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ACADIA
CENTRE FOR
ESTUARINE RESEARCH

ERODIBILITY OF COHESIVE SEDIMENT BEDS UNDER UNIDIRECTIONAL CURRENTS

Final report to

Atlantic Geoscience Centre

Wolfville, Nova Scotia
Canada

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by

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1. INTRODUCTION

The behaviour of cohesive sediment beds by currents and waves has great importance from the engineering, biological and chemical standpoints. The erodibility and the deposition of cohesive sediments are related, For instance, with the release of nutrients from beds, the maintenance of minimum depth (in tidal rivers, estuaries, and water ways), and the degrading water quality and the resulting harm to aquatic organisms.

In nature, the physical characteristics of a cohesive bed is affected by many factors (of biological, chemical, and physical origins) which change the behaviour of the sediment. To be able to measure those effects, it is necessary to have in the first place a good understanding of the sediment behaviour under abiotic and inorganic conditions. Once the response of certain cohesive sediment under known conditions is known, it is possible to study the changes caused by natural variables on the sediment.

For this reason, the original propose of this investigation was to carry out experiments under controlled conditions on a standard cohesive bed. Then to introduce external factors and to measure and describe any possible changes in the stability of the bed. At the same time, the purpose of this work was to evaluate the accuracy of the methodology usually used to measure the stability of cohesive sediment beds under both laboratory and field conditions.

According with Parchure (1984), and Hunt and Mehta (1985), a cohesive sediment deposited from a suspension will have a decrease in erodibility downwards (Type I profile), whereas a placed sediment bed (homogeneous properties with depth) will show no variation in the erodibility with depth (Type II profile). In estuaries, Type I profiles typify the superficial layers of sediments, which are frequently resuspended by the action of waves and currents. The present study is focused on the behaviour of the top sediment layers (profile Type I) under the action of unidirectional currents.

2. MATERIALS AND METHODS

All the experiments were carried out using the Lab Carousel located at the Acadia Centre for Estuarine Research, Acadia University. This instrument is composed of a 1 m radius annular flume that is 15 cm wide and 40 cm high. The currents inside the flume are produced by 8 paddles located on a rotating lid the speed of which is controlled by the user. The current speed is measured by a current meter located in the centre line of the channel, at a height of 10 cm, and the suspended sediment concentration (SSC) is measured by three optical back scattering sensors (OBS) located at different heights in the inside wall of the flume. On the external wall, there are three sampling taps at the same height as the OBS s. The information from the sensors is stored on a data logger at a frequency of 1 Hz. These data are time-averaged over 10 seconds to smooth the time-series.

The current meter was not used continuously due to problems of corrosion, Thus a calibration between current speed, current meter output, and input motor voltage was made. This calibration was established using water seeded with coffee grinds that have a high contrast and almost neutral buoyancy. The particle trajectories and their speeds were video-recorded and digitized. The relationships obtained are shown in figure 1.

The material used in the majority of the experiments to create the cohesive bed was Glomax kaolinite. The grain size distribution of this material is shown in figure 2. Also, a series of experiments were carried out with natural sediments collected from the surface of a tidal flat in Minas Basin (Starr's Point) in order to compare the erosional behaviour of the two sediment types. To eliminate organic matter, the natural sediments were digested with hydrogen peroxide (30%) for one month. The calibration between the OBS outputs and SSC, was done through filtration of samples collected from the middle tap of the flume. This calibration was done over several experiments because the OBS's showed a random time-dependent drift on the signal. An example of the calibration is shown in figure 3.

The salinity of the water was obtained by dissolving synthetic sea salt (Instant Ocean) in tap water. This sea salt was used instead of natural sea water to provide consistency between experiments through ellimination of contaminants (organic or inorganic) that could affect the results.

As secretions of microorganisms affect the sediment characteristics (through adhesion), our medium was maintained abiotic. This has been done using NaN_3 (sodium azide) at a concentration of 0.01 gm/l. The effectiveness of the poison to prevent the growth of microorganisms was checked periodically during the experiments on samples taken from suspension. A titration method was used to measure any decrease in dissolved oxygen (O_2) daily over four days of incubation. The sampling to measure dissolved O_2 was done weekly in triplicate. Results were compared against standards prepared from sterilized water. The water temperature in the flume was maintained within desirable value ranges by means of an external cooling system, which exchanged flume water at slow rate from the sampling taps.

The bed was prepared by mixing a slurry of sediment at high lid speed and then settling the sediments from the water column which was followed by a period of consolidation in still water. The consolidation period ranged from 20 to 44 hours. The experimental procedure to study the top layers of these cohesive sediment bed, was originally that used for the "Sea Carousel", which is a similar instrument to the Lab Carousel, but designed to be used in the field. This methodology comes originally from that one given by

Parchure (1984), Parchure and Mehta (1985), and Hunt and Mehta (1985).

