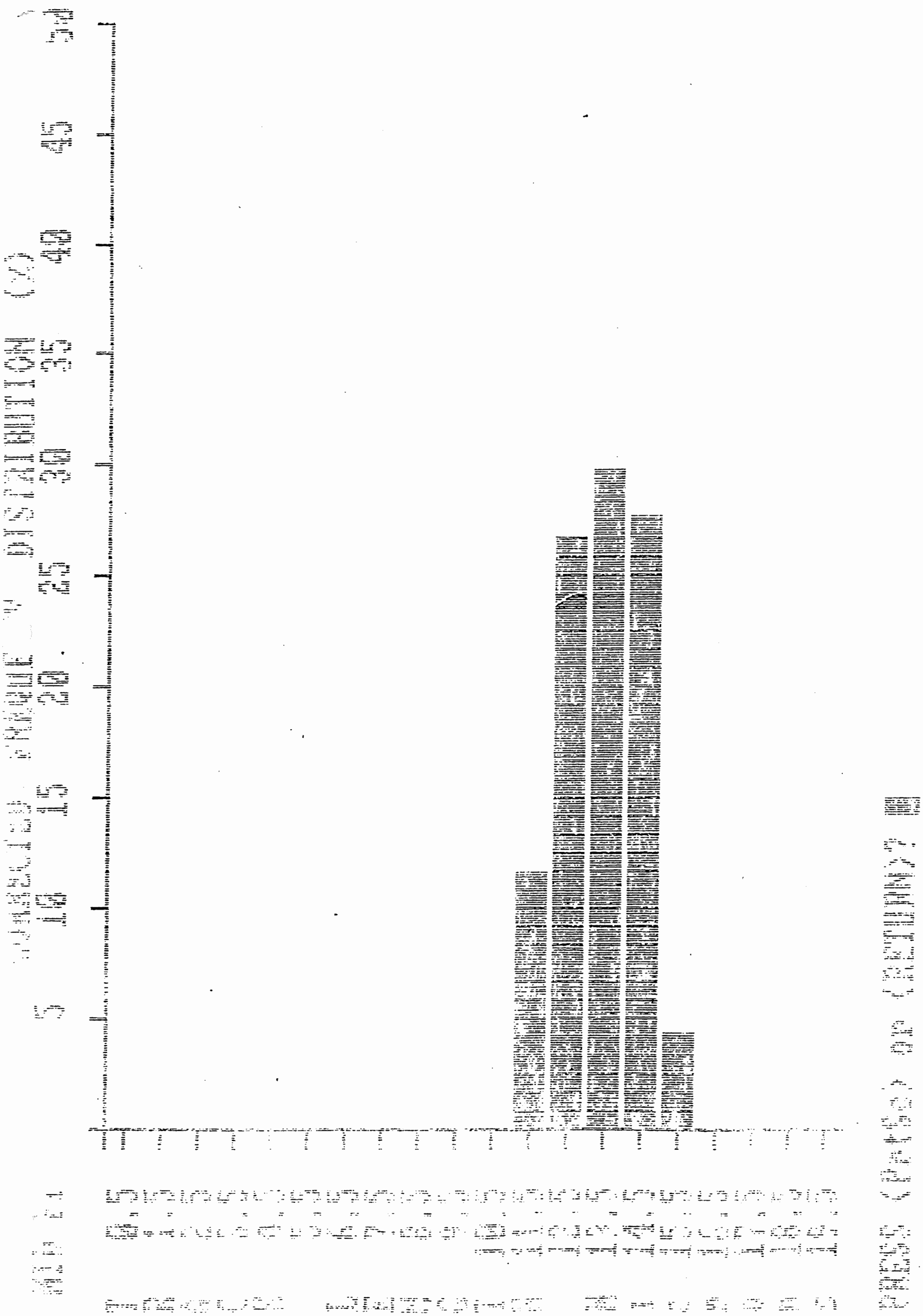
SUMMARY OF CORRECTED STATISTICS

	24.70	FT LENGTHS MEASURED
THE MEAN IS	13.363	
THE STD DEV IS	1.101	
THE STD ERROR IS	0.226	
THE SKEWNESS IS	-0.072	
THE KURTOSIS IS	-1.017	

CORRECTED FREQUENCY TABLE

INTERVAL RANGE FROM - TO	INT. MID. POINT	FREQUENCY VALUE	CUMULATIVE FREQUENCY	%
0.000- 1.000	0.500	0	0	0.0
1.000- 2.000	1.500	0	0	0.0
2.000- 3.000	2.500	0	0	0.0
3.000- 4.000	3.500	0	0	0.0
4.000- 5.000	4.500	0	0	0.0
5.000- 6.000	5.500	0	0	0.0
6.000- 7.000	6.500	0	0	0.0
7.000- 8.000	7.500	0	0	0.0
8.000- 9.000	8.500	0	0	0.0
9.000-10.000	9.500	0	0	0.0
10.000-11.000	10.500	0	0	0.0
11.000-12.000	11.500	3	3	11.6
12.000-13.000	12.500	7	9	26.7
13.000-14.000	13.500	7	17	29.7
14.000-15.000	14.500	7	24	27.6
15.000-16.000	15.500	1	25	4.3
16.000-17.000	16.500	0	25	0.0
17.000-18.000	17.500	0	25	0.0
18.000-19.000	18.500	0	25	0.0
19.000-20.000	19.500	0	25	0.0

18/01/88 JM



SAMPLE LOCATION (OR STD)...LIBERTY HILL,SOUTH CAROLINA
DATE OF ANALYSIS...........18/01/88
LAB IDENTIFICATION CODE....LIBH-002
IRRADIATION CODE...........
DISKETTE...................A:
DATAFILE...................LIBHJ002.A1L
MINERAL ANALYZED...........APATITE
ANALYSIS BY................JM

FT LENGTH DATA POINTS IN MICRONS

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				

SUMMARY OF MEASURED STATISTICS

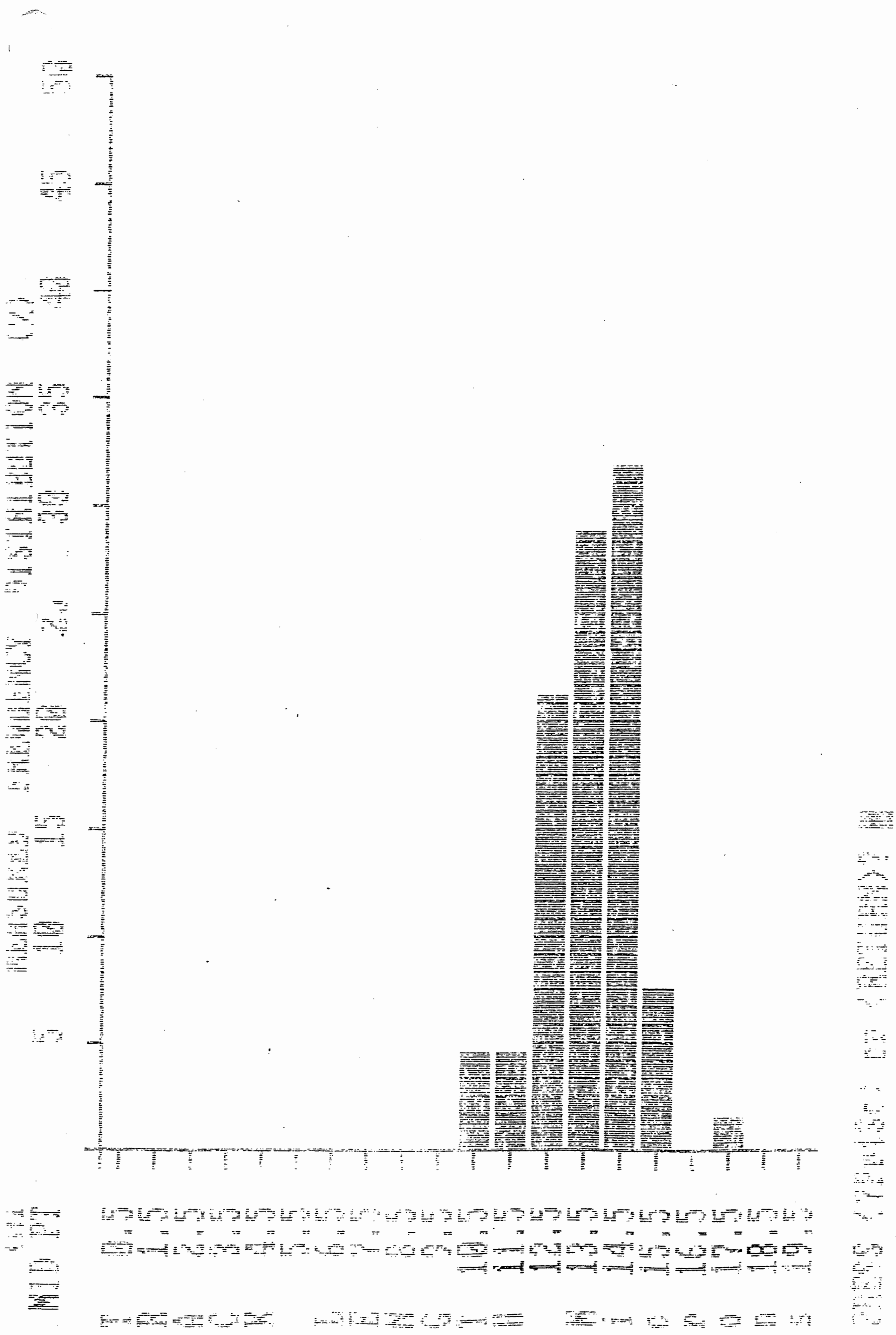
	66 FT LENGTHS MEASURED
THE MEAN IS	13.565
THE STD DEV IS	1.210
THE STD ERROR IS	0.150
THE SKEWNESS IS	-0.117
THE KURTOSIS IS	0.434

MEASURED FREQUENCY TABLE

INTERVAL RANGE FROM TO	INT. MID. POINT	FREQUENCY VALUE	CUMULATIVE FREQUENCY	%
0.000- 1.000	0.500	0	0	0.0
1.000- 2.000	1.500	0	0	0.0
2.000- 3.000	2.500	0	0	0.0
3.000- 4.000	3.500	0	0	0.0
4.000- 5.000	4.500	0	0	0.0
5.000- 6.000	5.500	0	0	0.0
6.000- 7.000	6.500	0	0	0.0
7.000- 8.000	7.500	0	0	0.0
8.000- 9.000	8.500	0	0	0.0
9.000-10.000	9.500	0	0	0.0
10.000-11.000	10.500	3	3	4.5
11.000-12.000	11.500	3	6	4.5
12.000-13.000	12.500	14	20	21.2
13.000-14.000	13.500	19	39	28.8
14.000-15.000	14.500	21	60	31.8
15.000-16.000	15.500	5	65	7.6
16.000-17.000	16.500	0	65	0.0
17.000-18.000	17.500	1	66	1.5
18.000-19.000	18.500	0	66	0.0
19.000-20.000	19.500	0	66	0.0

LIBH-002　　LIBERTY HILL, SOUTH CAROLINA　　A:LIBHJ002.AIL

18/01/88　　JM



SAMPLE LOCATION (OR STD)...LIBERTY HILL,SOUTH CAROLINA
DATE OF ANALYSIS...........18/01/88
LAB IDENTIFICATION CODE....LIBH-002
IRRADIATION CODE...........
DISKETTE...................A:
DATAFILE...................LIBHJ002.A1L
MINERAL ANALYZED...........APATITE
ANALYSIS BY................JM

FT LENGTH DATA POINTS IN MICRONS

[illegible]

