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Features of acoustic emission at various influences on rock samples

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In the report special features of acoustic emission (AE) in the rock samples during its deforming, loading, dissolving and heating are discussed. The AE-activity (AEA) and spectral characteristics of AE at the frequency band from on 30 kHz up to 500 kHz versus time at various influence forms are analyzed. AEA during continuous and growing mechanical loading has minimum under condition of maxima consolidation. Also transient time during step loading has also minimum. For rock salt with impurity during dissolving the AE spectral amplitudes in frequency band of 100-400 kHz relative to ones in band of 30-100 kHz are higher. AEA of gypsum during heating has two maxima connected with withdrawal of water and phase transfers.

1 Introduction

Acoustic emission (AE) is one of the non-destructive testing methods. It has advantages over others such as possibility to know internal processes on external measurements and to get information about all the object volume without local perturbations. This paper has considered results of testing rock specimens under various influences such as straining, dissolving, and heating. They are all accompanied by AE effects which is the result of inner and outer processes. Using these effects allows determining rock structure and condition parameters.

2 Acoustic emission at the deforming of rock specimens

The cylindrical specimens with dimensions D = 35-40 mm and H= 70-80 mm at linear growing and step growing load are investigated. They have been on loading machine EU-100 with 3D-loading device BV-21 deformed. Acoustic emission has been registered in the frequency band from on 20 kHz up to 500 kHz.

The various rocks have been investigated, such as rock salt, coal, carnallite and other ones.

2.1 Measuring and testing methods

2.2 Testing at the mode of linearly growing axis load

These series have been curried out at axial strain velocity about 10^{-5} and transversal stress in interval 3-10 MPa.

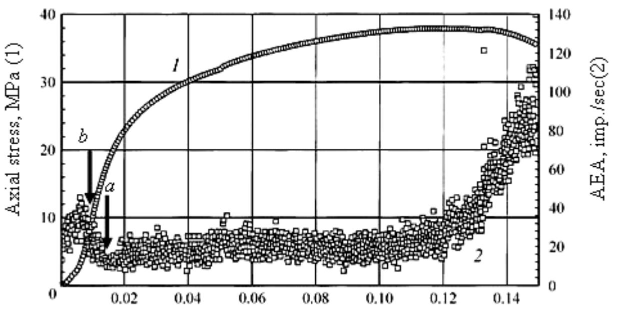

Fig. 1 Dependencies of axial stress (1) and of AEA $\dot{N}$ (2) versus axial strain ε_1

In fig. 1 the dependencies of the acoustic emission activity (AEA) $\dot{N}$ and of the axial strain ε_1 of the rock salt specimen from the well #6 of Tulskiy region versus axial strain are shown.

In fig. 2 the dependencies of the acoustic emission activity (AEA) $\dot{N}$ and of the volumetric strain are shown.

Thus the minimum of AEA can indicate maximum of volumetric strain that corresponds to long duration strength and it can be used for determining this parameter. This method can give more precise estimations than the ones determined from strain measurements.

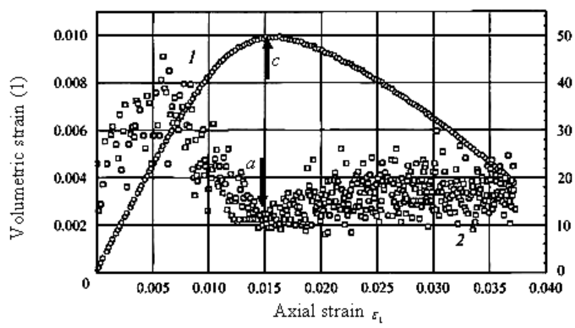

Fig. 2 Dependencies of volumetric strain (1) and AEA (2) versus axial strain ε_1; *a* – point of AEA minimum, *c* – point of volumetric strain maximum

Similar results have been obtained on specimens of coal, gypsum, carnallite and other rocks.

2.3 Testing at the mode of step growing differential load

The measurement results of the acoustic emission activity (AEA) transient time duration under step loading in the uniaxial stress state are shown in [1]. It was established that under stress increasing the AEA transient time at first increases rather than decreases, after that it increases again. The studies of this phenomena in the triaxial loading conditions has been described in this paper.

