Application of Acoustic Emission in Fundamental Studies of Salt Behavior

H. Reginald Hardy, Jr.
David A. Roberts[1]
and
Archie M. Richardson

Geomechanics Section
Department of Mineral Engineering
The Pennsylvania State University
University Park, Pennsylvania

ABSTRACT

When solid materials are subjected to stress they emit micro-level acoustic signals. The measurement and analysis of these so called acoustic emission (AE) signals provide useful information in regard to the micro- and macro-level mechanical stability of such materials. In recent years AE techniques have been extensively applied to the study of geologic materials and more recently the authors have undertaken AE studies associated with the mechanical behavior of salt (NaCl). The current paper will briefly review the concept of AE and the associated experimental techniques, and will describe the application of AE techniques to the study of three important areas of salt behavior, namely: yield strength, creep behavior, and structural breakdown during dissolution. Studies at low stress levels have shown that during mechanical deformation, both single crystal and polycrystalline salt generates AE signals which appear to be directly related to the initiation of yield. Furthermore during studies at higher stress levels a good correlation between AE and observed creep deformation has been observed. A preliminary series of AE studies have also been carried out on polycrystalline salt undergoing dissolution in water. Using time-lapse photography it has been shown that low-level AE signals are generated during the normal dissolution process, with larger, more pronounced, signals occurring when macroscopic structural breakdown occurs. Results to date suggest that the AE technique may be a useful tool for investigating the behavior of salt and studies are continuing.

INTRODUCTION

When solid materials are subjected to stress they emit micro-level acoustic signals. The measurement and analysis of these so called acoustic emission (AE) signals provide useful information in regard to the micro- and macro-level mechanical stability of such materials. Figure 1 illustrates a typical group of AE events monitored during a tensile test on limestone (Chugh et al. 1972). These were obtained by attaching a suitable transducer to the test specimen, amplifying and filtering the resulting signals, and recording them on magnetic tape. Such activity has been observed under both laboratory and field conditions and it provides a convenient, indirect method for monitoring the mechanical behavior of geologic materials and structures.

A considerable number of papers have been published recently dealing with acoustic emission activity in geologic materials and structures, although unfortunately these have been widely dispersed throughout the literature. For those unfamiliar with the field the recent publication by Hardy and Leighton (1977) provides a detailed review of the subject including a brief historical outline, discussions on monitoring and analysis procedures, and descriptions of a number of current laboratory and field studies.

In the present paper the writers will first briefly describe the phenomenon of acoustic emission and discuss techniques utilized in laboratory studies. This will be followed by a

[1]Present address: Shannon and Wilson Company, Seattle, Washington.

Figure 1. Typical Group of AE Events (After Chugh et al. 1972).

brief review of three current AE studies associated with the behavior of salt presently underway in the Geomechanics Section at The Pennsylvania State University. These studies form part of an ongoing project concerned with the development of criteria for design of salt cavities for the storage of natural gas.

ACOUSTIC EMISSION FUNDAMENTALS

In geologic materials the origin of acoustic emission (AE) activity is not well understood, but it appears to be related to processes of deformation and failure which are accompanied by a sudden release of strain energy. In geologic materials, which are basically polycrystalline in nature, AE activity may originate at the micro-level as a result of dislocations, at the macro-level by twinning, grain boundary movement, or initiation and propagation of fractures through and between mineral grains, and at the mega-level by fracturing and failure of large areas of material or relative motion between structural units. It is assumed that the sudden release of stored elastic strain energy accompanying these processes generates an elastic stress wave which travels from the point of origin within the material to a boundary where it is observed as an AE event.

The fundamental frequency character of an observed AE signal depends on the source, the distance between the source and the detector (transducer), and the character of the intermediate material. Frequencies below 1 Hz have been observed at large scale field sites, whereas in laboratory studies AE signals have often been observed to contain frequencies greater than 500 KHz.

Figure 2 illustrates a simplified AE monitoring system. Here a transducer attached to the test specimen detects the AE event and generates an equivalent electrical output. Since the transducer output is normally in the microvolt level it must first be highly amplified (up to 100 dB in some cases) and then filtered to remove undesired ambient noise. The resulting signal is usually recorded on magnetic tape for convenient later analysis. In most laboratory studies the signals of interest range from 10 KHz–1 MHz and commercially available accelerometers and piezoelectric crystals are used as transducers.

In recent years a number of manufacturers have developed complete AE monitoring systems. An example of one of these is the Dunegan series 3000 AE system which is discussed in more detail later in this paper. This system provides real-time data on a number of AE parameters including accumulated activity and event rate. Such systems are convenient in many applications but lack the flexibility provided by magnetic tape storage of experimental data.

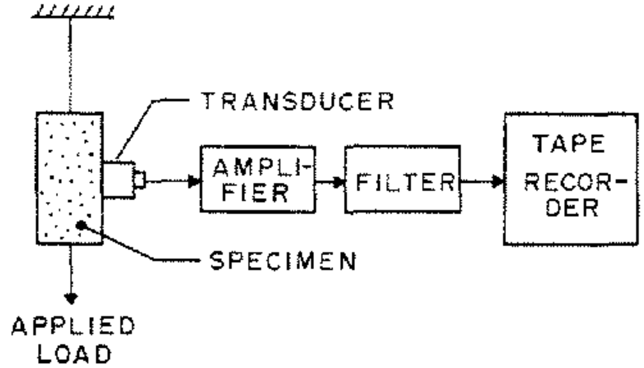


Figure 2. Simplified AE Monitoring System.

An important factor which must be considered in all AE experiments is the level and frequency character of the ambient background. In most studies relatively high frequency transducers (100 – 300 KHz) are employed to insure that only acoustic signals generated within the test specimen are monitored. Where it is necessary to monitor lower frequency activity (<100 KHz) suitable filters must be employed to develop a frequency window in the ambient background, or experiments must be carried out under low background conditions.

In the past the majority of AE laboratory studies associated with geologic materials have involved the measurement of either accumulated activity or event rate. To date only limited studies have involved the evaluation of event energy, frequency and amplitude distribution, and event duration, although it is becoming increasingly apparent that these more sophisticated parameters may be necessary in some situations.

OUTLINE OF CURRENT STUDIES

Introduction. The purpose of this paper is to briefly introduce the concept of acoustic emission (AE) as a tool in evaluating the behavior of salt. As has been noted earlier AE has been employed with increased frequency to a variety of problems associated with geologic materials and recently it has been utilized by the writers in studies carried out to investigate the fundamental behavior of salt. A number of these studies will be briefly outlined in this section.

Yield strength studies. A knowledge of the yield strength, or the stress at which plastic behavior is initiated, is of crucial importance in the rational design of an underground opening in a material exhibiting plastic behavior. Salt is a material which deforms by massive plastic deformation when subjected to a differential stress in excess of its yield strength. Considerable controversy exists amongst researchers in regard to a reasonable value for the yield strength of salt, and values from of the order of 50 psi to several thousand psi have appeared in the technical literature.