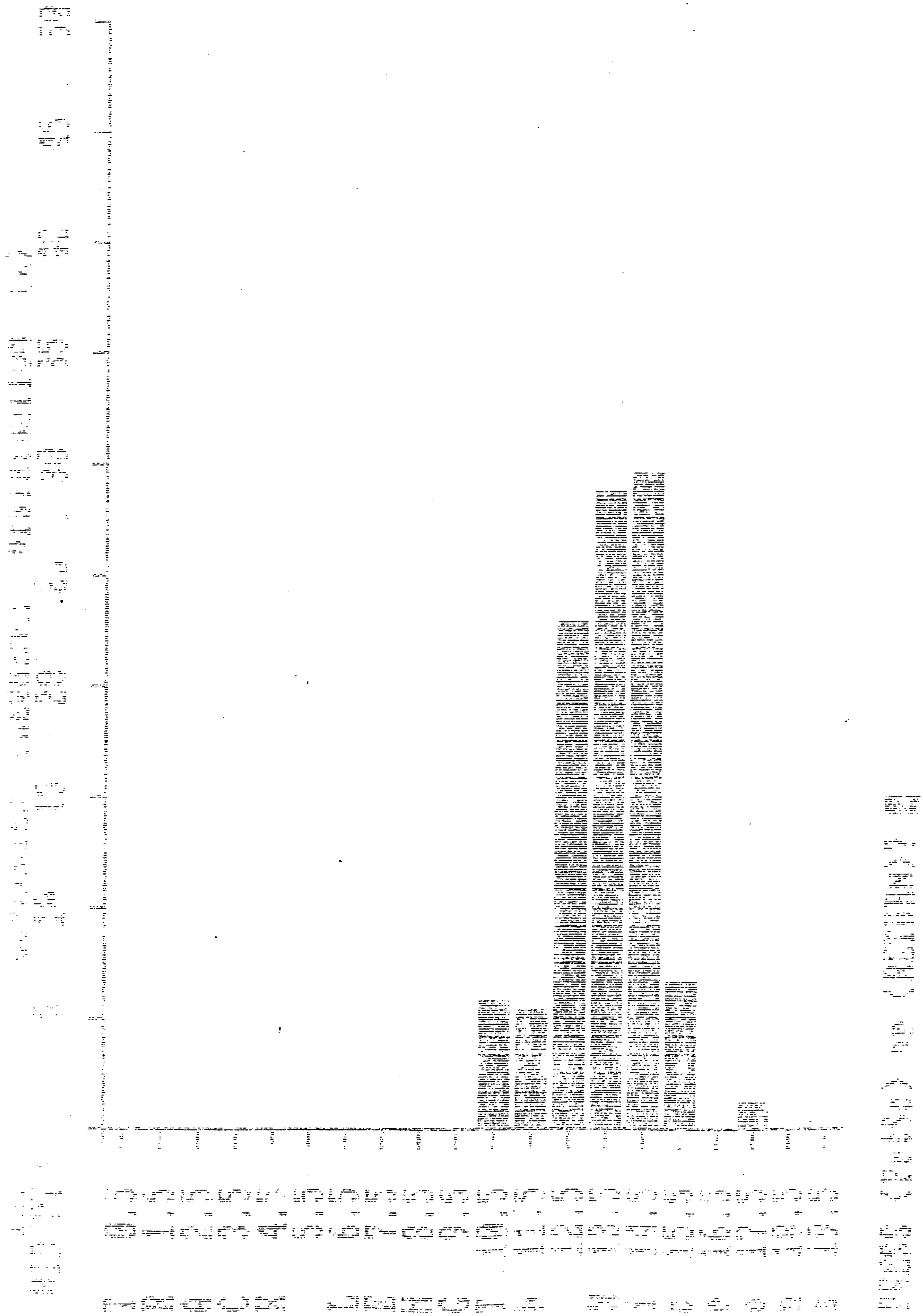
SUMMARY OF CORRECTED STATISTICS

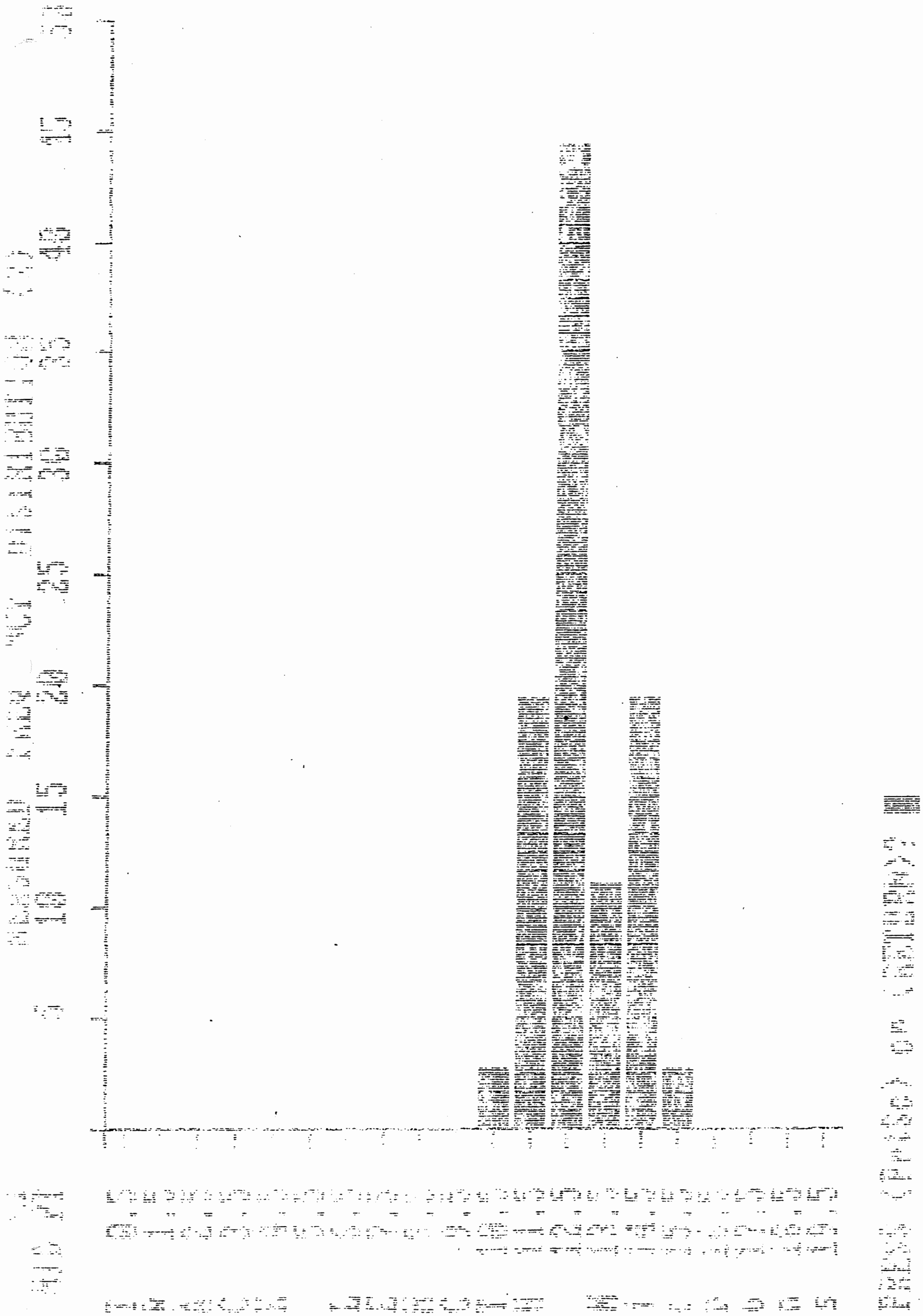
	80.88 FT LENGTHS MEASURED
THE MEAN IS	13.464
THE STD DEV IS	1.316
THE STD ERROR IS	0.147
THE SKEWNESS IS	-0.208
THE KURTOSIS IS	0.354

CORRECTED FREQUENCY TABLE

INTERVAL RANGE FROM TO	INT. MID. POINT	FREQUENCY VALUE	CUMULATIVE FREQUENCY	%
0.000- 1.000	0.500	0	0	0.0
1.000- 2.000	1.500	0	0	0.0
2.000- 3.000	2.500	0	0	0.0
3.000- 4.000	3.500	0	0	0.0
4.000- 5.000	4.500	0	0	0.0
5.000- 6.000	5.500	0	0	0.0
6.000- 7.000	6.500	0	0	0.0
7.000- 8.000	7.500	0	0	0.0
8.000- 9.000	8.500	0	0	0.0
9.000-10.000	9.500	0	0	0.0
10.000-11.000	10.500	5	5	5.8
11.000-12.000	11.500	4	9	5.3
12.000-13.000	12.500	18	27	22.8
13.000-14.000	13.500	23	51	28.7
14.000-15.000	14.500	24	75	29.5
15.000-16.000	15.500	5	80	6.6
16.000-17.000	16.500	0	80	0.0
17.000-18.000	17.500	1	81	1.2
18.000-19.000	18.500	0	81	0.0
19.000-20.000	19.500	0	81	0.0

18/01/88 JM





SAMPLE LOCATION (OR STD)...LIBERTY HILL,SOUTH CAROLINA
DATE OF ANALYSIS...........01/15/88
LAB IDENTIFICATION CODE....LIBH-003
IRRADIATION CODE...........
DISKETTE...................A:
DATAFILE...................LIBHJ003.A1L
MINERAL ANALYZED...........APATITE
ANALYSIS BY................JM

FT LENGTH DATA POINTS IN MICRONS

[illegible]	12.10	[illegible]	[illegible]	14.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	14.21	[illegible]	11.35	14.02	[illegible]	12.09	[illegible]	[illegible]	[illegible]
12.51	14.51	12.64	[illegible]	11.70	12.80	[illegible]	[illegible]	[illegible]	[illegible]
11.38	12.67	12.29	[illegible]	12.46	11.95				

SUMMARY OF MEASURED STATISTICS

	36 FT LENGTHS MEASURED
THE MEAN IS	12.779
THE STD DEV IS	1.097
THE STD ERROR IS	0.185
THE SKEWNESS IS	0.362
THE KURTOSIS IS	-0.476

MEASURED FREQUENCY TABLE

INTERVAL RANGE FROM TO	INT. MID. POINT	FREQUENCY VALUE	CUMULATIVE FREQUENCY	%
0.000- 1.000	0.500	0	0	0.0
1.000- 2.000	1.500	0	0	0.0
2.000- 3.000	2.500	0	0	0.0
3.000- 4.000	3.500	0	0	0.0
4.000- 5.000	4.500	0	0	0.0
5.000- 6.000	5.500	0	0	0.0
6.000- 7.000	6.500	0	0	0.0
7.000- 8.000	7.500	0	0	0.0
8.000- 9.000	8.500	0	0	0.0
9.000-10.000	9.500	0	0	0.0
10.000-11.000	10.500	1	1	2.8
11.000-12.000	11.500	7	8	19.4
12.000-13.000	12.500	16	24	44.4
13.000-14.000	13.500	4	28	11.1
14.000-15.000	14.500	7	35	19.4
15.000-16.000	15.500	1	36	2.8
16.000-17.000	16.500	0	36	0.0
17.000-18.000	17.500	0	36	0.0
18.000-19.000	18.500	0	36	0.0
19.000-20.000	19.500	0	36	0.0

SAMPLE LOCATION (OR STD)...LIBERTY HILL.SOUTH CAROLINA
DATE OF ANALYSIS...........01/15/88
LAB IDENTIFICATION CODE....LIBH-003
IRRADIATION CODE...........
DISKETTE...................A:
DATAFILE...................LIBHJ003.A1L
MINERAL ANALYZED...........APATITE
ANALYSIS BY................JM

FT LENGTH DATA POINTS IN MICRONS

13.59	12.10	11.86	13.06	[illegible]	15.45	13.23	12.66	[illegible]	11.87
12.20	14.21	14.12	11.08	14.32	12.87	12.09	11.72	12.58	15.37
12.51	14.51	12.64	12.53	[illegible]	12.90	12.90	12.23	11.40	10.46
12.36	12.67	12.29	14.22	12.42	[illegible]				