The AE signals were indicated at triaxial compression of salt specimen in the pressure camera BU-61. The tests were carried out on the step changing of both axial σ_1 and lateral σ_2 and stresses difference $\sigma_3 = \sigma_1 - \sigma_2$. In the initial state the stress 27 MPa for all axes were established. Then steps dropped about 1 MPa the lateral stress down.

The specimens had 35 mm diameter and 70 mm height. The specimens were located between two fulcrums in the camera and were insulated for oil by rubber membrane.

During the tests axial and lateral loadings were registered. These ones were recalculated to stresses. Axial and lateral strains of sample and AEA were also registered. The scheme of the data acquisition and processing is described in [1]. The main parameters of this acquisition system: 1) measuring parameters: axial and lateral stresses in specimen, axial and transverse strains of samples, acoustic emission activity; 2) stress range: 0-50 MPa; 3) relative error of stress measurement: 1.5%; 4) axial strain range: 0-10 mm; 5) axial strain measurement relative error 0.25%; 6) transversal strain measurement range 0-5 mm; 7) transversal strain measurement relative error 0.65%; 8) AE count rate (AEA) range 0-500 imp/sec; 9) minimum of the deformation sampling rate 1 sec; 10) digitalization interval change pitch 1 second.

The AE sensor was located on the camera outside. The tests results are shown in fig. 3.

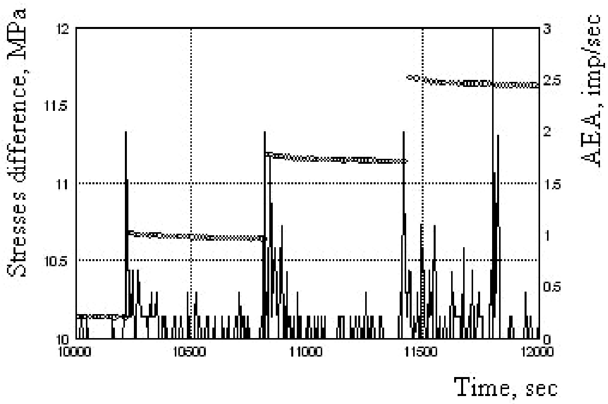

Fig. 3 Stresses difference and AEA versus time

There are two peculiarity in comparison with tests at uniaxial stress state should be noted: 1) total level of AEA at triaxial compressive is smaller than the one under axial stress state; 2) the effect of AEA decreasing on each loading step is indicated both in the case of axial stress state and in triaxial case. However in the second case acoustic interferences influence becomes comparable with AEA of salt more prominent. Sources of acoustic interferences are friction of test set parts and oil moving with pressure changing.

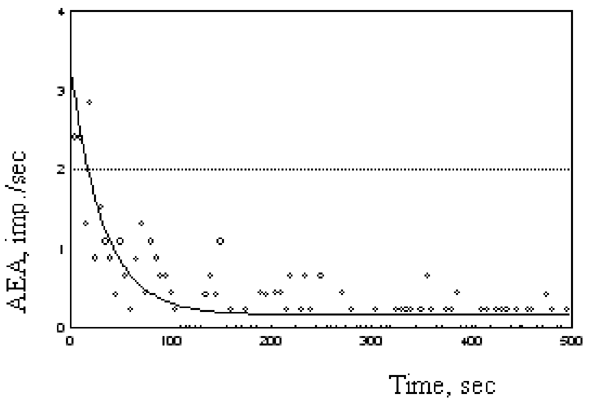

Fig. 4 Acoustic emission activity versus time

After acquisition the data from file have been segregated in to steps and have been approximated by dependence

$$a(t)=a_0+a_1*(1-\exp(-t/a_2)) \quad (1)$$

for each AEA step.

The fig. 4 shows the results of observations (points) and approximation (solid line) of this dependence for salt of Karachaganak field.