Basically salt may be classified as an inelastic material, of which the simplest type is the perfectly elastic-plastic material. Up to a critical stress level (yield point), such a material is linearly elastic, and stress is related to strain by a proportionality factor. Above the yield point, no further increase in stress is necessary to cause an increase in strain. The more typical elastic-plastic material, however, exhibits strain hardening after yield, which means that an increase in stress is necessary for deformation to continue in the material above the yield point, as shown in Figure 3. Single crystals of halite exhibit essentially elastic-plastic behavior with strain hardening when uniaxially loaded at room temperature.

Plastic deformation in a crystalline material is related to the movement of "dislocations", which are molecular-scale imperfections in the crystal lattice. Dislocations are mobile to a certain degree and can multiply under proper circumstances. At the yield point, both the number and mobility of dislocations increases, decreasing the material's ability to resist load.

Yielding in both single and polycrystalline materials is similar, however, in the latter there are additional major complications due to grain boundary interactions. Grain boundaries interfere with the movement and multiplication of dislocations, causing most polycrystalline materials to have a higher yield strength than single crystals.

Figure 4 shows a uniaxial stress-strain curve for a specimen of pressed polycrystalline salt. The curve is highly non-linear and lacks a pronounced yield point. Yield in such a material is commonly defined as the stress level at which the permanent strain exceeds some value, usually 0.2%. Physicists tend to choose a smaller value of permanent strain, such as 0.001% to indicate yield has occurred. Any such definition of yield is extremely arbitrary, and yield in such materials can be said to depend on the particular yield convention applied and on the sensitivity of the available deformation measuring instruments.

Recently a detailed study has been underway to explore some of the phenomena associated with yielding in polycrystalline salt and salt single crystals, with the ultimate goal of developing a means for objectively assessing the yield strength of such materials (Richardson, 1978). Acoustic emission (AE) is one technique that has been investigated for this purpose. In this section only the results obtained for single crystals will be discussed.

AE rate was selected as the first parameter to be investigated in the present study because of its relative ease of measurement and its established applicability in a wide range of previous studies. The heart of the AE system used in these studies was a commercially available Dunegan

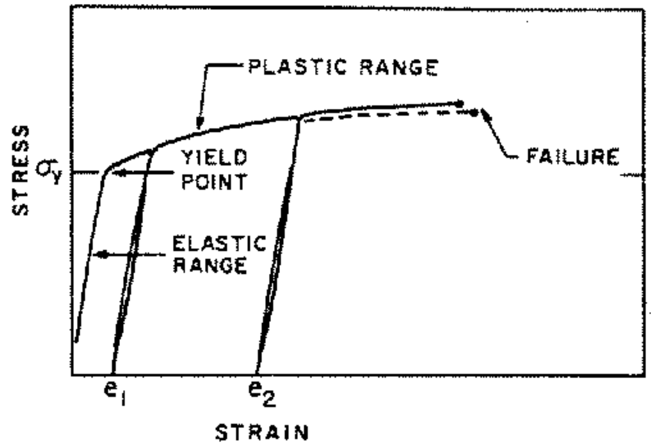


Figure 3. Generalized Stress-Strain Relationship in a Strain Hardening Elastic-Plastic Material. (After Ramsey, 1967).

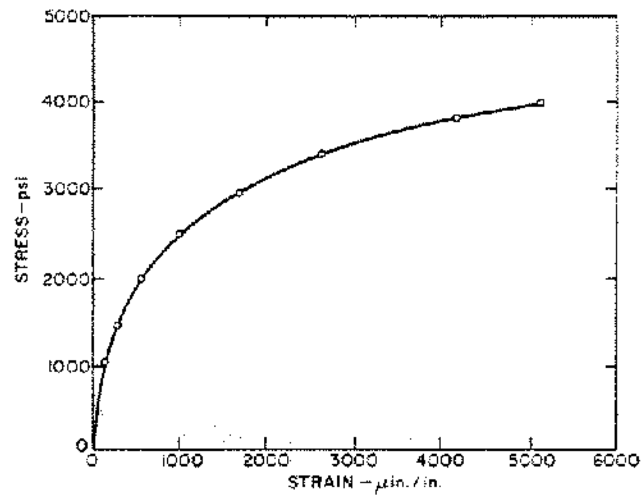


Figure 4. Uniaxial Stress-Strain Curve for Pressed Polycrystalline Salt Tested at a Constant Loading Rate of 100 psi/sec. (After Hardy et al., 1975).

series 3000 AE system (Fig. 7). This system utilizes digital electronics to provide an output proportional to the rate, or frequency of occurrence of a sequence of AE signals. In the Dunegan system, acoustic emission pulses are detected by a transducer, amplified, and filtered. A threshold detector then converts the signals to digital form by producing a standard pulse for each AE signal in excess of one volt. These pulses are then counted by a digital counter, controlled by a reset clock to provide rate, and the corresponding rate value is indicated on a three-digit display. An analog output, proportional to the AE rate, is also available through a digital-to-analog converter, and in some tests this is used to drive a strip chart recorder to provide a permanent record of the experiment.

During the experiments salt specimens were deformed under uniaxial load in an MTS closed-loop loading system, and applied load, axial strain (or deformation), and AE activity were monitored. It was found that salt single crystals loaded under both constant loading rate and constant strain rate conditions generated considerable AE activity, as shown in Figures 5 and 6. Under the constant loading rate conditions (Fig. 5) the AE rate peak is seen to occur in the post-yield region rather than at yield, which is believed to reflect the rapid plastic deformation caused as the loading system forced a constant loading rate in a region of easy glide. In comparison under constant rate of strain conditions (Fig. 6) a definite peak in the AE rate occurred near yield. A likely source for this peak is the multiplication and rearrangement of dislocations known to occur at yield, although at present this is speculation.

The second AE parameter investigated in the yield strength studies was AE amplitude. There are several possible approaches to the design of a system for AE amplitude studies. A system utilizing a magnetic tape recorder was selected because it provided a permanent record of the raw AE data for future reference and possible later more refined analysis. The concept of the system utilized is relatively simple. Amplified electrical signals representing AE activity are first recorded on magnetic tape. The recorded signals are then replayed repeatedly through the previously described Dunegan system, using a different gain setting for each replay cycle. The net result of this process is an amplitude sorting of the AE events.

Figure 7A shows a block diagram of the recording stage of the AE amplitude sorting system. The AE events detected by the transducer are first amplified, and passed through a double bandpass filter. The resulting signals are then recorded on one channel of a Honeywell 5600C instrumentation tape recorder, and simultaneously displayed on a Tektronix type 503 dual-beam oscilloscope for in-test monitoring. Figure 7B shows a block diagram of the associated playback system. Previously recorded signals were replayed through a Rockland Model 1100 analog filter (bandpass 100–300 KHz) to remove low frequency tape recorder noise, then fed into the Dunegan system described earlier. The signals were attenuated 5dB within the tape recorder by the record-playback process. Additional amplification was provided by the variable amplifier stage in the Dunegan system. This feature permitted the selection of a different amplification value for each of the playback cycles to accomplish the desired amplitude sorting.