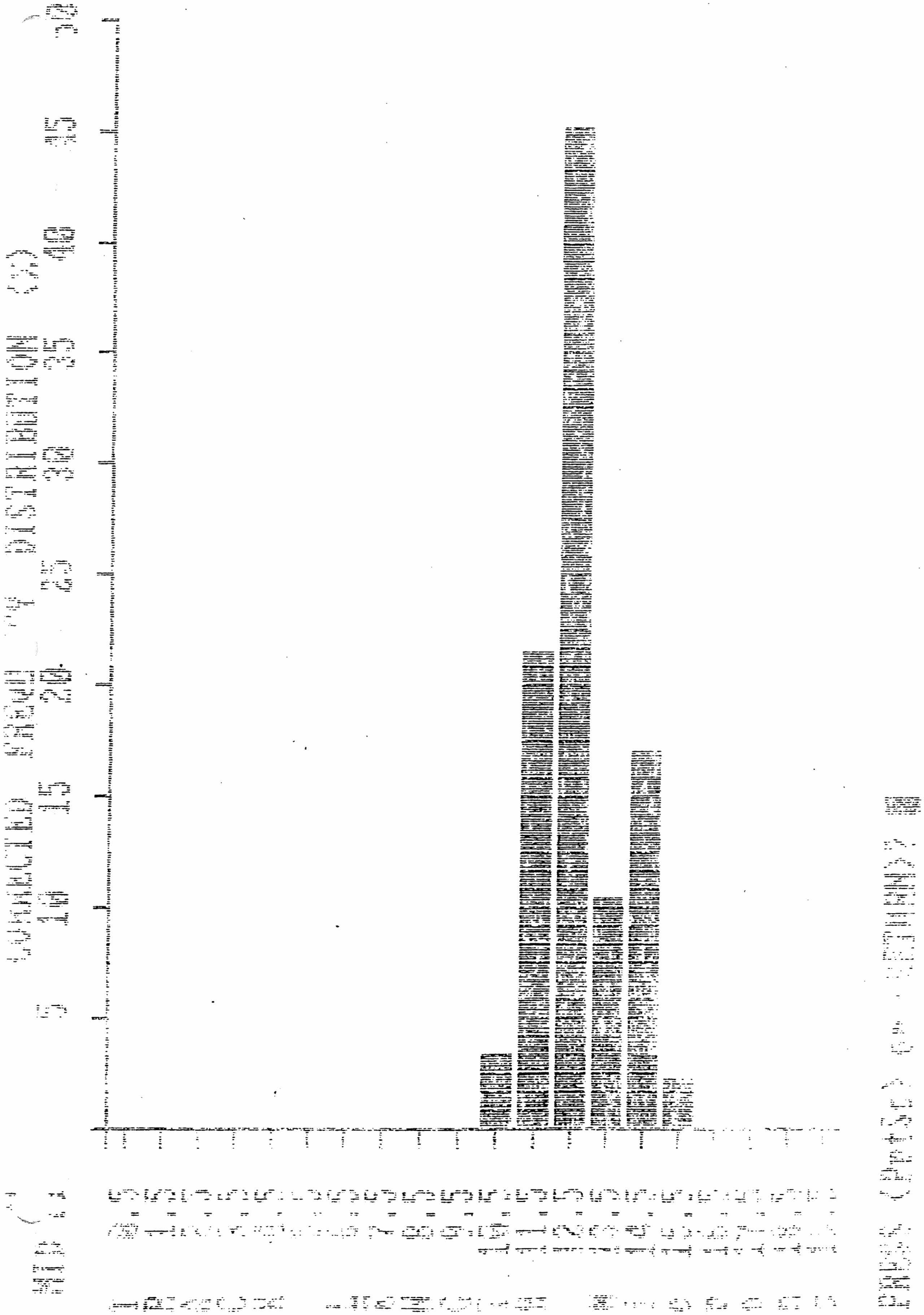
SUMMARY OF CORRECTED STATISTICS

	46.65 FT LENGTHS MEASURED
THE MEAN IS	12.732
THE STD DEV IS	1.148
THE STD ERROR IS	0.170
THE SKEWNESS IS	0.458
THE KURTOSIS IS	-0.478

CORRECTED FREQUENCY TABLE

INTERVAL RANGE FROM TO	INT. MID. POINT	FREQUENCY VALUE	CUMULATIVE FREQUENCY	%
0.000- 1.000	0.500	0	0	0.0
1.000- 2.000	1.500	0	0	0.0
2.000- 3.000	2.500	0	0	0.0
3.000- 4.000	3.500	0	0	0.0
4.000- 5.000	4.500	0	0	0.0
5.000- 6.000	5.500	0	0	0.0
6.000- 7.000	6.500	0	0	0.0
7.000- 8.000	7.500	0	0	0.0
8.000- 9.000	8.500	0	0	0.0
9.000-10.000	9.500	0	0	0.0
10.000-11.000	10.500	2	2	3.4
11.000-12.000	11.500	10	12	21.5
12.000-13.000	12.500	21	33	45.3
13.000-14.000	13.500	5	38	10.5
14.000-15.000	14.500	8	46	17.1
15.000-16.000	15.500	1	47	2.3
16.000-17.000	16.500	0	47	0.0
17.000-18.000	17.500	0	47	0.0
18.000-19.000	18.500	0	47	0.0
19.000-20.000	19.500	0	47	0.0

LIBH-003 LIBERTY HILL, SOUTH CAROLINA A:LIBHJ003.A1L
01/15/88 JM



SAMPLE LOCATION (OR STD)...LIBERTY HILL,SOUTH CAROLINA
DATE OF ANALYSIS...........01/14/88
LAB IDENTIFICATION CODE....LIBH-005
IRRADIATION CODE...........
DISKETTE...................A:
DATAFILE...................LIBHJ005.A2L
MINERAL ANALYZED...........APATITE
ANALYSIS BY................JM

FT LENGTH DATA POINTS IN MICRONS

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

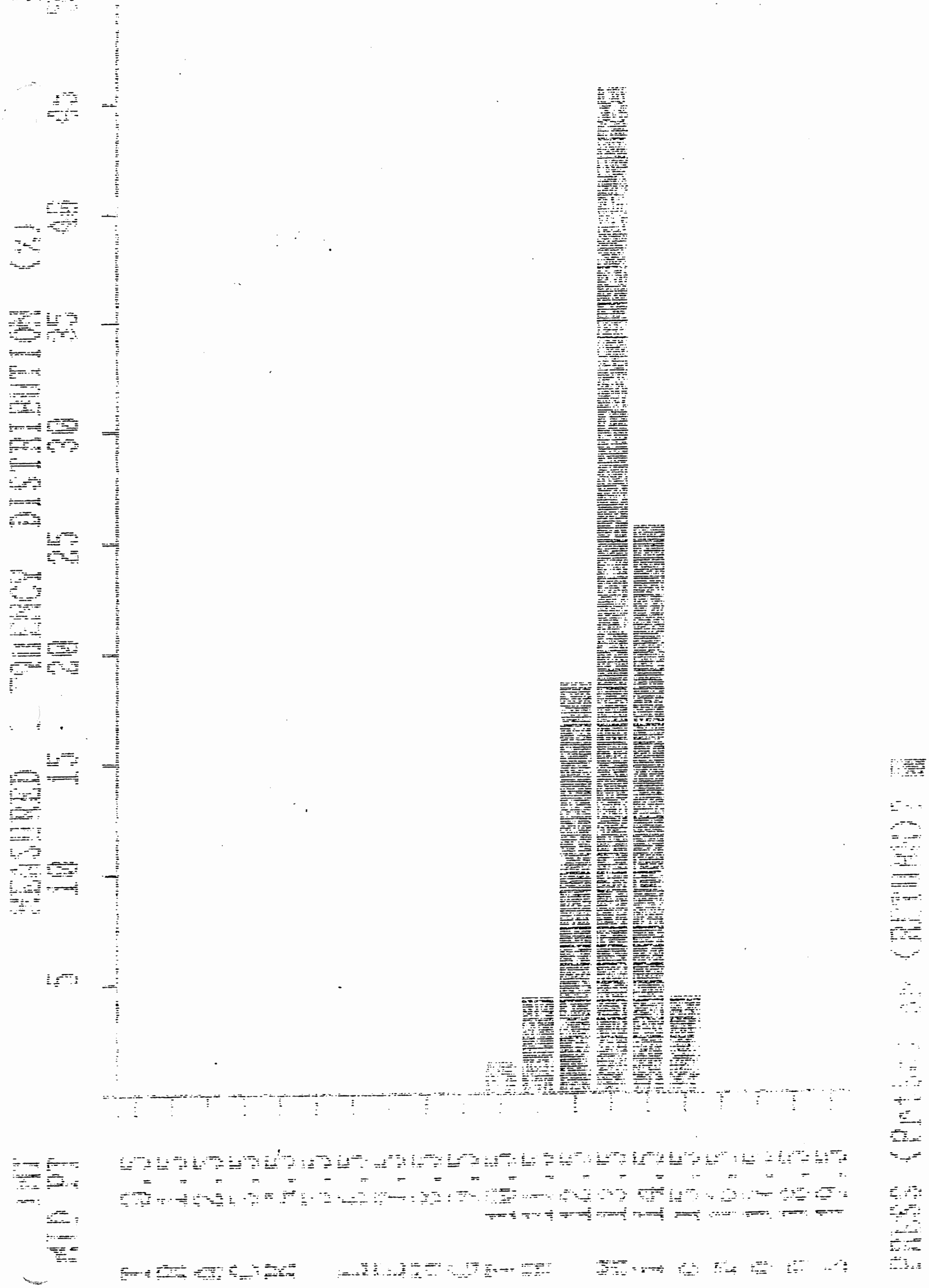
SUMMARY OF MEASURED STATISTICS

	70 FT LENGTHS MEASURED
THE MEAN IS	13.508
THE STD DEV IS	0.954
THE STD ERROR IS	0.115
THE SKEWNESS IS	-0.368
THE KURTOSIS IS	0.374

MEASURED FREQUENCY TABLE

INTERVAL RANGE FROM TO	INT. MID. POINT	FREQUENCY VALUE	CUMULATIVE FREQUENCY	%
0.000- 1.000	0.500	0	0	0.0
1.000- 2.000	1.500	0	0	0.0
2.000- 3.000	2.500	0	0	0.0
3.000- 4.000	3.500	0	0	0.0
4.000- 5.000	4.500	0	0	0.0
5.000- 6.000	5.500	0	0	0.0
6.000- 7.000	6.500	0	0	0.0
7.000- 8.000	7.500	0	0	0.0
8.000- 9.000	8.500	0	0	0.0
9.000-10.000	9.500	0	0	0.0
10.000-11.000	10.500	1	1	1.4
11.000-12.000	11.500	3	4	4.3
12.000-13.000	12.500	13	17	18.6
13.000-14.000	13.500	32	49	45.7
14.000-15.000	14.500	18	67	25.7
15.000-16.000	15.500	3	70	4.3
16.000-17.000	16.500	0	70	0.0
17.000-18.000	17.500	0	70	0.0
18.000-19.000	18.500	0	70	0.0
19.000-20.000	19.500	0	70	0.0

LIBH-005 LIBERTY HILL, SOUTH CAROLINA A:LIBHJ005.A2L
01/14/88 JM



SAMPLE LOCATION (OR STD)...LIBERTY HILL,SOUTH CAROLINA
DATE OF ANALYSIS...........01/14/88
LAB IDENTIFICATION CODE....LIBH-005
IRRADIATION CODE..........
DISKETTE...................A:
DATAFILE...................LIBHJ005.A2L
MINERAL ANALYZED...........APATITE
ANALYSIS BY................JM