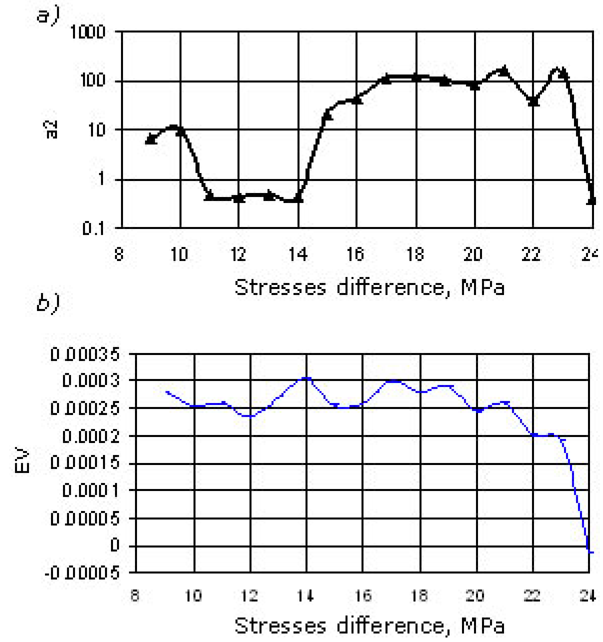

Fig. 5 Factor a_2 (a) and volumetric strain ε_v (b) versus stress difference $\sigma_3 = \sigma_1 - \sigma_2$

Processing coefficients of equation (1) were determined using least square method. So, for example the results for step are shown in fig. 4 and this dependence has form

$$y = 3.28 + (-3.12)\cdot\left(1-\exp\left(-\frac{x}{32.68}\right)\right) \quad (2)$$

Fig. 5 shows the volumetric strain and parameter a_2 versus stresses difference. Obtained results indicated that parameter a_2 increases on the 14th step. This increasing exceeds moreover 100 times over. Also this parameter decreasing on steps 11-14 in comparison with steps 9 and 10 exceeds 10 times. It testifies that this phenomenon was caused not by random character of AE but by appropriate phenomena which is associated with changing of salt characteristic under the maximum consolidation condition.

Similar results have been obtained for salt specimens of Rossoshinskaya area (fig. 6).

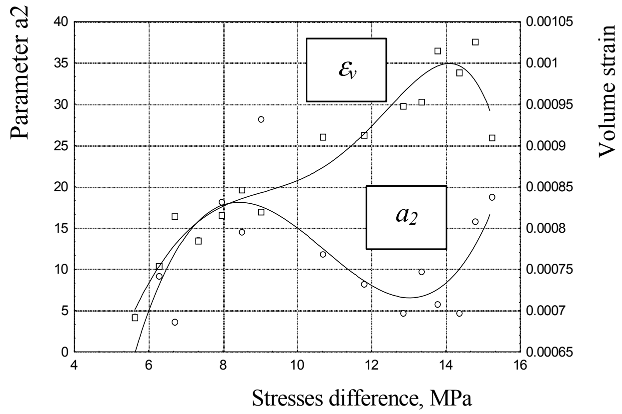

Fig. 6 Volumetric strain and AEA versus time

In this case the rock salt maximum consolidation (maximum value of volumetric strain ε_v) also corresponds to the beginning of area of parameter a2 increasing with stresses difference 14 MPa after decreasing. However in this case the change of this parameter is smaller. The relation of a2 at stress difference 8 MPa to its value at 13 MPa equals 3. That gives reason to say about not random character of this factor dependence.

Similar results have been obtained also on specimens of coal and of other rocks of various deposits in mode of increasing step loading when transverse strain was constant.

3 Acoustic emission at the rock salt dissolution

Dissolution is one of the technological methods used in extraction and processing minerals. Acoustical emission (AE) appears during the interaction between liquid and rock. The analysis of such signals helps us to come to conclusion about rock condition and properties and also to investigate the character of this effect origin. Spectral analyses play an important role in such investigations. In reports [2, 3] it was shown that it needs stable characteristics' averaging with use of more than 20 – 30 signals of AE. Now we will show that the presence of insolubles (anhydrite) have an influence on the spectrum form. In this report we also consider possibilities of identifying litotype of rock salt with different impurity contents.

Three specimens of 3 lithological sorts of rock salt have been selected for researches: #52 without insoluble anhydrite; #64 where the content of anhydrite is 5 – 7 %; #68 where the content of anhydrite is 12 – 15 %. For convenience it appropriates numbers 1, 2, 3 accordingly.

Recognition technique was applied for identification of the lithotype of rock salt with different impurity content with amplitude 2 or 3 spectral constituents which have been chosen at the beginning and the end of frequency band. When 3 constituents have been used they were at the beginning, in the middle, and at the end of this one.