Typical results for this type of AE analysis for a salt single crystal specimen are shown in Figure 8 along with the associated stress-strain curve. Data for total equivalent system gains of 89, 92, 95 and 98 dB are presented. At the lowest gain levels only the largest events are counted. As the gain level is increased more of the smaller events reach a detectable level and are included in the result. At the 89 dB level the AE rate versus strain distribution is relatively flat

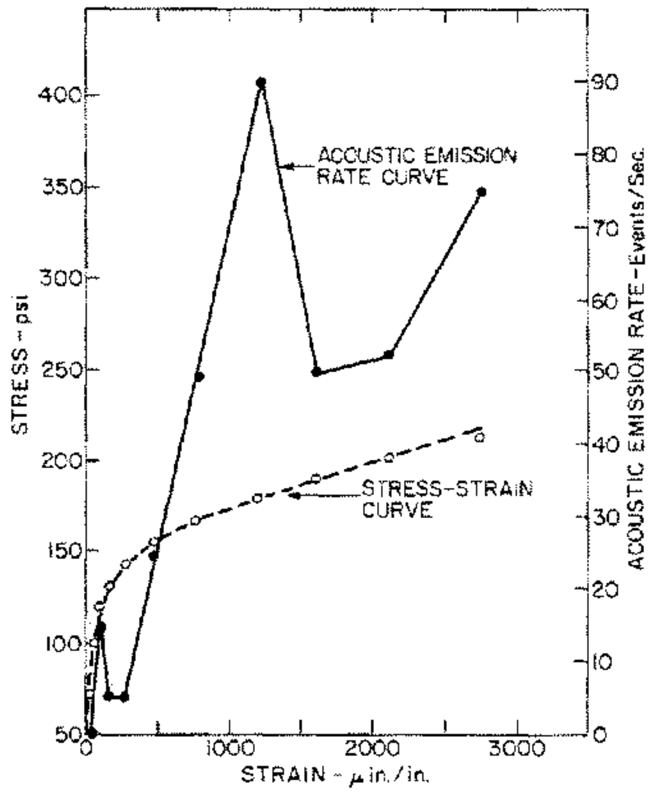


Figure 5. Stress-Strain and Acoustic Emission Rate Behavior of a Salt Single Crystal Observed at a Constant Loading Rate of 11 psi/sec. (Specimen #2).

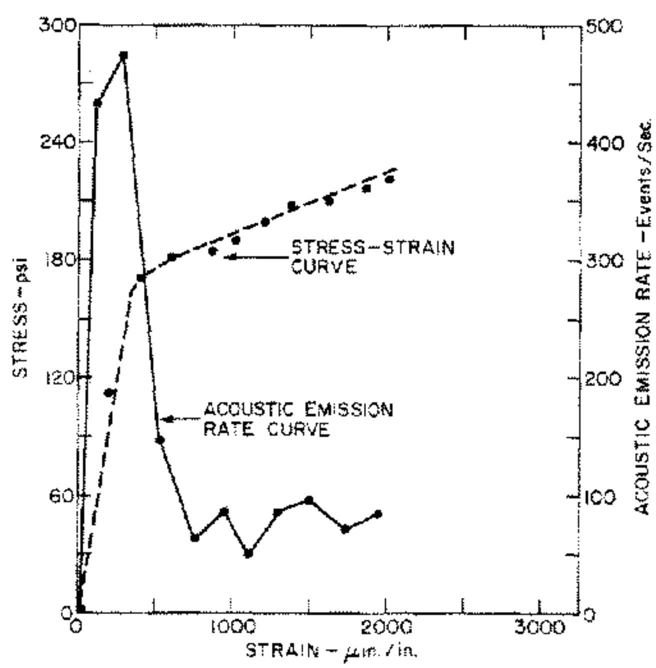


Figure 6. Stress-Strain and Acoustic Emission Rate Behavior of a Salt Single Crystal Observed at a Constant Strain Rate of 13 μin./in./sec. (Specimen #10).

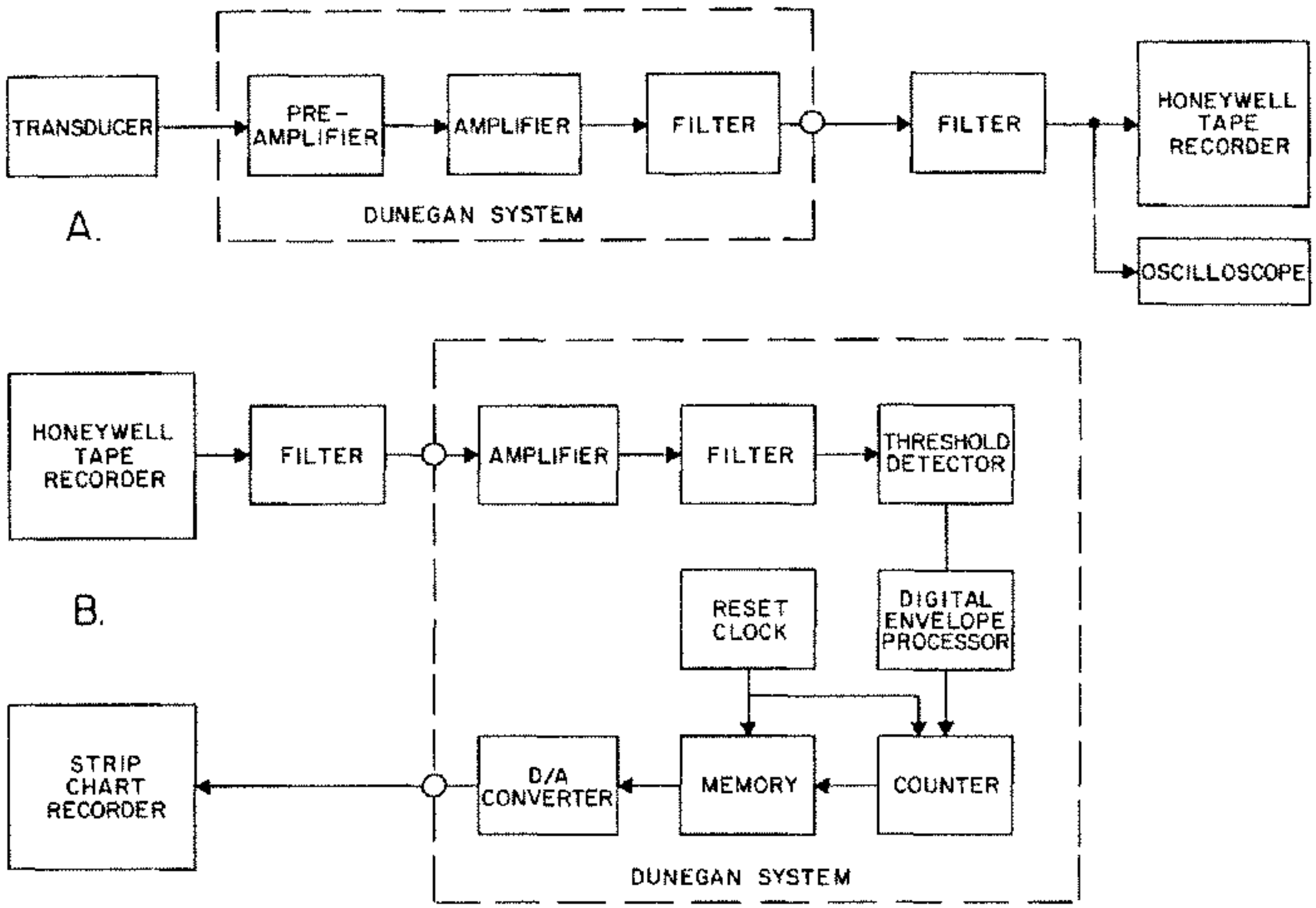


Figure 7. Acoustic Emission Monitoring System Used for Amplitude Studies. (Equipment shown in areas defined by dashed lines is part of the Dunegan monitoring system).

with only a suggestion of a peak in the region of the yield point. No AE activity is evident in the elastic region. At the 92 dB level two pronounced peaks have developed in the distribution at points which appear to be in the immediate pre-yield and post-yield regions of the stress-strain curve. For gains of 95 and 98 dB these two peaks become much better defined, and as well limited AE activity is detected at the upper end of the elastic region.