FT LENGTH DATA POINTS IN MICRONS

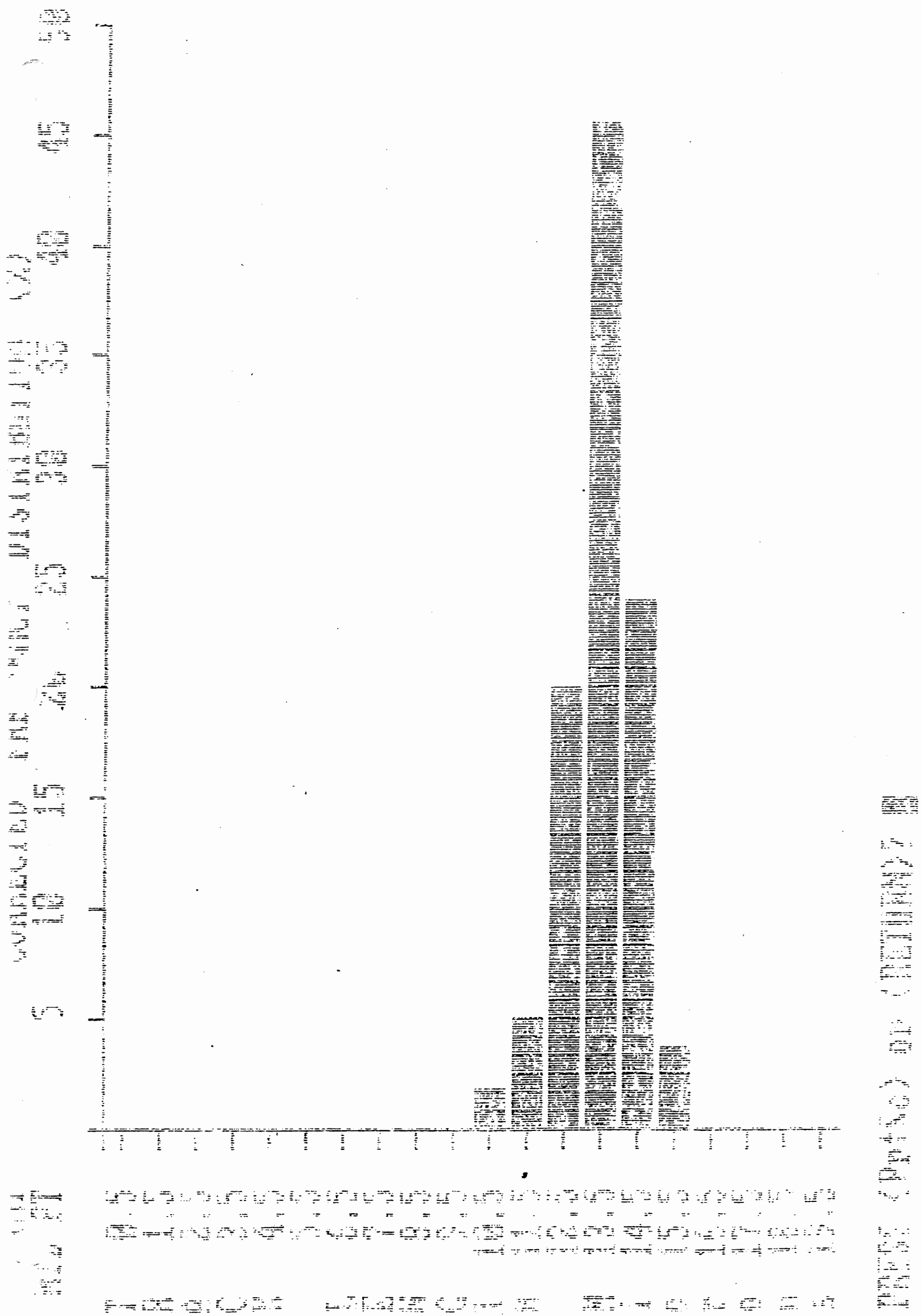
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	14.58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12.45	[illegible]	12.73	13.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13.54	[illegible]	[illegible]	13.25	14.02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13.32	15.73	13.01	10.72	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12.95	11.68	13.83	13.49	13.56	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	14.66	[illegible]	14.52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SUMMARY OF CORRECTED STATISTICS

	85.82 FT LENGTHS MEASURED
THE MEAN IS	13.458
THE STD DEV IS	0.981
THE STD ERROR IS	0.107
THE SKEWNESS IS	-0.465
THE KURTOSIS IS	0.494

CORRECTED FREQUENCY TABLE

INTERVAL RANGE FROM - TO	INT. MID. POINT	FREQUENCY VALUE	CUMULATIVE FREQUENCY	%
0.000- 1.000	0.500	0	0	0.0
1.000- 2.000	1.500	0	0	0.0
2.000- 3.000	2.500	0	0	0.0
3.000- 4.000	3.500	0	0	0.0
4.000- 5.000	4.500	0	0	0.0
5.000- 6.000	5.500	0	0	0.0
6.000- 7.000	6.500	0	0	0.0
7.000- 8.000	7.500	0	0	0.0
8.000- 9.000	8.500	0	0	0.0
9.000-10.000	9.500	0	0	0.0
10.000-11.000	10.500	2	2	1.8
11.000-12.000	11.500	4	6	5.0
12.000-13.000	12.500	17	23	20.0
13.000-14.000	13.500	39	62	45.6
14.000-15.000	14.500	20	83	23.9
15.000-16.000	15.500	3	86	3.7
16.000-17.000	16.500	0	86	0.0
17.000-18.000	17.500	0	86	0.0
18.000-19.000	18.500	0	86	0.0
19.000-20.000	19.500	0	86	0.0



APPENDIX 5

Microprobe result for hornblende geobarometer

JN SCHEDULE ZZZ
3-NOV-87
14:15:34

EF WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
WDS:NA WDS:K

AF CORRECTION 15.00 KV 40.00 Deg

. Of Iterations 0

---	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.150	0.998	1.343	0.998	1.340	16.83	20.18	
-K	0.006	1.134	1.033	0.981	1.151	0.34	0.70	
-K	0.032	1.030	1.483	0.991	1.515	4.32	5.00	*
-K	0.000	1.139	1.014	0.954	1.102	0.02	0.03	
-K	0.149	1.146	1.004	1.000	1.152	7.19	17.23	
-K	0.000	1.138	1.013	1.000	1.153	0.00	0.00	
-K	0.004	1.163	1.008	1.000	1.173	0.21	0.50	
-K	0.027	0.985	1.721	0.994	1.688	4.56	4.68	*
-K	0.078	1.029	1.044	0.992	1.067	4.88	8.35	
-K	0.006	1.023	2.250	0.996	2.295	1.45	1.43	*
-K	0.010	1.051	1.065	0.981	1.099	0.66	1.11	
-K	0.186	0.954	2.298	0.999	2.192	59.54	40.79 D	*
					TOTAL=		100.00	

- High Absorbance

IDE RESULTS

	WT%
O2	43.23
O2	1.17
	9.44
3	0.05
	22.15
O	0.00
O	0.65
O	7.81
O	11.69
2O	1.93
2O	1.34
TAL=	99.44

OF OXY = 23.00 #1b (NEAR XTL RIM)

kb = 4.80 ± 1

SI	6.5884
TI	0.1337
AL	1.6948
CR	0.0060
FE	2.8239
NI	0.0000
MN	0.0840
MG	1.7730
CA	1.9088
NA	0.5692
K	0.2597

14:18:39

N SCHEDULE ZZZ
- -87
21:28

F.S WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
:CA WDS:NA WDS:K

F CORRECTION 15.00 KV 40.00 Deg

. Of Iterations 0

--	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.147	0.998	1.339	0.998	1.336	16.38	19.75	
-K	0.007	1.135	1.033	0.981	1.151	0.42	0.86	
-K	0.031	1.030	1.480	0.991	1.513	4.14	4.81	*
-K	0.000	1.139	1.014	0.954	1.104	0.01	0.02	
-K	0.147	1.147	1.004	1.000	1.152	7.07	17.04	
-K	0.000	1.139	1.013	1.000	1.154	0.00	0.00	
-K	0.004	1.164	1.008	1.000	1.174	0.22	0.52	
-K	0.025	0.986	1.725	0.994	1.693	4.22	4.36	*
-K	0.077	1.030	1.043	0.992	1.067	4.81	8.28	
-K	0.006	1.023	2.260	0.996	2.306	1.40	1.39	*
-K	0.010	1.052	1.063	0.981	1.098	0.71	1.18	
-K	0.190	0.955	2.296	0.999	2.191	60.64	41.79 D	*

TOTAL= 100.01

- High Absorbance

RESULTS

	WT%
J2	42.33
J2	1.44
2O3	9.09
2O3	0.03
J	21.91
J	0.00
J	0.67
J	7.27
J	11.60
2O	1.87
2O	1.43
AL=	97.62

#2a (NEAR XTL RIM)

OF OXY = 23.00 Kb = 4.64 ± 1

SI	6.5870
TI	0.1684
AL	1.6670
CR	0.0034
FE	2.8520
I	0.0000
MN	0.0877
MG	1.6859
CA	1.9333
NA	0.5646
K	0.2834

0:24:34

N SCHEDULE 222
-NOV-87
10:43: 2

F WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
: WDS:NA WDS:K

F CORRECTION 15.00 KV 40.00 Deg

. Of Iterations 0

--	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
K	0.147	0.998	1.341	0.998	1.338	16.35	19.70	
K	0.007	1.135	1.033	0.981	1.151	0.40	0.83	
K	0.031	1.030	1.483	0.991	1.516	4.17	4.85	*
K	0.000	1.139	1.014	0.954	1.103	0.01	0.02	
K	0.148	1.147	1.004	1.000	1.152	7.12	17.16	
K	0.000	1.139	1.013	1.000	1.154	0.00	0.00	
K	0.004	1.164	1.008	1.000	1.174	0.20	0.48	
K	0.026	0.986	1.725	0.994	1.692	4.41	4.56	*
K	0.078	1.030	1.043	0.992	1.067	4.89	8.42	
K	0.005	1.023	2.259	0.996	2.306	1.39	1.37	*
K	0.009	1.052	1.064	0.981	1.098	0.60	1.01	
K	0.189	0.955	2.294	0.999	2.190	60.44	41.60 D	*

TOTAL= 100.00

- High Absorbance

DE RESULTS

	WT%
2	42.21
2	1.39
-	9.16
.	0.04
	22.06
	0.00
	0.62
	7.59
	11.79
	1.85
	1.22
L=	97.91

OF OXY = 23.00

#3a (NEAR RIM OF XTL)
Kb= 4.69 ±1

SI	6.5489
TI	0.1621
AL	1.6750
CR	0.0043
FE	2.8634
NI	0.0000
MN	0.0810
MG	1.7555
CA	1.9595
	0.5564
	0.2415

46: 7

ꟷ SCHEDULE ZZZ
-NOV-87
0:28:33

WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
WDS:NA WDS:K

CORRECTION 15.00 KV 40.00 Deg

Of Iterations 0

-	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
K	0.148	0.998	1.342	0.998	1.338	16.54	19.87	
K	0.007	1.134	1.033	0.981	1.150	0.44	0.91	
K	0.031	1.030	1.485	0.991	1.517	4.13	4.78	*
K	0.000	1.139	1.014	0.954	1.102	0.00	0.00	
K	0.150	1.146	1.004	1.000	1.152	7.24	17.38	
K	0.000	1.138	1.013	1.000	1.153	0.00	0.00	
K	0.004	1.163	1.008	1.000	1.173	0.21	0.49	
K	0.027	0.985	1.728	0.994	1.695	4.45	4.58	*
K	0.077	1.029	1.044	0.992	1.066	4.82	8.28	
K	0.006	1.023	2.263	0.996	2.309	1.45	1.43	*
K	0.009	1.051	1.064	0.981	1.098	0.65	1.09	
K	0.187	0.954	2.299	0.999	2.193	60.06	41.22 D	*
						TOTAL=	100.03	

- High Absorbance

DE RESULTS

	WT%
	42.57
	1.52
	9.03
	0.00
	22.35
	0.00
	0.63
	7.64
	11.59
	1.93
	1.31
L=	98.56

OF OXY = 23.00 #2b (NEAR XTL RIM)