Illustration in fig. 7 represents spectrums averaging on 35 signals. The spectrum of the AE signals passing through the water demonstrates by solid line when the transducer is set on the pot wall where dissolution was passing. Point lines illustrate signal spectrum detected by transducer that has been placed on the sample.

From these diagrams of the signal spectrums passing through water, it is visible, that the maximal distinction in spectra of AE signals is observed in area from 50 kHz up to 100 kHz. The amplitudes of harmonious components were chosen as informative parameters. The diagrams of relative

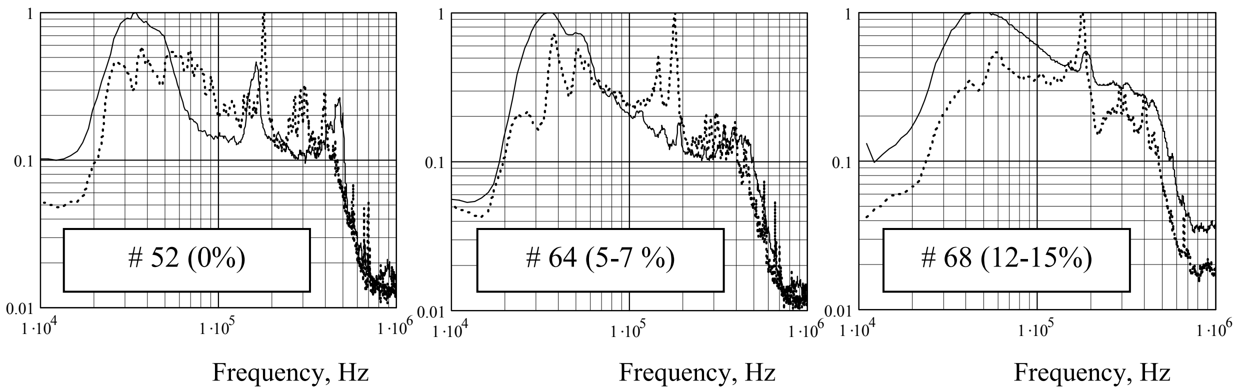

Figure 7 The AE signal spectrums of *salt* rock samples with the different admixture content

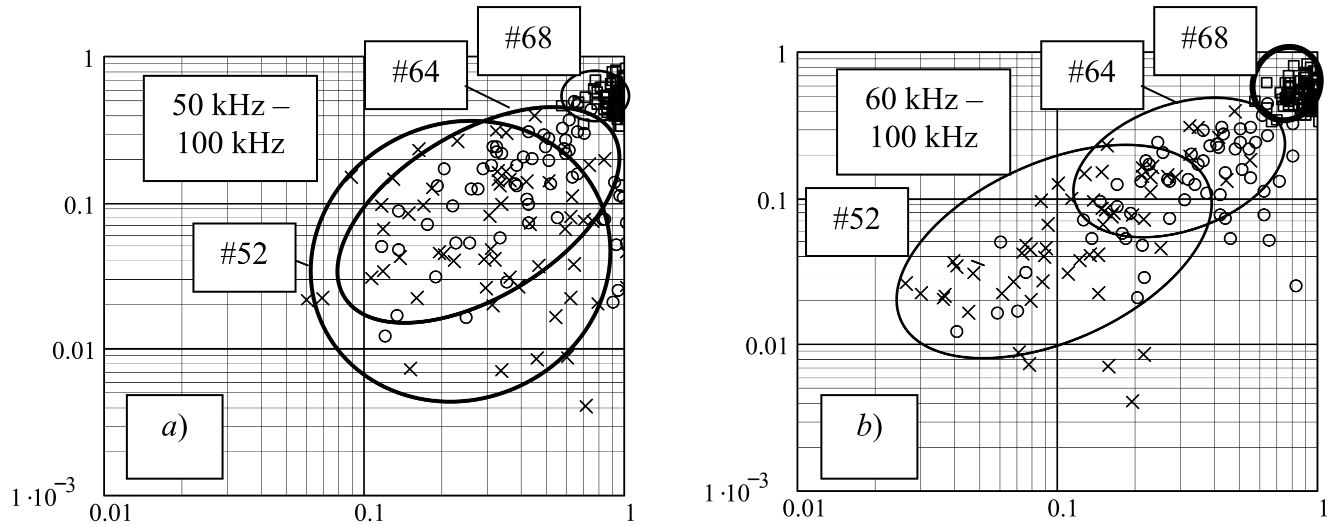

Figure 8 Diagram of spectrum components distribution: *a*) frequencies are 50 and 100 kHz, *b*) frequencies are 60 and 100 kHz