The strategy used to study sediments with a Type I profile consisted of increasing lid speed (and hence the shear stress, τ) in small increments. According with Parchure and Mehta (1985), at a given water speed, the erosion rate (ϵ) decreases as erosion proceeds and eventually stops as the bed strength equals the applied bed shear stress. Once this steady state condition has been reached, the concentration of suspended mass remains constant ($\epsilon \cong 0$). Repeating this step for increasing water speeds, it is possible to obtain the bed shear strengths at different sediment depths (through the erosion process). The shear strength values correspond to the critical shear stresses at depth z ($\tau_{cr(z)}$). The erodibility of the sediment bed may be described by this parameter and its variation. These authors have obtained the following ϵ-τ relationship

$$\ln\left(\frac{\epsilon}{\epsilon_f}\right)=\alpha\left(\tau_b-\tau_{cr(z)}\right)^n [1]$$

where τ_b is the applied shear stress on the bed, $\tau_{cr(z)}$ is the critical τ for a given depth z, ϵ_f is the erosion rate when $\tau_b=\tau_{cr(z)}$, and n is an empirical value equal to 0.5.

According with Amos et al. (1992a), the root-mean-square friction velocity (U_{*rms}) in the Sea Carousel, is related linearly with the mean azimuthal velocity (Ux) in the form U_{*rms}=0.0167+0.097Ux. These authors have shown that there is a decrease in U*rms with increase of SSC. Because of the uncertainty of this relationship above the tested SSC range (300 mg/l), and its small effect within that range, this effect has been ignored. Thus the relationship used here is:

$$\tau=(0.097\,Ux)^2\rho$$

where ρ is the density of the water (kg/m3).

Observations made during the present study have shown that massive erosion (irregular erosion surface) starts to take place at water speeds of the order of 0.5 m/s. So our experimental water speed range was kept below 0.5 m/s, while the speed increments were between 0.0134 m/s and 0.054 m/s.

The grain size distribution of several successive samples of the suspension, taken during the execution of some of the experiments, have been analyzed by means of a coulter counter. This was determine if the erodability of the bed could be related to a possible downward change in grain size, The results for kaolinite, given as an example in figure 4, show that a big difference in the grain size distribution from successive eroded layers does not exist.

3. RESULTS

3.1. GENERAL CONSIDERATIONS

During the present investigation, a total of 92 experiments were carried out. However, for clarity, we present only the results of those experiments which were representative. Many times the results obtained from an experiment series led to other experimental series. Because of this, discussion is provided with results.

As the sediment bulk density (and its variation with depth) was not known, the suspended sediment concentrations (SSC) was used as a proxy.

3.2. KAOLINITE EXPERIMENTS RELATED WITH SALINITY AND TEMPERATURE VARIATIONS

In first place, a series of experiments were undertaken to determine the behaviour of kaolinite under changing water temperature and salinity. The bed thickness was 1.9 cm (dry bulk density 503 kg/m^3), and the compaction time after total resuspension was 20 hours. Initially, four replicate experiments were carried out in order to evaluate the repeatability (fig. 5). Then a series of 5 experiments were carried out changing the water temperature (between 5.3 and 24^{0}C) but at a fixed salinity of 5‰ (fig. 5, 6 and 7). Finally, a series of 4 experiments were carried out changing the water salinity (between 5 and 35.3‰) while keeping temperature fixed at 17^0C (fig. 7 and 8).

It is seen from the time-series of the experiments, that during the small interval of time for each speed increment (10 minutes), a steady state condition was not reached (where the erosion rate (ϵ) becomes close to zero and, for a constant current speed, the SSC would remain constant with time). Under this condition it is not possible to determine τ_{cr}, and the related sediment shear strength. For this reason, another series of experiments was carried out as follows.

3.3. TIME INTERVAL TO REACH $\epsilon \cong 0$

A series of experiments were carried out to determine the minimum time interval necessary to reach the equilibrium point where $\epsilon = 0$. The current steps were maintained at a constant for steadily longer time intervals. From the results obtained (fig. 9), it is clear that this state was not achieved within a reasonably-short interval of time. ϵ always appeared to decrease with time but never reached zero. How small should ϵ be to consider it zero seems to be a subjective choice and is often defined by the sensitivity of the instrumentation. Assuming that a measurable τ_{cr} exists, a possible explanation for this behaviour may be that the variation in shear strength with depth is small in relation to the change in current speed at each step. This implies that once the currents exceeds the small range of critical values for the sediments (τ_{cr}), the bed erosion will continue to erode (Type II profile).