Kb=4.50±1

SI	6.5656
TI	0.1761
AL	1.6413
CR	0.0000
FE	2.8838
NI	0.0000
MN	0.0824
MG	1.7550
CA	1.9147
	0.5781
	0.2585

31:38

N SCHEDULE ZZZ
-NOV-87
14:27: 5

F- WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
WDS:NA WDS:K

F CORRECTION 15.00 KV 40.00 Deg

. Of Iterations 0

--	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.149	0.998	1.343	0.998	1.339	16.67	19.98	
-K	0.004	1.134	1.033	0.981	1.151	0.26	0.54	
-K	0.033	1.030	1.482	0.991	1.514	4.35	5.02	*
-K	0.000	1.139	1.014	0.953	1.101	0.00	0.00	
-K	0.153	1.146	1.004	1.000	1.151	7.37	17.66	
-K	0.000	1.138	1.013	1.000	1.153	0.00	0.00	
-K	0.004	1.163	1.008	1.000	1.173	0.20	0.48	
-K	0.026	0.985	1.726	0.994	1.692	4.35	4.47	*
-K	0.079	1.029	1.044	0.992	1.067	4.98	8.53	
-K	0.005	1.023	2.266	0.996	2.311	1.26	1.24	*
-K	0.009	1.051	1.065	0.981	1.099	0.62	1.04	
-K	0.187	0.954	2.290	0.999	2.185	59.93	41.04 D	*
						TOTAL=	99.99	

- High Absorbance

IDE RESULTS

	WT%
O2	42.80
O2	0.90
2	9.49
	0.00
	22.70
O	0.00
O	0.62
O	7.46
O	11.94
2O	1.67
2O	1.25
TAL=	98.83

OF OXY = 23.00

#3b (NEAR XTL RIM)
Kt = 4.94 ± 1

SI	6.5820
TI	0.1040
AL	1.7195
CR	0.0000
FE	2.9205
NI	0.0000
MN	0.0811
MG	1.7085
CA	1.9664
'A	0.4980
	0.2454

14:30:11

N-SCHEDULE ZZZ
- -87
: 9:12

F.S WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
:CA WDS:NA WDS:K

F CORRECTION 15.00 KV 40.00 Deg

. Of Iterations 1

--	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.145	0.998	1.348	0.998	1.344	16.24	19.50	
-K	0.005	1.134	1.033	0.981	1.150	0.29	0.59	
-K	0.036	1.030	1.480	0.991	1.513	4.79	5.55	*
-K	0.000	1.138	1.013	0.952	1.100	0.01	0.03	
-K	0.153	1.146	1.004	1.000	1.151	7.38	17.72	
-K	0.000	1.138	1.013	1.000	1.153	0.00	0.00	
-K	0.003	1.163	1.008	1.000	1.172	0.17	0.41	
-K	0.024	0.985	1.731	0.994	1.698	4.04	4.16	*
-K	0.077	1.029	1.044	0.992	1.067	4.80	8.23	
-K	0.006	1.023	2.269	0.996	2.314	1.45	1.43	*
-K	0.010	1.051	1.064	0.981	1.098	0.66	1.11	
-K	0.190	0.954	2.272	0.999	2.167	60.15	41.27 D	*
						TOTAL=	100.00	

- High Absorbance

RESULTS

.	WT%
O2	41.79
O2	0.99
2O3	10.48
2O3	0.04
O	22.78
O	0.00
O	0.53
O	6.93
O	11.52
2O	1.93
2O	1.34
TAL=	98.33

OF OXY = 23.00

#4b (NEAR EDGE AGAINST PLAG)

Kb = 6.02 ± 1

SI	6.4706
TI	0.1147
AL	1.9122
CR	0.0052
FE	2.9504
I	0.0000
MN	0.0698
MG	1.5995
CA	1.9111
NA	0.5791
K	0.2645

11:12:19

N SCHEDULE ZZZ
-[illegible]-87
7:13

F.S WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
:CA WDS:NA WDS:K

F CORRECTION 15.00 KV 40.00 Deg

. Of Iterations 2

--	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.148	0.998	1.340	0.998	1.337	16.56	19.90	
-K	0.006	1.137	1.031	0.980	1.150	0.38	0.79	
-K	0.030	1.030	1.488	0.991	1.521	4.01	4.65	*
-K	0.000	1.141	1.013	0.951	1.101	0.02	0.04	
-K	0.151	1.147	1.004	1.000	1.152	7.24	17.40	
-K	0.000	1.141	1.013	1.000	1.156	0.00	0.00	
-K	0.003	1.166	1.007	1.000	1.175	0.19	0.45	
-K	0.026	0.986	1.731	0.994	1.698	4.44	4.57	*
-K	0.079	1.030	1.043	0.992	1.066	4.92	8.44	
-K	0.006	1.023	2.266	0.996	2.312	1.45	1.43	*
-K	0.008	1.054	1.056	0.979	1.090	0.58	0.97	
-K	0.192	0.956	2.246	0.999	2.147	60.21	41.35 D	*
						TOTAL=	99.98	

- High Absorbance

I RESULTS

	WT%
)2	42.65
)2	1.31
2O3	8.79
2O3	0.05
)	22.37
)	0.00
)	0.58
)	7.62
)	11.82
2O	1.93
2O	1.17
AL=	98.28

OF OXY = 23.00 #4c (NEAR XTL RIM)

Kb = 4.27 ± 1

SI	6.5961
TI	0.1524
AL	1.6017
CR	0.0066
FE	2.8946
[illegible]	0.0000
[illegible]N	0.0764
[illegible]G	1.7557
CA	1.9588
NA	0.5775
K	0.2314

4:10:32

N SCHEDULE ZZZ
-M?U-87
35:18

F.S WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
:CA WDS:NA WDS:K

F CORRECTION 15.00 KV 40.00 Deg

. Of Iterations 2

--	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.153	0.999	1.335	0.998	1.333	16.90	20.41	
-K	0.008	1.138	1.030	0.981	1.151	0.47	0.98	
-K	0.028	1.031	1.486	0.991	1.520	3.71	4.33	*
-K	0.000	1.142	1.013	0.953	1.104	0.01	0.03	
-K	0.144	1.148	1.004	1.000	1.153	6.91	16.69	
-K	0.000	1.142	1.012	1.000	1.157	0.00	0.00	
-K	0.004	1.167	1.007	1.000	1.176	0.22	0.53	
-K	0.028	0.986	1.721	0.994	1.690	4.68	4.84	*
-K	0.076	1.031	1.043	0.992	1.067	4.73	8.16	
-K	0.006	1.024	2.246	0.996	2.293	1.52	1.51	*
-K	0.007	1.054	1.057	0.979	1.092	0.52	0.87	
-K	0.194	0.957	2.239	0.999	2.142	60.33	41.64 D	*
						TOTAL=	99.98	

- High Absorbance

I RESULTS

	WT%
)2	43.74
)2	1.63
2O3	8.17
2O3	0.04
)	21.45
)	0.00
)	0.68
)	8.07
)	11.42
2O	2.04
2O	1.05
AL=	98.30

OF OXY = 23.00

#5a (CLOSE TO XTL RIM) (NEAR QTZ)

Kb = 3.58 ± 1

SI	6.7123
TI	0.1886
AL	1.4784
CR	0.0050
FE	2.7540
I	0.0000
N	0.0884
1G	1.8457
CA	1.8783
NA	0.6068
K	0.2060

1:38:35

N SCHEDULE ZZZ
-MAY-87
18:16

F.S WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
:CA WDS:NA WDS:K

F CORRECTION 15.00 KV 40.00 Deg

. Of Iterations 0

--	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.149	0.998	1.341	0.998	1.337	16.70	20.05	
-K	0.006	1.134	1.033	0.981	1.151	0.37	0.76	
-K	0.031	1.030	1.483	0.991	1.516	4.12	4.77	*
-K	0.000	1.139	1.014	0.954	1.102	0.01	0.02	
-K	0.150	1.146	1.004	1.000	1.152	7.25	17.40	
-K	0.000	1.138	1.013	1.000	1.153	0.00	0.00	
-K	0.004	1.163	1.008	1.000	1.173	0.21	0.49	
-K	0.026	0.985	1.728	0.994	1.695	4.37	4.50	*
-K	0.078	1.029	1.043	0.992	1.066	4.90	8.40	
-K	0.006	1.023	2.262	0.996	2.307	1.49	1.47	*
-K	0.009	1.051	1.064	0.981	1.098	0.60	1.01	
-K	0.187	0.954	2.295	0.999	2.190	59.98	41.15 D	*
						TOTAL=	100.01	

- High Absorbance

I RESULTS

	WT%
	42.96
O2	1.27
2O3	9.02
2O3	0.02
O	22.37
O	0.00
O	0.63
O	7.50
O	11.77
2O	1.98
2O	1.21
AL=	98.72

OF OXY = 23.00 #66 (NEAR GRAIN RIM)

Kb = 4.46 ± 1

SI	6.6087
TI	0.1469
AL	1.6348
CR	0.0030
FE	2.8780
	0.0000
N	0.0816
1G	1.7184
CA	1.9391
NA	0.5906
K	0.2380

3:21:21

JN SCHEDULE ZZZ
3- V-87
.26:40

EF.S WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
S:CA WDS:NA WDS:K

AF CORRECTION 15.00 KV 40.00 Deg

). Of Iterations 0

---	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.151	0.997	1.342	0.998	1.338	16.99	20.30	
-K	0.005	1.133	1.033	0.981	1.149	0.30	0.61	
.-K	0.031	1.029	1.485	0.991	1.516	4.18	4.81	*
:-K	0.000	1.138	1.014	0.952	1.099	0.01	0.02	
:-K	0.156	1.145	1.004	1.000	1.151	7.52	17.96	
-K	0.000	1.137	1.013	1.000	1.153	0.00	0.00	
I-K	0.004	1.162	1.008	1.000	1.172	0.21	0.49	
i-K	0.026	0.985	1.732	0.994	1.697	4.31	4.42	*
i-K	0.078	1.029	1.044	0.992	1.066	4.88	8.32	
i-K	0.005	1.022	2.272	0.996	2.316	1.39	1.37	*
-K	0.009	1.051	1.065	0.981	1.099	0.62	1.04	
-K	0.186	0.954	2.287	0.999	2.180	59.59	40.67 D	*
						TOTAL=	100.00	

- High Absorbance

RESULTS

	WT%
U2	43.49
02	1.02
203	9.09
203	0.03
O	23.09
O	0.00
O	0.63
O	7.36
O	11.65
20	1.84
20	1.25
TAL=	99.45

OF OXY = 23.00 #6c (FAr CCGC [illegible] XTL)

Kb-4.47±1

SI	6.6458
TI	0.1175
AL	1.6372
CR	0.0030
FE	2.9520
'I	0.0000
N	0.0814
1G	1.6766
CA	1.9079
NA	0.5461
K	0.2435

13:29:46

=.S WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
:CA WDS:NA WDS:K

= CORRECTION 15.00 KV 40.00 Deg

f Iterations 0

--	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.154	0.999	1.336	0.998	1.334	17.11	20.66	
-K	0.003	1.136	1.033	0.981	1.152	0.21	0.44	
-K	0.030	1.031	1.479	0.991	1.513	3.92	4.56	*
-K	0.000	1.140	1.013	0.953	1.102	0.01	0.01	
-K	0.148	1.148	1.004	1.000	1.153	7.10	17.15	
-K	0.000	1.140	1.012	1.000	1.155	0.00	0.00	
-K	0.003	1.165	1.007	1.000	1.174	0.20	0.46	
-K	0.028	0.987	1.716	0.994	1.684	4.58	4.74	*
-K	0.078	1.031	1.043	0.992	1.068	4.86	8.39	
-K	0.005	1.024	2.251	0.996	2.299	1.18	1.17	*
-K	0.007	1.053	1.065	0.981	1.101	0.47	0.79	
-K	0.192	0.955	2.265	0.999	2.163	60.37	41.66 D	*
						TOTAL=	100.03	