The foregoing analysis suggests that a large number of small AE events are generated in the immediate pre-yield and post-yield regions, a limited number of large events are associated with the yield point itself, and a range of event magnitudes occur in the post-yield region (which in this test appears to exhibit pronounced strain hardening). Based on the preliminary studies carried out to date it would appear that amplitude sorting of AE events may assist in better definition of the yield point in salt single crystals.

In review then studies have shown that salt (both polycrystalline and single crystal) emit AE activity under load. It is apparent from preliminary studies that the AE rate increases rapidly in the yield region and this phenomenon may well be useful as an indirect and objective means of delineating the yield point in salt single crystal specimens. Whether or not this technique will be applicable to polycrystalline natural salt has yet to be validated and further studies are presently underway in this area.

Creep studies. Time-dependent inelastic strain, generally referred to as creep, occurs in geologic materials such as salt, when they are stressed above some critical stress level. For example, in Figure 9 a series of stress increments (A, B, C, D) have been applied to a specimen and the resulting strains, occurring during a period of time following each increment, are illustrated. For stress increments A and B the strain is seen to remain constant with time following the stress increment. For increment C the observed strain is seen to increase slightly with time following the stress increment, however, after a short time it reaches an equilibrium value. In contrast stress increment D causes extensive time-dependent strain which, even after a considerable period of time, still appears to be increasing linearly

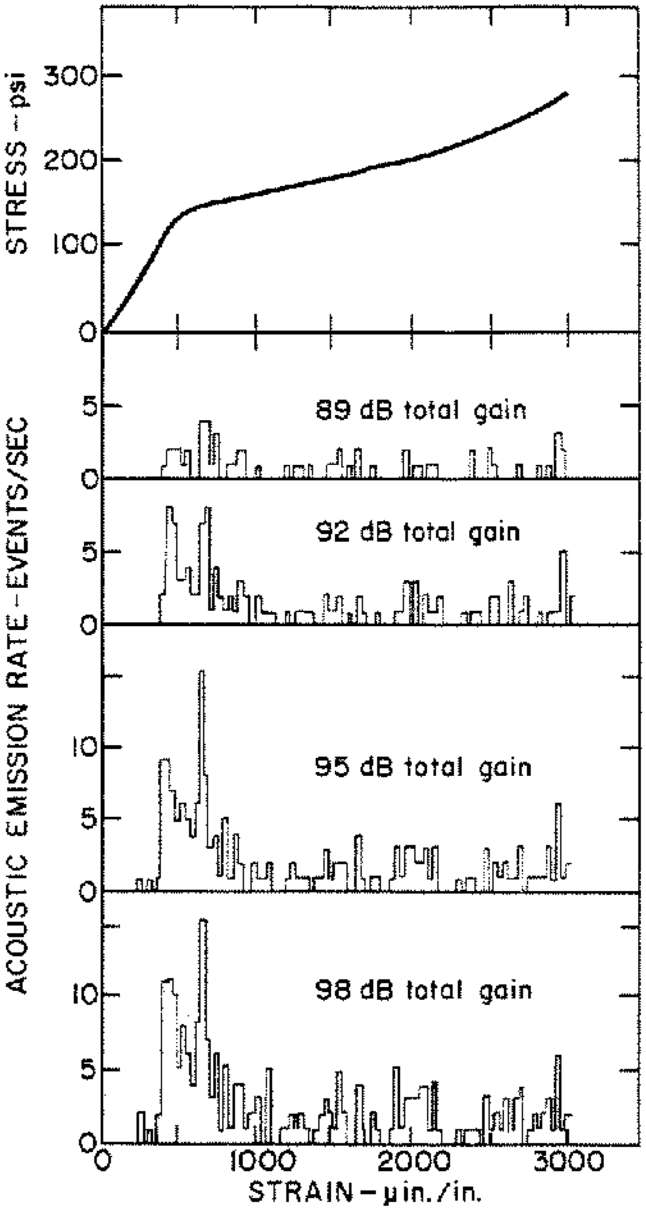


Figure 8. Stress-Strain, and the Acoustic Emission Rate Versus Strain Information for a Salt Single Crystal Loaded at a Constant Strain Rate of 13 μin./in. per sec. (Specimen #20; a series of AE rate curves are shown obtained at different playback gain settings).