amplitude on the 1st frequency versus this one on the 2nd frequency are plotted on the fig. 8 for the frequencies choice for the better recognition. The amplitudes on 50 kHz versus the ones on 100 kHz (a) and also 60 kHz versus 100 kHz (b) are taken for plotting points on diagrams. The points corresponding to the sample #52 are designated on the diagrams by slanting daggers, to #64 by circles, to #68 by squares. These amplitudes have been used at recognition on two parameters. At recognition on three parameters, amplitudes on frequencies 60 kHz, 80 kHz and 100 kHz have been used.

Areas of point's distribution of each sample are allocated on fig. 8. Apparently from the submitted results, the points corresponding to the sample #68 are well separated from points of other samples. Points of samples #52 and #64 are divided less clearly. Especially it is demonstrated when the smaller frequency is $f1$ = 50 kHz. At $f1$ = 60 kHz the points are divided better. From these diagrams it follows, that the second combination provides the best classification of these specimens.

The regularity that follows from fig. 8, *b*, is increasing quantity of insoluble impurity shifts the point's distribution area to the right top corner of the diagram.

For improvement of classification of the points corresponding to samples with the various contents of impurity, it is necessary to enlarge the number of informative parameters, for example amplitudes on frequencies 60 kHz, 80 kHz and 100 kHz.

4 AE in rocks at thermo influence

We can define several AE formation mechanisms at rock heating.

1) AE formed by stress due to structure peculiarities and differences of thermal expansion coefficients in individual grains making up rock at uniformed temperature field.

2) AE formed by stress as a result of ununiformed character of temperature field:

- due to temperature gradient at areas of heating and cooling in volumes observed and due to ununiformity of heat conductivity coefficients at different space points under stationary condition;

- due to migration of heat front in initial stationary stage.

3) AE formed by phase transfer or chemical reactions at heating.

We don't consider detailed factor actions, but only provide specimens' test results of gypsiferous rock where all these factors can find themselves. To carry out experiments a test unit has been set up. It consists of piped heating furnace with cylindrical cell of 50 mm in diameter and control panel allowing heating with preset speed and maintaining the desired temperature within desired time periods.

The measuring component incorporates AE system base (A-Line-32D by "Interunis" company, Russia, Moscow). It has AE-signal registration channels, two channels hooked up by thermocouples to measure temperature of the specimens under observation. Thermocouples tail points (1.5 mm in diameter) were placed in drilled reassess of the specimens which were situated at different distances from the outside, where heating was applied. That enables temperature gradient measuring.

The specimen of rock under investigation is placed in the central part of cell and clamped between the ends of two quartz rods. Acoustic transducers are placed at other protruding ends. Let's take the results of two tests on two specimens taken from one and the same sample (35 mm in diameter, 9 mm high). The specimens were heated up to the same temperature of 300 ^{o}C, but at a different speed. Maximum speed heating was 10 ^{o}C/min (specimen #1), while the speed of slow heating was 1.5 ^{o}C/min (specimen #2). Fig. 9, 10 are graphical representations of temperature (1) and AEA (2) versus time. Both AEA graphs demonstrate double maxima with a minimum in between.

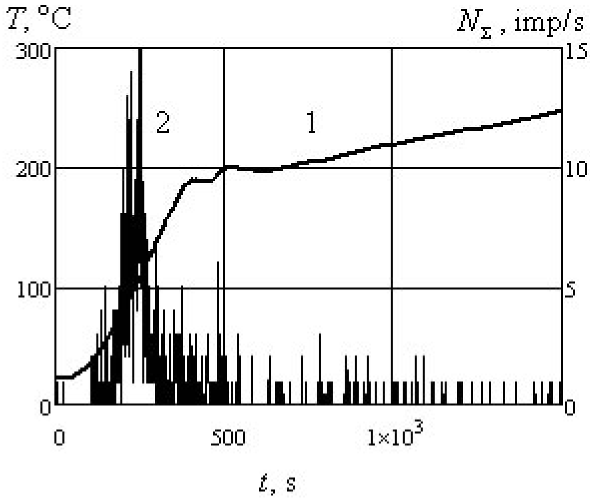

Fig. 9 Temperature (1) and AEA $\dot{N}_\Sigma$ (2) versus time at fast heating of gypsum specimen (10 ^{o}C/min)