- High Absorbance

DE RESULTS

	WT%
2	44.28
2	0.73
O3	8.62
O3	0.02
	22.05
	0.00
	0.60
	7.90
	11.74
O	1.58
O	0.95
AL=	98.46

OF OXY = 23.00 #7b (NEAR RIM, NEXT TO BIOTITE)

kb=4.01±1

SI	6.7733
TI	0.0836
AL	1.5546
CR	0.0023
FE	2.8210
NI	0.0000
MN	0.0773
MG	1.8003
CA	1.9247
NA	0.4689
K	0.1850

3:42:48

IN SCHEDULE ZZZ
3-NOV-87
13:45:41

:F	WDS:SI	WDS:TI	WDS:AL	WDS:CR	WDS:FE	WDS:NI	WDS:MN	WDS:MG	W
∕	WDS:NA	WDS:K							

ıF CORRECTION 15.00 KV 40.00 Deg

›. Of Iterations 0

---	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.151	0.999	1.339	0.998	1.337	16.86	20.31	
-K	0.007	1.135	1.033	0.982	1.152	0.41	0.86	
.-K	0.030	1.031	1.484	0.991	1.518	4.00	4.65	*
:-K	0.000	1.140	1.014	0.955	1.104	0.00	0.00	
:-K	0.146	1.147	1.004	1.000	1.153	7.01	16.90	
-K	0.000	1.139	1.012	1.000	1.154	0.00	0.00	
:-K	0.003	1.164	1.008	1.000	1.174	0.19	0.44	
›-K	0.029	0.986	1.716	0.994	1.684	4.84	5.00	*
›-K	0.078	1.030	1.043	0.992	1.067	4.85	8.35	
›-K	0.006	1.024	2.243	0.996	2.290	1.40	1.39	*
-K	0.008	1.052	1.065	0.981	1.100	0.54	0.91	
-K	0.187	0.955	2.298	0.999	2.194	59.89	41.24	D *
					TOTAL=		100.04	

· - High Absorbance

IDE RESULTS

	WT%
O2	43.52
O?	1.43
∕	8.78
3	0.00
:O	21.73
O	0.00
›O	0.57
›O	8.33
›O	11.70
›2O	1.87
2O	1.10
TAL=	99.01

OF OXY = 23.00 #7c (NEAR XTL RIM)

Kb = 4.14 ± 1

SI	6.6370
TI	0.1636
AL	1.5774
CR	0.0000
FE	2.7724
NI	0.0000
MN	0.0730
MG	1.8932
CA	1.9109
IA	0.5521
K	0.2134

13:48:46

N SCHEDULE ZZZ
:-NOV-87
14:41:40

F WDS:SI WDS:TI WDS:AL WDS:CR WDS:FE WDS:NI WDS:MN WDS:MG W
WDS:NA WDS:K

F CORRECTION 15.00 KV 40.00 Deg

. Of Iterations 0

---	K	[Z]	[A]	[F]	[ZAF]	ATOM.%	WT.%	
-K	0.142	1.000	1.337	0.998	1.337	15.58	19.10	
-K	0.004	1.137	1.031	0.981	1.152	0.24	0.50	
-K	0.030	1.032	1.480	0.991	1.516	3.97	4.70	*
-K	0.000	1.142	1.012	0.954	1.104	0.00	0.00	
-K	0.144	1.150	1.003	1.000	1.154	6.82	16.72	
-K	0.000	1.142	1.012	1.000	1.156	0.00	0.00	
-K	0.004	1.167	1.007	1.000	1.175	0.21	0.51	
-K	0.026	0.988	1.723	0.994	1.694	4.31	4.53	*
-K	0.074	1.032	1.042	0.992	1.068	4.56	7.99	
-K	0.005	1.025	2.262	0.996	2.313	1.30	1.31	*
-K	0.009	1.054	1.062	0.981	1.099	0.64	1.09	
-K	0.205	0.956	2.226	0.999	2.128	62.36	43.67	D *
						TOTAL=	100.12	

- High Absorbance

IDE RESULTS

	WT%
O2	40.92
O?	0.83
;	8.87
3	0.01
u	21.50
O	0.00
O	0.66
O	7.55
O	11.19
2O	1.76
2O	1.31
TAL=	94.60

OF OXY = 23.00

SI	6.5763
TI	0.1002
AL	1.6808
CR	0.0007
FE	2.8906
NI	0.0000
MN	0.0902
MG	1.8083
CA	1.9264
A	0.5483
	0.2693

= 8b (NEAR XTL RIM)
Fb- 4.72 ± 1

:45

SAMPLE LOCATION (OR STD)...SOUTH CAROLINA, U.S.A.
DATE OF ANALYSIS...........21/12/87
LAB IDENTIFICATION CODE....LH2
IRRADIATION CODE...........MM007-16
DISKS (ALIGNMENT/CALCS).... /
DATAFILE...................A:LH2V.A1A
MINERAL ANALYZED...........APATITE
ANALYSIS BY / NOTES PAGE #.VM /

INDIVIDUAL GRAIN DATA

CRYSTAL	NS	NI	QUADS	RATIO	RHO S	RHO I	U PPM	AGE (MA)
1	11	15	25	0.733	[illegible]	3.34E+05	6	72.4 ± [illegible]
2	28	27	25	1.0[illegible]	[illegible]	[illegible]	12	[illegible] ± 31.[illegible]
3	[illegible]	15	25	0.667	[illegible]	[illegible]	[illegible]	[illegible] ± 16.[illegible]
4	11	13	25	0.846	2.[illegible]E+05	[illegible]E+05	6	35.[illegible] ± 33.[illegible]
5	11	12	25	0.917	2.32E+05	3.07E+05	5	102.8 ± 42.9
6	[illegible]	17	25	1.41[illegible]	[illegible]	[illegible]E+05	7	16.4 ± 20.[illegible]
7	8	11	25	0.727	2.05E+05	2.[illegible]E+05	5	81.7 ± 38.0
8	17	18	25	0.944	4.35E+05	4.61E+05	8	105.9 ± 35.8
9	11	12	25	0.917	2.32E+05	3.07E+05	[illegible]	102.8 ± 42.3
10	[illegible]	28	25	1.036	[illegible]	[illegible]	12	116.0 ± 30.7
11	[illegible]	11	25	0.545	[illegible]	[illegible]	[illegible]	61.4 ± 31.1
12	[illegible]	14	25	0.429	1.54E+05	[illegible]	6	48.3 ± 23.[illegible]
13	22	19	25	1.158	5.33E+05	4.16E+05	[illegible]	129.6 ± 40.6
14	5	6	25	0.833	1.28E+05	1.54E+05	[illegible]	83.5 ± 56.6
15	10	15	25	0.667	2.56E+05	3.84E+05	[illegible]	74.9 ± 30.5
16	14	18	25	0.778	3.59E+05	4.61E+05	8	87.3 ± 31.1
17	8	12	25	0.667	2.05E+05	3.07E+05	[illegible]	71.3 ± 34.2
18	[illegible]	20	25	0.85[illegible]	4.35E+05	5.12E+05	[illegible]	95.4 ± 31.5
19	[illegible]	16	25	[illegible].750	[illegible]E+05	4.10E+05	[illegible]	84.[illegible] ± 32.3
	246	299			2.01E+05	4.03E+05	7	

SUMMARY OF STATISTICS

- Variance of Square root of NS = 0.8172
- Variance of Square root of NI = 0.4396
- Correlation coefficient (R for NS vs. NI) = 0.9069

- Chi^2 = 8.740728 with 18 degrees of freedom. TEST PASS

AGE CALCULATION

- Glass dosimeter = SRM614
- ND counted = 1200 — 92.4 ± 8.9 MA
- RHOD D for glass = 1.980E+04 ± 0.572E+03
- Area of 1 QUAD = 1.5625E-06
- Pooled NS/NI = 0.823 ± 0.071 — MEAN AGE =
- Mean NS/NI = 0.795 ± 0.046

89.3 ± 6.5 MA

SAMPLE LOCATION (OR STD)...LIBERTY HILL, SOUTH CAROLINA U.S.A.
DATE OF ANALYSIS...........21/12/87
LAB IDENTIFICATION CODE....LH-3
IRRADIATION CODE...........MM007-13
DISKS (ALIGNMENT/CALCS).... /
DATAFILE...................A:LH-3J.A1A
MINERAL ANALYZED...........APATITE
ANALYSIS BY / NOTES PAGE =.JM /

INDIVIDUAL GRAIN DATA

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SUMMARY OF STATISTICS

- Variance of Square root of NS = 2.1767
- Variance of Square root of NI = 1.4849
- Correlation coefficient (R for NS vs. NI) = 0.9036

- Chi² = 19.36049 with 27 degrees of freedom. TEST PASS

AGE CALCULATION

- Zeta factor used = 11420.0 ± 380.0
- Glass dosimeter = SRM614
- ND counted = 1200
- RHOD D for glass = 1.975E+04 ± 0.570E+03
- Area of 1 QUAD = 1.21E-06
- Pooled NS/NI = 1.105 ± 0.068
- Mean NS/NI = 1.085 ± 0.062

POOLED AGE =

123 ± 9.4 MA

MEAN AGE =

121 ± 8.7 MA

SAMPLE LOCATION (OR STD)...LIBERTY HILL, SOUTH CAROLINA
DATE OF ANALYSIS...........01/04/88
LAB IDENTIFICATION CODE....LH5
IRRADIATION CODE...........MM008-3
DISKS (ALIGNMENT/CALCS).... /
DATAFILE...................A:LH5J.A1A
MINERAL ANALYZED...........APATITE
ANALYSIS BY / NOTES PAGE =.JM /

INDIVIDUAL GRAIN DATA

CRYSTAL	NS	NI	QUADS	RATIO	RHO S	RHO I	U ppm	AGE (MA)
[illegible]	[illegible]	12	25	1.080	4.30E+05	[illegible]	7	113.3 ± 47.2
[illegible]	[illegible]	16	25	0.688	[illegible]	[illegible]	[illegible]	75.7 ± [illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	13	25	0.462	1.33E+05	[illegible]	[illegible]	50.9 ± 25.1
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	39.1 ± [illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	64.[illegible] ± [illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	89.4 ± [illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	37.7 ± [illegible]
[illegible]	[illegible]	[illegible]	25	0.640	[illegible]	[illegible]	14	70.5 ± [illegible]
[illegible]	[illegible]	27	25	[illegible]	[illegible]	[illegible]	15	73.4 ± [illegible]
[illegible]	[illegible]	32	25	[illegible]	[illegible]	[illegible]	15	89.4 ± [illegible]
[illegible]	[illegible]	[illegible]	25	0.313	[illegible]	[illegible]	13	100.4 ± 30.3
[illegible]	[illegible]	34	25	0.724	[illegible]	[illegible]	19	87.4 ± [illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	100.8 ± 42.1
[illegible]	[illegible]	16	25	[illegible]	4.36E+05	4.36E+05	[illegible]	10[illegible].3 ± 40.1
[illegible]	[illegible]	15	25	0.600	[illegible]	[illegible]	[illegible]	65.1 ± [illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] ± 36.5
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	11	93.5 ± [illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	64.4 ± [illegible]
[illegible]	[illegible]	26	25	[illegible]	4.20E+05	[illegible]	[illegible]	[illegible] ± 20.[illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	4.63E+05	[illegible]	6	[illegible] ± [illegible]
[illegible]	42	42	25	1.000	[illegible]	[illegible]	24	109.8 ± [illegible]
[illegible]	[illegible]	34	25	[illegible]	3.31E+05	[illegible]	19	32.5 ± 11.7
[illegible]	[illegible]	19	25	[illegible]	3.64E+05	[illegible]	11	63.8 ± 24.2
[illegible]	[illegible]	[illegible]	25	[illegible]	4.63E+05	[illegible]	[illegible]	102.6 ± [illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	[illegible]	66.1 ± [illegible]
[illegible]	[illegible]	[illegible]	25	0.800	[illegible]	[illegible]	[illegible]	89.0 ± 23.5
[illegible]	[illegible]	[illegible]	25	1.286	[illegible]	[illegible]	12	140.[illegible] ± [illegible]
[illegible]	[illegible]	[illegible]	25	[illegible]	[illegible]	[illegible]	26	[illegible] ± 15.7
	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	

SUMMARY OF STATISTICS

- Variance of Square root of NS = 0.9167
- Variance of Square root of NI = 1.3831
- Correlation coefficient (R for NS vs. NI) = 0.8011