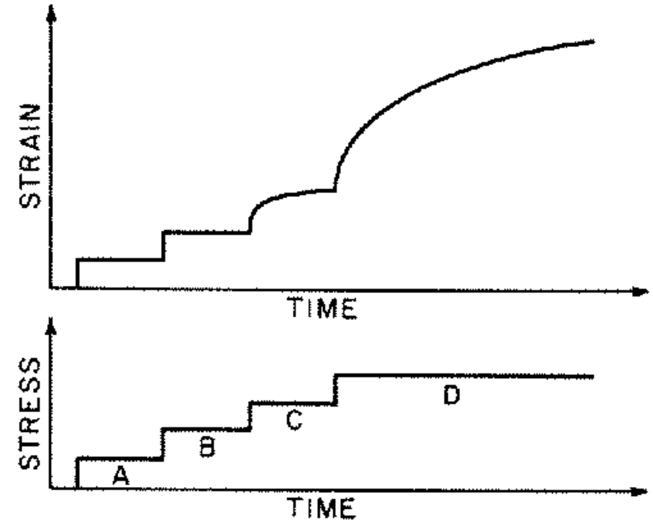


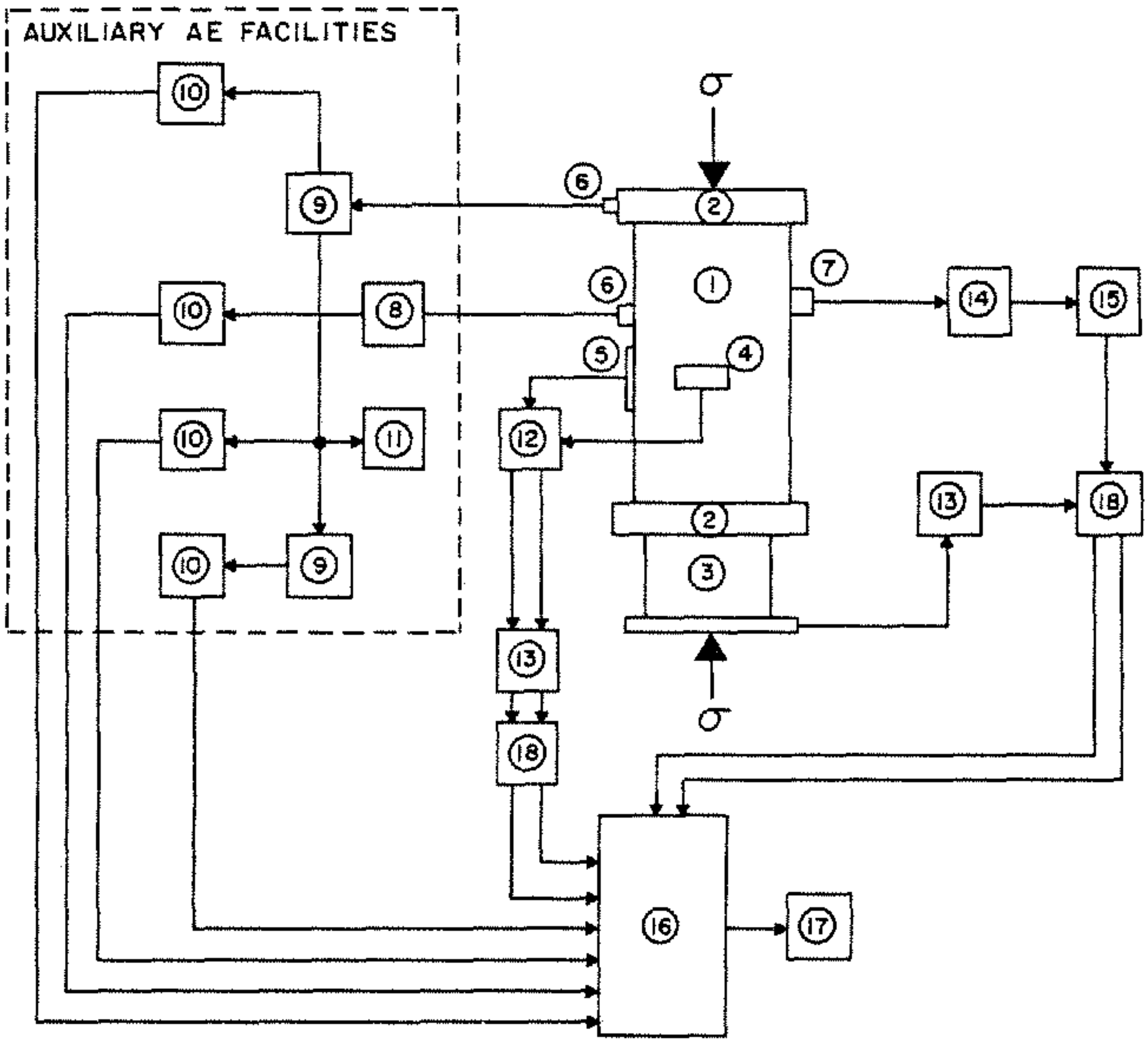
Figure 9. Strain Versus Time Data for a Geologic Material as a Function of Applied Stress for a Series of Stress Increments.

with time. Such behavior indicates that a critical stress level exists somewhere between increment B and C, at which time-dependent inelastic behavior is initiated. A knowledge of this critical stress level and the higher level for which continuing time-dependent strain occurs are important factors for salt cavity design. Such factors are obtained by carrying out suitable creep experiments.

Since 1975 experiments have been underway at Penn State to investigate a number of mechanical properties of salt including creep (Hardy and Roberts, 1977). During a number of the short term tests (1–14 days) acoustic emission (AE) techniques have been employed in an attempt to better understand the various mechanisms active during creep deformation. A block diagram of the experimental arrangement used for the short term uniaxial creep studies is given in Figure 10. In these tests specimens were instrumented for measurement of both axial and transverse strain, and for AE. A constant axial stress was applied during the creep tests using a lever-type loading system and monitored using an associated load cell. As shown in Figure 10, all parameters were recorded on strip chart recorders and, as well during some of the experiments, on a multichannel magnetic tape recorder.

Initial creep experiments on salt were extensively instrumented to study AE activity. Basically two separate systems were employed; one utilizing a Dunegan model D140B AE-transducer attached directly to the specimen and an associated Dunegan series 3000 monitoring system, and the other utilizing barium titinate crystals and/or commercial accelerometers as transducers and a monitoring system assembled from various commercial units. In the latter system one of the transducers was attached directly to the specimen, while the other was mounted on the upper specimen end-cap. Data from this system was used to evaluate the frequency character of the observed AE activity and to monitor activity generated within the loading system itself.

A report outlining results of an extensive series of short-term creep tests carried out on pressed salt is presently in preparation. Typical experimental results (specimen S-18) for a test at a stress level of approximately 1150 psi are presented in Figures 11 and 12. Here both the observed strain and the AE rate (monitored by the Dunegan system) are plotted against time. Figure 11 shows the results during the early stages of the experiment (0–600 seconds). During the application of the required stress level there was an



(1) Salt Specimen
(2) End Cap
(3) Load Cell
(4) Transverse Strain Gage
(5) Longitudinal Strain Gage
(6) Barium Titanate Crystal
(7) Dunegan Transducer
(8) P.A.R. Preamplifier
(9) Ithaca Postamplifier
(10) Rockland Filter
(11) Dual Channel Oscilloscope
(12) Wheatstone Bridge
(13) Conditioning Module
(14) Dunegan Preamplifier
(15) Dunegan Totalizer
(16) Honeywell Tape Recorder
(17) Recording Oscilloscope
(18) Dual Channel Strip Chart Recorder

Figure 10. Block Diagram of Experimental Arrangement for Short Term Uniaxial Creep Studies on Salt.