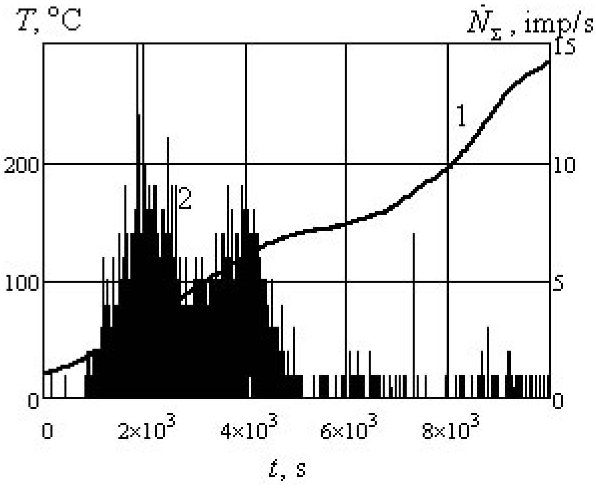

Fig. 10 Temperature (1) and AEA $\dot{N}_\Sigma$ (2) versus time at slow heating of gypsum specimen (1.5 ^{o}C/min)

For the purpose of comparison of characteristics at different heating speeds (fig. 11) we have plotted AEA versus temperature at fast and slow heating by moving average.

The graphs show that fast heating compared to slow heating reveals the following differences:

- AEA level observed is higher;

- the minimum between two maxima is observed at fast heating with higher temperature 98 °C, than at slow heating (89-95 °C).
- with temperatures above 140 °C a rather high level is observed, while at slow heating it almost not existant.

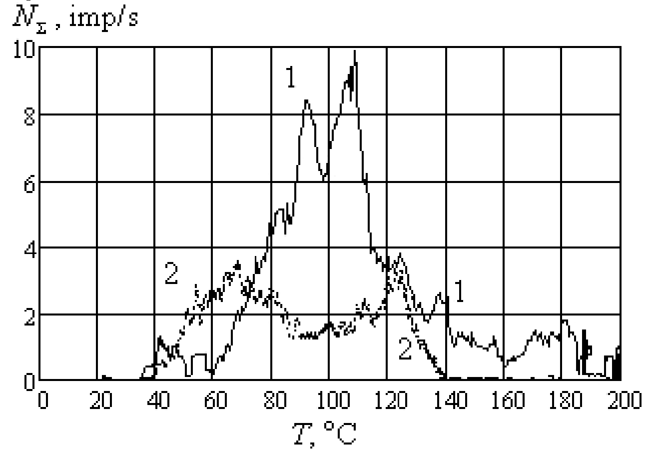

Fig. 11 AEA versus temperature at fast (1) and slow (2) heating of gypsum specimen

The peculiarities mentioned above testify to the fact of significant contribution of non stationary temperature distribution at fast heating, its contribution at slow heating is much less. The phenomenon of double AEA maximum may be connected with withdrawal of free water and the beginning of crystallized water withdrawal from gypsum $CaSO_4 \cdot 2H_2O$ at temperatures corresponding to the first maximum. With further temperature increase structural transfer of gypsum into CaSO4·0.15H2O is observed which gives rise to the second maximum. That is the processes accompanying gypsum heating consists of two phases. It should be noted that with other types of rock AE double maximum is not observed. It confirms the hypothesis of AE acoustic formation mechanism at gypsum heating connected with phase transfers.

Conclusion

The main conclusions to be drawn from the experiments are as follows:
Acoustic emission reflects state changes of rock at various influences. In the paper AE features in state of maxima consolidation of rock were discussed. AEA during continuous and growing loading has minimum under this condition. Also transient time during step loading has also minimum.
For rock salt with impurity during dissolving the AE spectral amplitudes in frequency band of 100-400 kHz relative to ones in band of 30-100 kHz are higher.
AEA of gypsum during heating has two maxima connected with withdrawal of water and phase transfers.
These results can be used for understanding of various physical and chemical processes at straining, dissolving and heating of rocks and for development of new control methods.

Acknowledgments

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