- Chi^2 = 26.10124 with 29 degrees of freedom. TEST PASS

- Zeta factor used	=	11420.0 ± 380.0
- Glass dosimeter	=	SRM614
- ND counted	=	1225
- RHOD D for glass	=	1.940E+04 ± 0.554E+03
- Area of 1 QUAD	=	1.21E-06
- Pooled NS/NI	=	0.746 ± 0.044
- Mean NS/NI	=	0.797 ± 0.048

POOLED AGE =

82.1 ± 6.0 MA

MEAN AGE =

87.7 ± 6.5 MA

SAMPLE LOCATION (OR STD)...LIBERTY HILL. SOUTH CAROLINA
DATE OF ANALYSIS...........05/02/88
LAB IDENTIFICATION CODE....~~=~~AGE COMPILATION
IRRADIATION CODE...........MM008-3
DISKS (ALIGNMENT/CALCS).... /
DATAFILE...................A:LH5J.A2A
MINERAL ANALYZED...........APATITE
ANALYSIS BY / NOTES PAGE =.JM / COMPOSITE

INDIVIDUAL GRAIN DATA

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]		

SUMMARY OF STATISTICS

- Variance of Square root of NS = 11.9543
- Variance of Square root of NI = 12.7810
- Correlation coefficient (R for NS vs. NI) = 0.?070

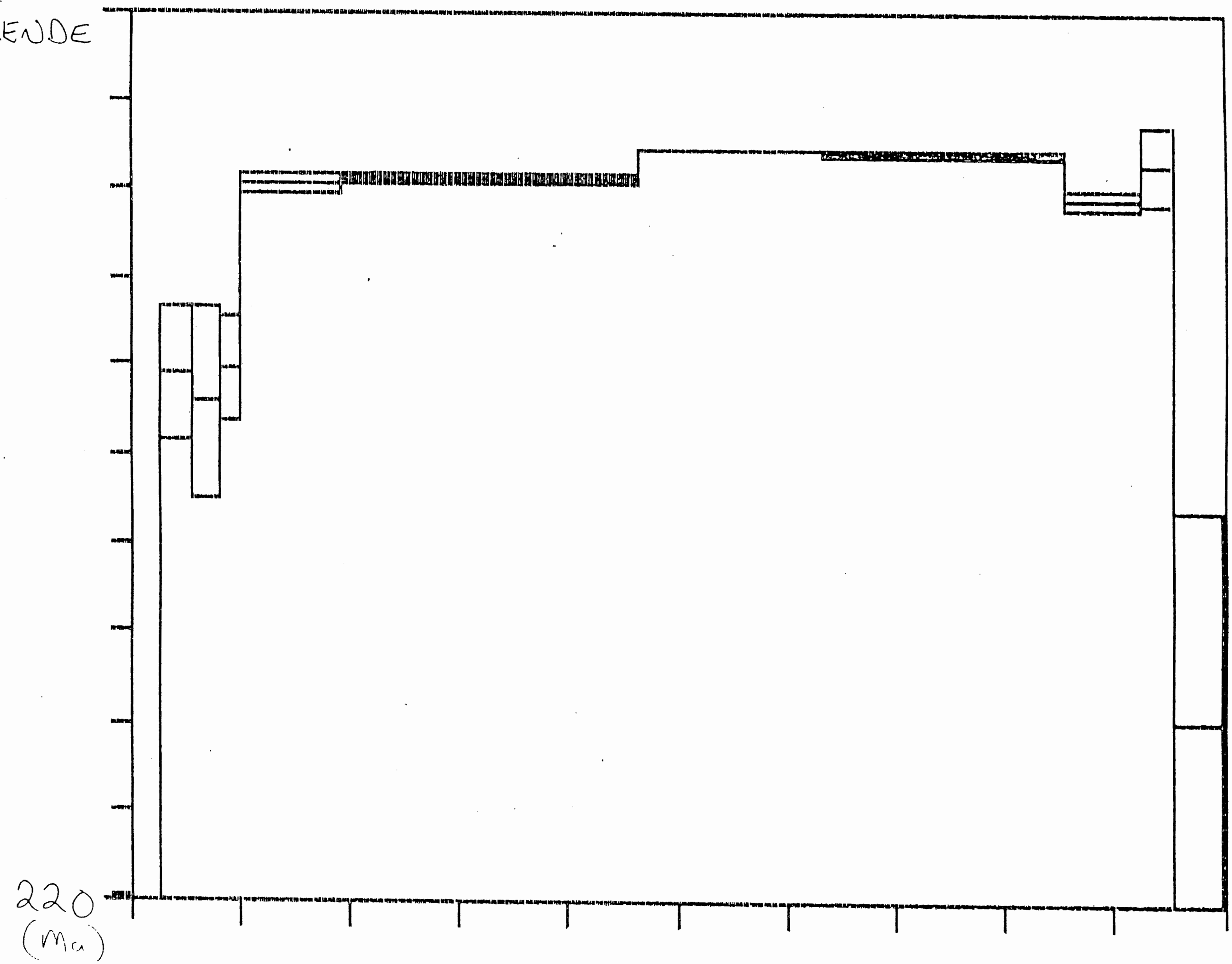
- Chi² = 22.01237 with 3 degrees of freedom. TEST FAIL