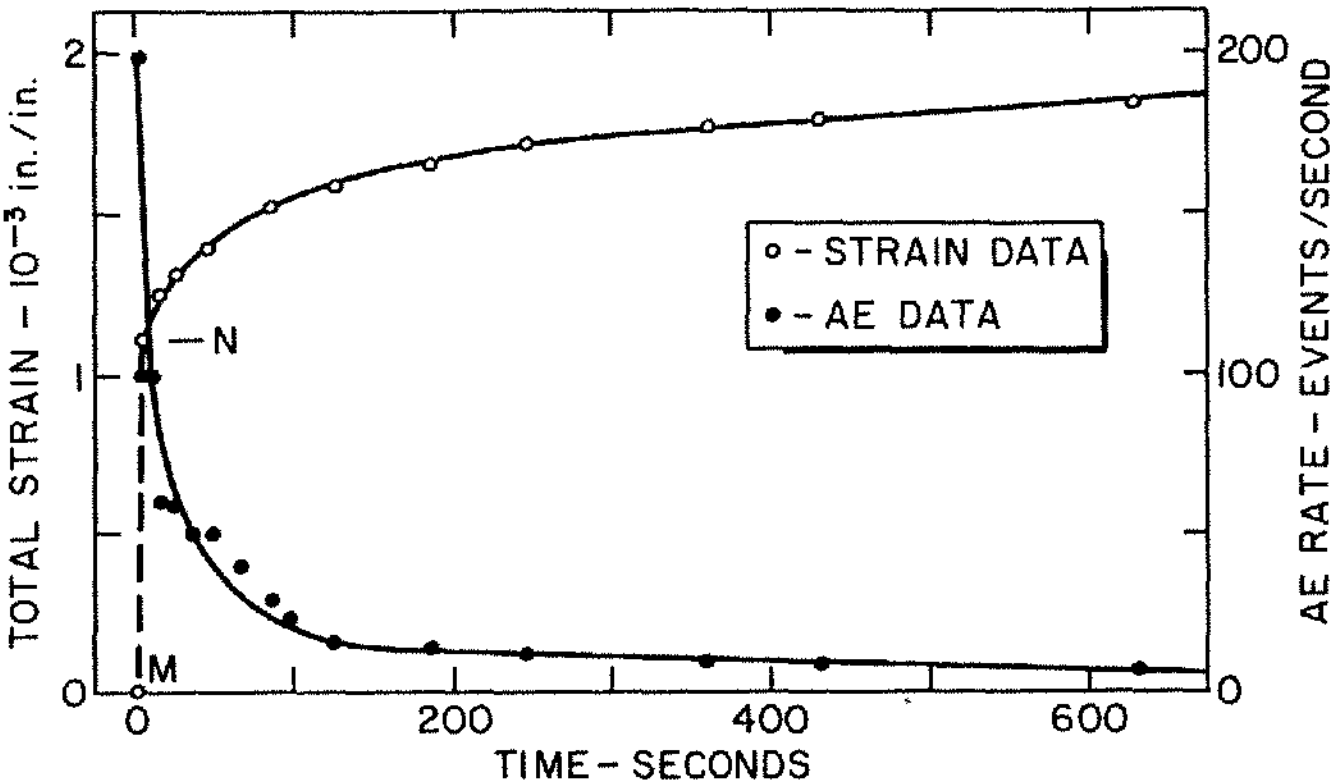


Figure 11. Strain and AE Rate versus Time for Creep Test on Pressed Salt During the Time Period 0–600 seconds. [Specimen S-18, uniaxial stress—1150 psi].

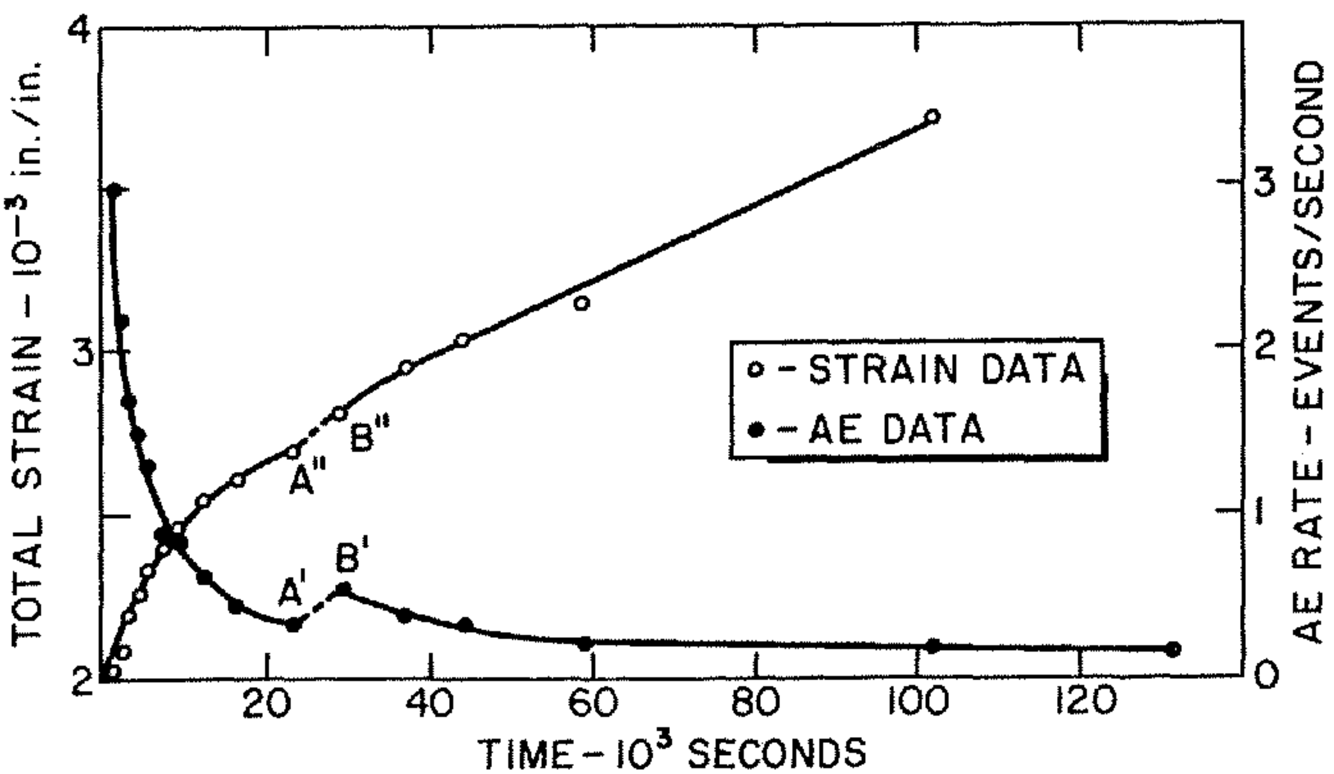


Figure 12. Strain and AE Rate versus Time for Creep Test on Pressed Salt During the Time Period 0-130 × 10^3 Seconds. [Specimen S-18, uniaxial stress—1150 psi].

instantaneous elastic strain (M–N). The stress was then held constant and the specimen continued to deform with time, at a decelerating rate, appearing to approach a constant rate after approximately 200 seconds. The AE rate versus time data is seen to be an approximately mirror-image of the strain versus time data. Initially, just following specimen loading, the AE rate was high; but is seen to drop rapidly with time, reaching a constant rate of decrease at approximately 200 seconds.

Looking at the experimental data over a longer period of time ($0-130 \times 10^3$ seconds, approximately 36 hours), it is noted that the apparently constant slopes of the strain and AE rate versus time curves noted in Figure 11 are virtual (as a result of the graphing scale utilized) and in fact there is a continual decrease in the slope of both curves. It is interesting to note that even after some 36 hours the salt specimen continued to exhibit AE activity at a rate of approximately 12 events per minute. Another feature of interest is the subtle increase in strain rate noted at the point A". Normally there would be a tendency to overlook this feature and a continuous curve would be fitted to the data. The fact that a pronounced change also occurs at the same time in the AE rate curve (point A') indicates that a definite change in mechanical behavior of the salt has in fact occurred.

Similar creep experiments have been carried out by one of the writers (Hardy et al., 1970) on geologic materials other than salt, including limestone, granite and sandstone. In these experiments a linear relationship was observed between creep strain and accumulated AE activity (summation of AE events). Due to the long-term nature of the current studies accumulated activity data was not available and as an alternative the variation of the AE rate with strain rate was investigated. Figure 13 shows the data from Figures 11 and 12 replotted in this form. For strain rates up to approximately 0.1×10^{-6}/second the relationship is seen from the figure-insert to be highly linear. On the main figure the projection of the data is represented by the tangent line R–S. For higher strain rates the relationship is also linear but with a somewhat different slope as represented by the tangent line R–U. Above a strain rate of approximately 3×10^{-6}/second the curve becomes strongly non-linear, and after the point V the AE rate was found to increase extremely rapidly with increasing strain rate. The data in Figure 13 suggests that there are probably a number of deformation mechanisms active during creep of salt. This possibility is presently under further investigation.

In review then creep studies on salt indicate that AE activity is generated during creep deformation. Furthermore there is a definite correlation between observed creep strain and AE rate data. At high strain rates, corresponding to the early stages of the creep experiment, AE rates are high and the relation between AE rate and strain rate is highly non-linear. During later stages of the experiment a number of regions were observed where AE rate and strain rate were found to be linearly related. The fact that a number of such regions were observed suggests that more than one deformation mechanism is active during creep of salt. Studies are continuing in this area.

Dissolution studies. Many underground salt cavities are formed by a solution mining process. Here fresh water is pumped into the salt formation, the salt is dissolved forming a cavity, and the brine is recovered and processed to remove the salt. The progress of solution mining, however, may at times be rather erratic with the cavity developing in an often unpredictable manner. It is possible that such behavior has been the cause of a number of surface subsidence problems noted recently in solution mining areas. It is felt that if solution mining progress could be remotely monitored, these subsidence problems could be largely avoided.

In early 1976 one of the writers (Hardy) proposed that if AE activity were generated during the dissolution process this phenomenon might be utilized for remote monitoring of salt cavity development. It is a well known fact that when salt comes into contact with a polar solvent such as water, the positive sodium ions at the solution interface strongly attract the negative oxygen ions of the polar water molecules, and a similar mutual attraction exists between the chloride and hydrogen ions. The attraction is sufficiently powerful to overcome the strong interatomic forces within the salt, causing it to dissolve in the water. Such a continuous, microscopic process would not ordinarily be expected to result in emission of detectable acoustic energy. However, natural rock salt typically occurs as a coarse-grained interlocking crystalline aggregate. As water attacks this material, small chunks break away and settle to the bottom of the solution cavity, internal stresses previously locked into the material are gradually relieved, and many other minor readjustments occur within the salt mass. It was anticipated that some acoustic activity would be generated during such a process, and should be detectable with a sufficiently sensitive system.

Late in 1976 a series of simple laboratory experiments were undertaken (Richardson, 1976) to investigate the possibility that salt undergoing dissolution would generate detectable acoustic emission. In these experiments a specimen of fine grained pressed salt with an attached Dunegan Model D140B AE Transducer was partially immersed in water and allowed to dissolve. AE activity was monitored using a Dunegan series 3000 AE system and an associated strip chart recorder (similar to the system described earlier in this paper). An overall system gain of 50 dB and a filter band width of 100–300 KHz was utilized. During normal dissolution a small but measurable emission of acoustic energy was noted, however a peak in the AE rate occurred each time a piece of the specimen broke away and settled to the bottom of the container. A natural rock salt specimen of much coarser fabric was similarly instrumented and dissolved. The natural salt was found to be considerably

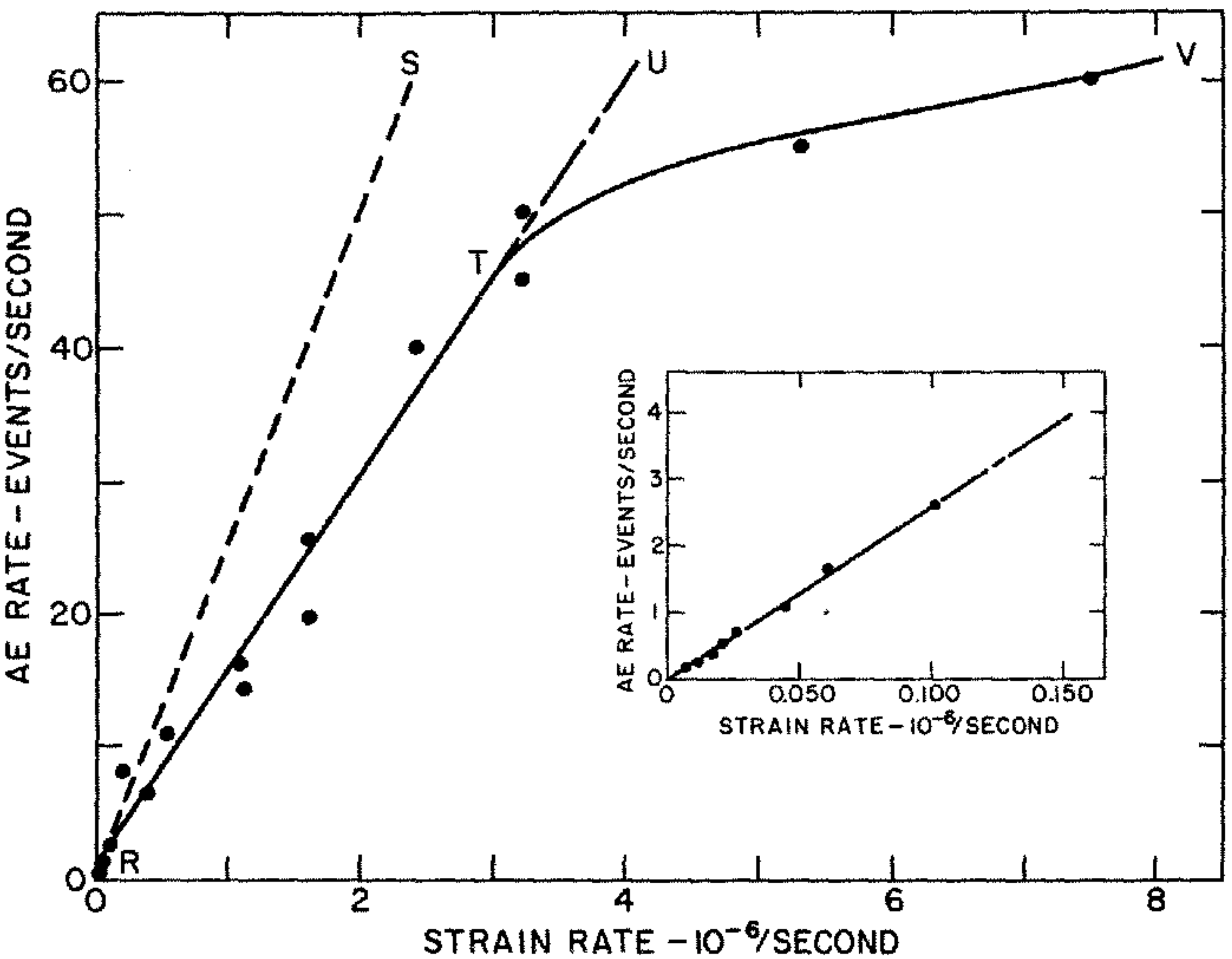


Figure 13. AE Rate versus Strain Rate for Creep Test on Pressed Salt. [Specimen S-18, Uniaxial stress—1150 psi].

"noisier" than the pressed salt, reflecting either more numerous, or larger magnitude emissions. Subsequent runs made using natural salt indicated that the total immersed volume of the specimen had some effect on the AE rate. Of much greater importance, however, was the distance between the AE transducer and the water surface. This suggested that the amplitude of the AE signals were rather low, and that they were attenuated rapidly in the salt medium.

Following the success of the preliminary AE studies a series of more detailed experiments were carried out (Berezniak and Richardson, 1977). These included tests to evaluate if the acoustic energy generated by the dissolving salt could be detected by means of a hydrophone located in the water surrounding the test specimen. If so it was felt that a suitable array of hydrophones could possibly be used in the field to detect and locate the major regions of salt dissolution and hence provide information on the geometry and dimensions of the developing cavity.