AGE CALCULATION

APPENDIX 2

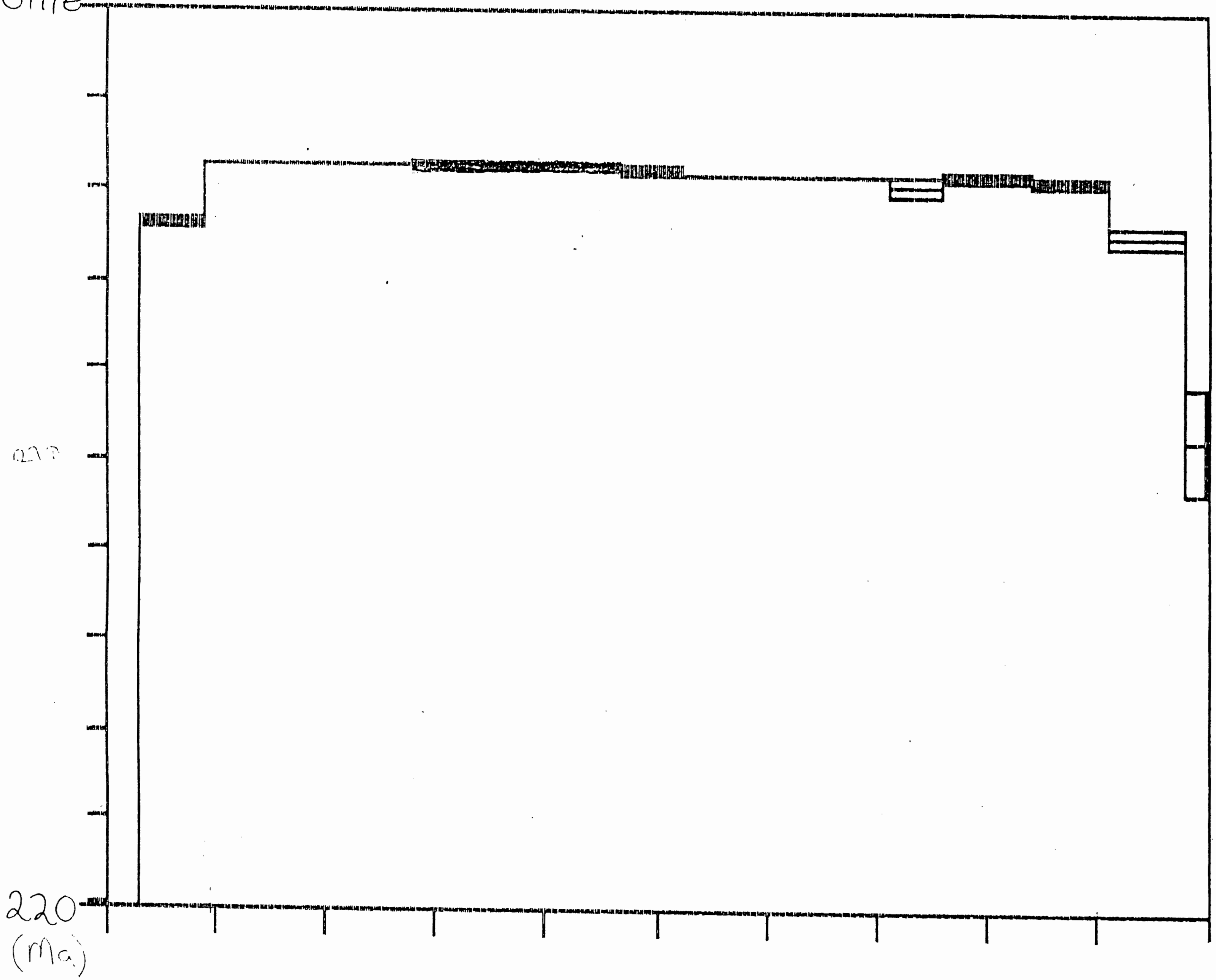
Age spectra of analyzed minerals

LH-2
HORNBLENDE

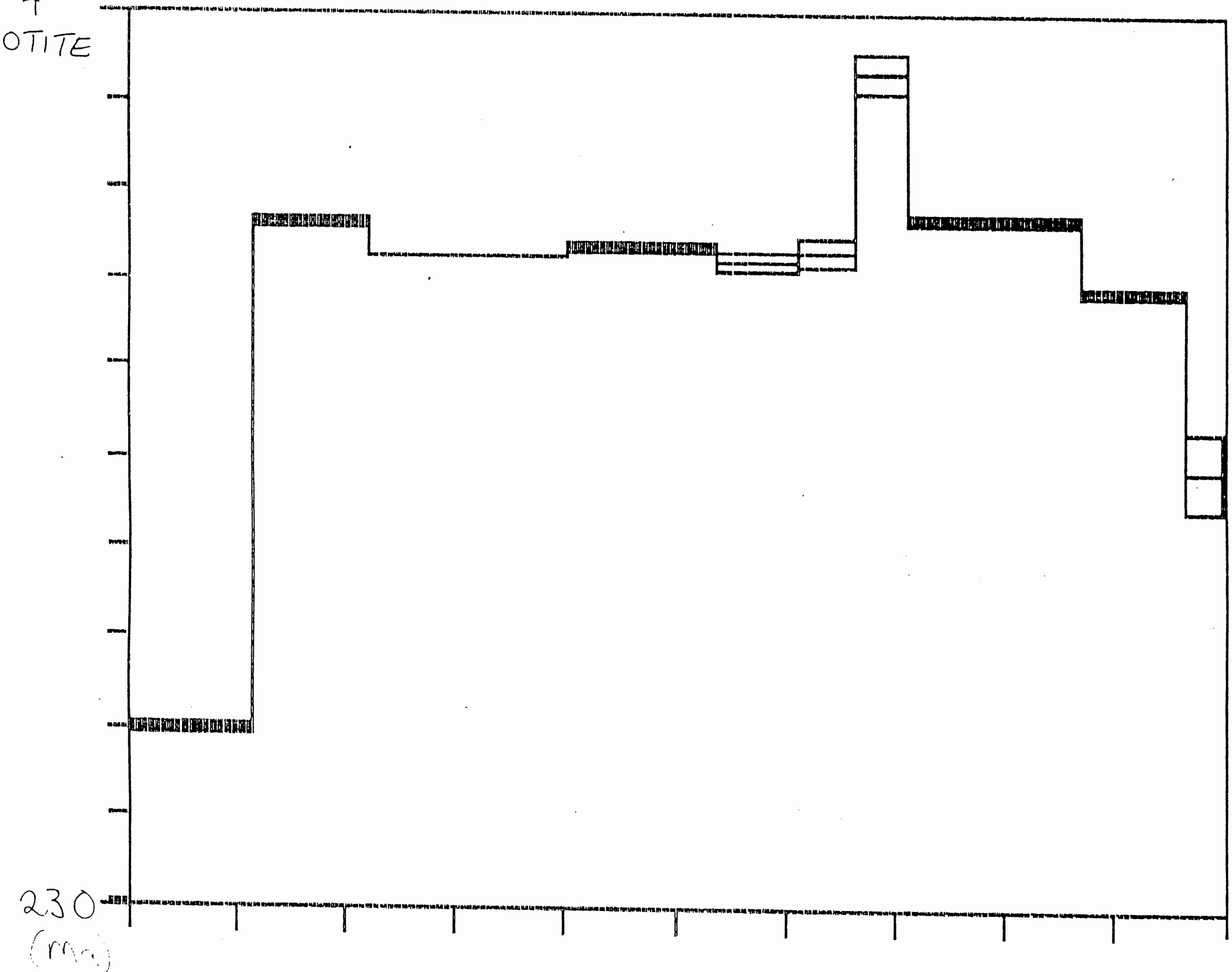


10

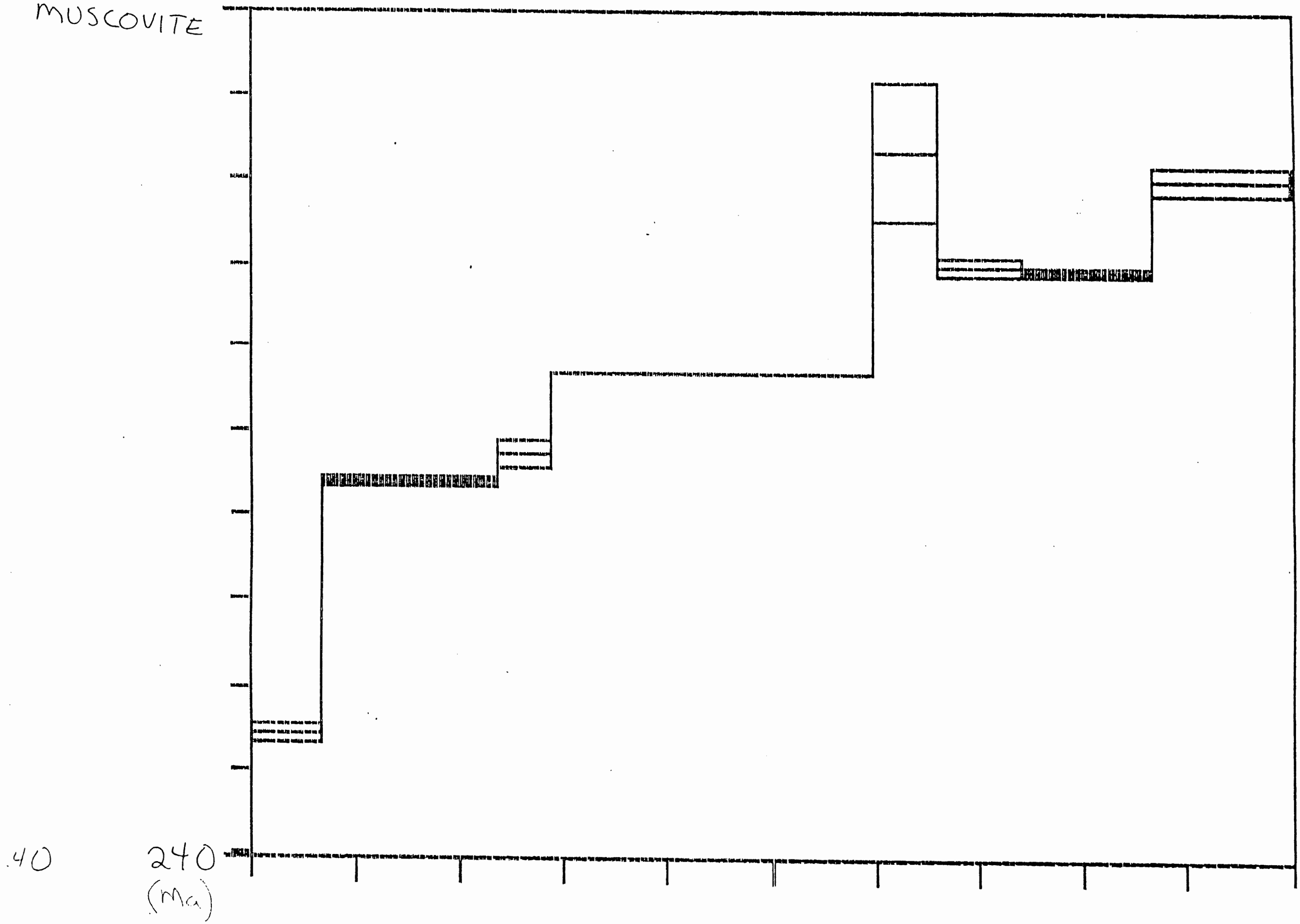
LH-2
BIOTITE



LH-4
BIOTITE

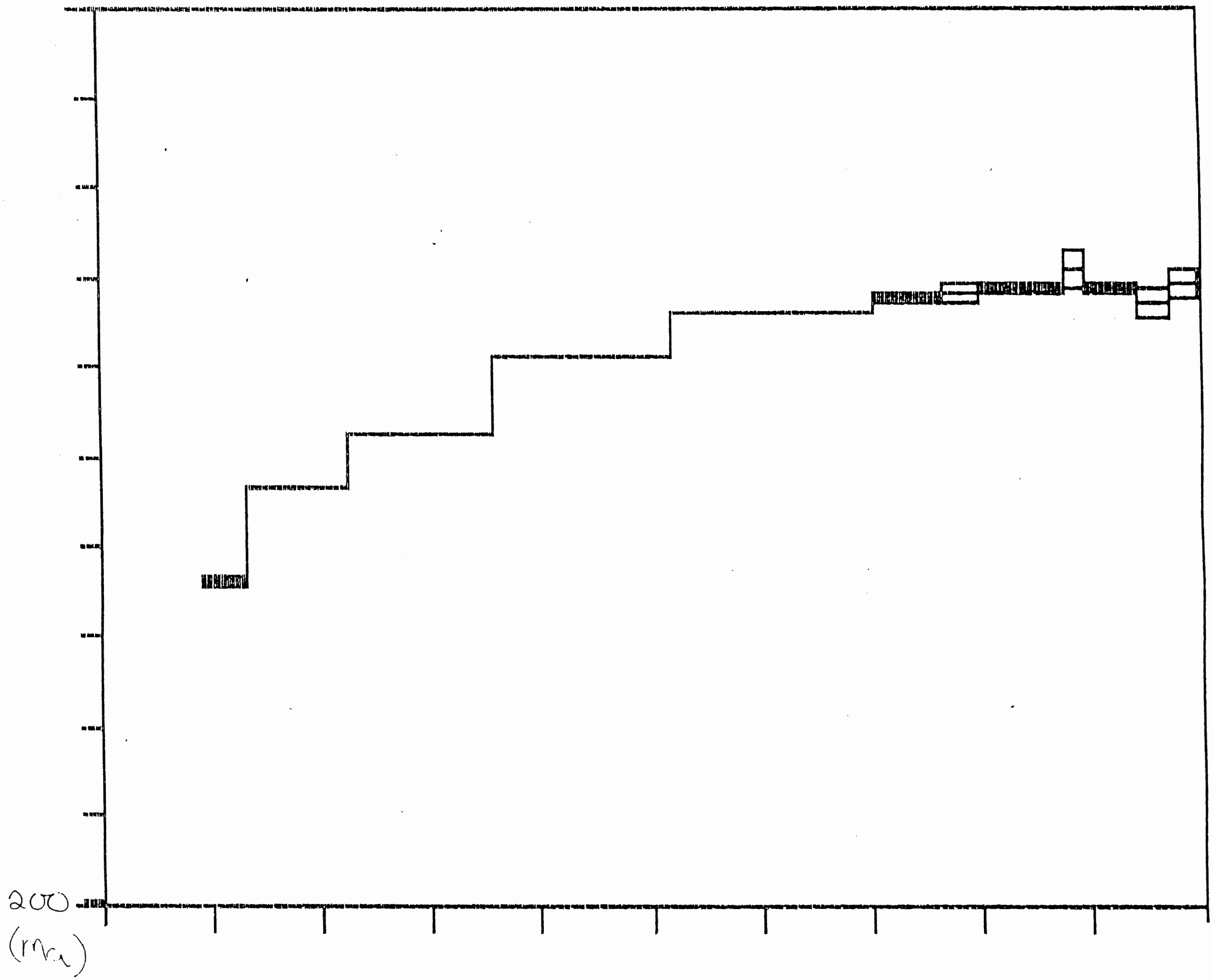


LH-4
MUSCOVITE



L

K-SPAR



APPENDIX 3

Raw data for fission track age calculation

SAMPLE LOCATION (OR STD)...LIBERTY HILL, SOUTH CAROLINA
DATE OF ANALYSIS...........06/01/88
LAB IDENTIFICATION CODE....LH1
IRRADIATION CODE...........MM008-2
DISKS (ALIGNMENT/CALCS).... /
DATAFILE...................A:LH1V.A1A
MINERAL ANALYZED...........APATITE
ANALYSIS BY / NOTES PAGE #.VM /

INDIVIDUAL GRAIN DATA

CRYSTAL	NS	NI	QUADS	RATIO	RHO S	RHO I	U ppm	AGE (MA)
1	[illegible]	[illegible]	25	[illegible]	[illegible]	1.83E+06	[illegible]	93.0 ± [illegible]
2	[illegible]	[illegible]	25	[illegible]	[illegible]	4.51E+05	3	[illegible]
3	21	22	25	[illegible]	[illegible]	[illegible]	11	[illegible]
4	22	[illegible]	25	[illegible]	[illegible]	4.35E+05	[illegible]	120.5 ± 53.7
5	26	29	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].6 ± [illegible]
6	14	17	25	0.824	[illegible]	5.22E+05	10	[illegible]
7	13	11	25	1.182	[illegible]	3.34E+05	6	123.6 ± [illegible]
8	[illegible]	35	25	[illegible]	[illegible]	1.16E+06	20	97.4 ± [illegible]
9	14	19	25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	15	15	25	1.000	[illegible]	[illegible]	9	103.3 ± [illegible]
11	21	[illegible]	25	[illegible]	[illegible]	[illegible]	20	[illegible]
12	24	[illegible]	25	1.091	[illegible]	[illegible]	12	113.7 ± [illegible]
13	[illegible]	19	25	0.632	[illegible]	[illegible]	11	[illegible]
14	[illegible]	20	25	[illegible]	[illegible]	[illegible]	11	58.3 ± [illegible]
15	22	20	25	1.100	[illegible]	[illegible]	11	120.7 ± [illegible]
16	31	28	25	1.107	1.02E+06	[illegible]	16	121.5 ± 31.7
17	5	[illegible]	25	0.556	[illegible]	[illegible]	5	61.2 ± [illegible]
18	14	17	25	0.824	4.59E+05	5.62E+05	10	90.5 ± [illegible]
19	13	19	25	0.684	4.30E+05	6.28E+05	11	75.4 ± [illegible]
20	13	14	25	0.929	[illegible]	4.63E+05	8	102.0 ± [illegible]
21	6	6	25	1.000	[illegible]	1.99E+05	3	[illegible]
22	19	24	25	0.792	6.28E+05	7.93E+05	14	87.1 ± [illegible]
23	21	25	25	0.840	6.94E+05	8.26E+05	14	92.1 ± 27.3
24	22	[illegible]	25	0.840	[illegible]	8.60E+05	15	93.1 ± [illegible]
	457	[illegible]			6.29E+05	7.13E+05	12	

SUMMARY OF STATISTICS

- Variance of Square root of NS = 0.9111
- Variance of Square root of NI = 1.1165
- Correlation coefficient (R for NS vs. NI) = 0.8903
- Chi^2 = 10.8229 with 23 degrees of freedom. TEST PASS

AGE CALCULATION

- Zeta factor used = 11420.0± 380.0
- Glass dosimeter = SRM614

POOLED AGE =

- RHOD D for glass = 1.940E+04 ± 0.554E+03
- Area of 1 QUAD = 1.21E-06
- Pooled NS/NI = 0.882 ± 0.057
- Mean NS/NI = 0.909 ± 0.044

MEAN AGE =

99.9 ± 6.6 MA