The experimental arrangement used in these studies was basically very simple. It mainly consisted of suspending both the salt specimen and the hydrophone in an open glass tank filled with water as shown in Figure 14. One transducer (T1) was attached to the salt specimen and a second (T2) was attached directly to the glass tank, very close to the bottom. The two transducers (T1 and T2) used were Endevco model 2219 accelerometers and the hydrophone was a Celesco model LC-50. The output of both the accelerometers and the hydrophone were monitored by a facility described in detail elsewhere (Berezniak and Richardson, 1977). During experiments data was recorded on magnetic tape which was later played-back through a uv-recorder to provide hard copy for detailed analysis. Monitoring system gains were 90 and 85 dB respectively for transducers T1 and T2, and 65 dB for the hydrophone. Filter settings were 10–20 KHz for transducers T1 and T2 and 100 Hz–10 KHz for the hydrophone. The glass tank itself was seated directly on several foam rubber pads, to

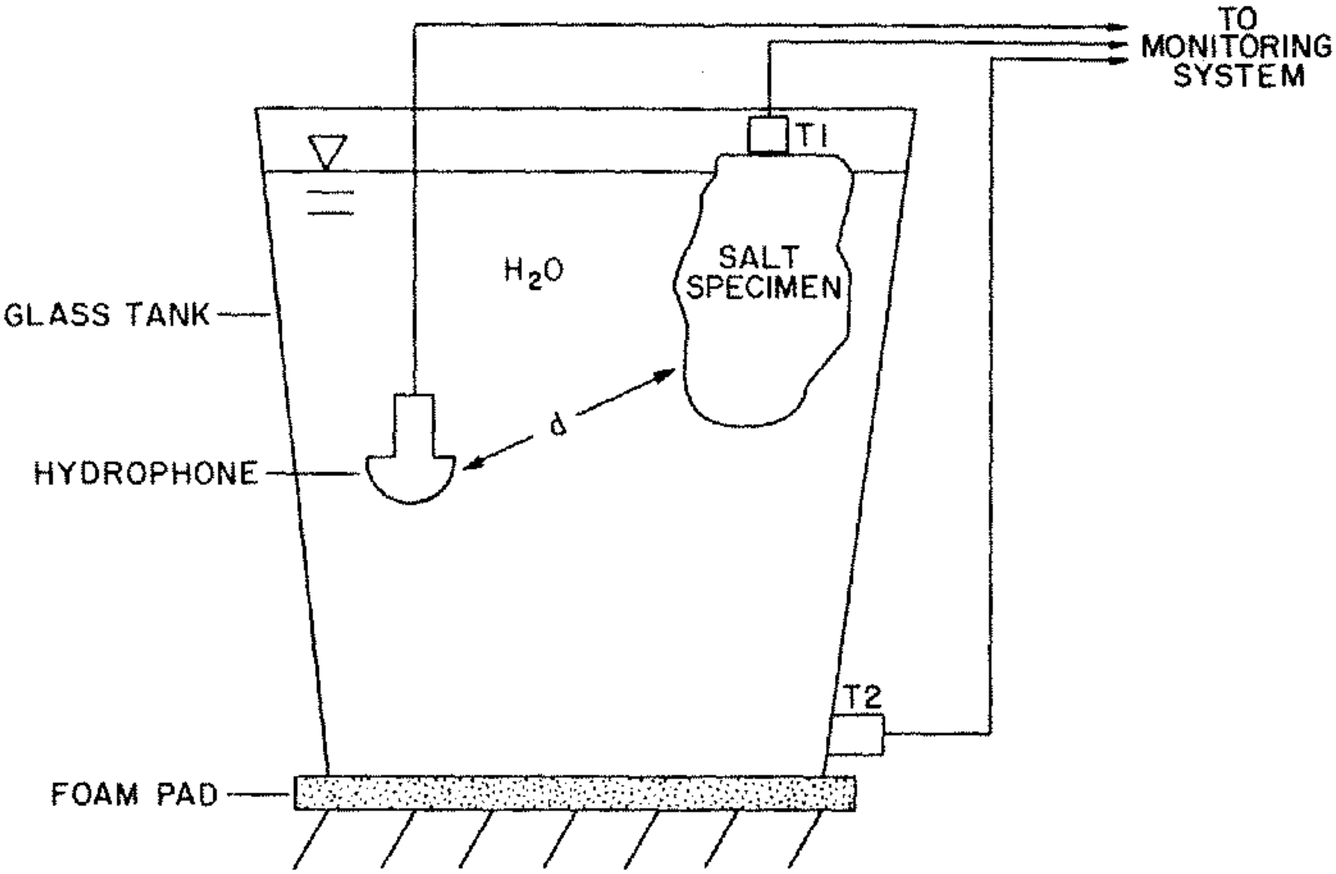


Figure 14. Experimental Arrangement used in Detailed Dissolution Studies.

help dampen culturally generated noise that might be induced into the system. Recording was mainly performed in the evening, when cultural noise was at a minimum.

The results of a number of experiments indicated the following:

1. AE activity during dissolution was detected by the transducer mounted directly on the salt specimen. Best results were obtained when the transducer was very close (< 1 inch) to the water surface.
2. The hydrophone utilized was not sufficiently sensitive to detect the continuous AE activity monitored by the specimen-mounted transducer, however it was capable of detecting the noise of even small pieces of salt impacting the bottom of the glass tank. This impact was also detected by a relatively low-gain transducer mounted on the side of the tank.
3. The hydrophone was found to be very sensitive to minor disturbances such as water currents and falling water droplets.

In review then studies to date indicate that salt does in fact generate AE activity during dissolution. The low magnitude of this activity and the highly attenuating character of salt, however, appears to preclude detection at distances greater than at most a few feet from the source. These studies however suggest that in a field situation, a sufficiently sensitive hydrophone could detect macroscopic phenomena associated with salt cavity development, namely; the separation of material from the roof and/or walls of the solution cavity, the strains produced in the cavity walls by the redistribution of stresses produced by solution progress, and the impact of pieces of salt or rock as they strike the bottom of the cavity.

In the future it is planned to continue studies relative to the macroscopic phenomena both in the laboratory and under suitably controlled field conditions. Furthermore although AE activity associated with the microscopic aspects of dissolution does not appear to be applicable to field monitoring of solution mining processes it may well provide a useful tool in fundamental dissolution studies. With this in mind one of the writers (Richardson) recently completed the production of a time-lapse movie which demonstrates vividly the direct relationship between various phases of the dissolution process and the observed AE activity.

DISCUSSION

In this paper the writers have attempted to present a brief review of the concept of acoustic emission and associated experimental techniques. A number of current applications of these techniques to the study of the basic mechanical behavior of salt have been briefly outlined. These studies indicate that salt emits acoustic emission associated with the transition from elastic to plastic behavior (yield point), and during creep and dissolution. Detailed reports covering both the yield point and creep studies are presently in preparation. In general results to date indicate that acoustic emission is a valuable tool for investigating the behavior of salt and studies in this area are continuing.

ACKNOWLEDGEMENTS

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