3.4. MEASURE OF τ_{cr}

The results above illustrate that the methodology of analysis was not appropriate to describe the erosional behaviour of soft cohesive sediments in a reasonably short period of time (i.e. 1 hour). In order to obtain τ_{cr} values, another methodology of analysis was tried. This methodology consisted of subjecting a fixed depth (constant SSC) in the sediment to differing shear stresses (τ) in a series of related experiments. For a given sediment depth, ϵ from each experiment was measured and plotted against τ; a strong positive correlation between the two variables was found. In figure 10 the time-series for the first set of experiments (CA2) is shown. The results obtained are shown in figure 11 and 12, and they exhibit a logarithmic relationship in the form:

$$\ln(\epsilon)=\alpha(\tau)+\beta$$

$$\epsilon=e^{\beta}e^{\alpha\tau}=Me^{\alpha\tau}$$

The variation of α and β with depth for the experimental series CA2 is shown in figure 13. From the obtained relationship, a true value of τ_{cr} does not exist. The deviation from the fitted curve in the results shown in figures 11 and 12 may be related to another very important process related to the bed thickness (explained in section 3.6). For this reason, another series of experiments was carried out for a bed thickness of 2 mm (dry bulk density 374 kg/m^3). A τ of 0.1869 N/m2 (13.9 cm/s pre-erosional current speed) was applied for 30 minutes, one hour before each experiment started. The time-series for this set of experiments (CA3) is shown in figure 14, and the results figures 15 and 16. The scatter has decreased significantly. The values of α and β obtained for each sediment depth (SSC), describe the erosional behaviour of this soft inorganic cohesive bed. Their variation with depth for the experimental series CA3 is shown in figure 17.

3.5. EXPERIMENTS WITH NATURAL SEDIMENTS

Similar experiments to those described above, but without applying pre-erosional currents, were carried out with a 3 mm bed thickness of inorganic natural sediment (series NATAU composed by 10 experiments). For this series, the time of consolidation was 44 hours, the salinity 30‰ and the water temperature between 18.5 and 17.3^{0}C. With the exeption of the topmost layers, the results (fig. 18 and 19) follow the same relationship of ϵ-τ as the kaolinite bed. In these experiments, the deviation of the results from the best-fit curve in the top layers may be related to the lack of the homogenizing pre-erosional currents. In figure 20, the variation of α and β with depth is shown.

In order to evaluate if there were any grain size variations with the bed depth that could be related with changes in ϵ, a series of samples of the suspension were taken at different stages during one experiment. The coulter counter analysis of those samples (fig. 21), have shown that there was a small increase in the coarser population with depth.

These experiments with natural sediments were originally carried out with the objective of analysing the changes in erodibility between inorganic sediment, and the same material but without removing, by H_2O_2 digestion, the organic substances that naturally occur in a tidal flat. However, the erosion with organic substances differs from that without. Instead of been eroded in a particle by particle (or floc by floc) way, the erosion takes place by removing irregular "patches" from the exposed surface, which can reach up to 4 cm in length. At the same time that the SSC is increasing by the erosion of the bed, those patches that have been already eroded and are in suspension become smaller, contributing to increase the average SSC values detected by the OBS's.

As a consequence of this erosional process, the indirect way of measuring bed erosion by means of the SSC detected by the OBS's may not be appropriate, because the OBS values deviation from the mean values is more than three times greater than that observed with the inorganic sediment, and at the same time the mean values do not represent the real amount of SSC within the flume. In figure 22, are shown two examples of the results obtained with the natural inorganic sediment (a) and with the same sediment but with the organic substances present (b). On the other hand, sampling from the taps does not represent the total SSC either. Under such conditions, the only possibility to obtain good representative values would be to use another device that could measure the bed erosion rate in a direct way as eroded depth, and not by means of the increment of the SSC.

3.6. EFFECT OF THE APPLIED τ ON THE SEDIMENT BED CHARACTERISTICS

The deviation in ϵ for the same applied τ, observed mainly at the beginning of some of the experiments, leads to the possibility that the physical proprieties of the bed, and so its erodibility, could be changed by the applied τ. To test this possibility, a particular series of experiments was designed and carried out. In these experiments, the bed was exposed to the action of different small current speeds acting during a variable interval of time. The current speeds were small enough no erosion was taking place, at least over one hour (τ_{sbcr}). After the action of these currents, in all the experiments, the bed was exposed to a clearly erosive current (the same for all the experiments). In order to be able to compare the results, the applied τ_{sbcr} were transformed to units of power/unit area to have a value representing both the current speed and the time over which it was applied.

From the results shown in figure 23, it is clear that the erodibility of the bed is highly affected by the history of the applied currents. This implies that while the sediment bed is been eroded, the applied stress are changing the proprieties of the underlying uneroded material, which will change its future erosion rate. This introduces another variable to be taken into account. It is not easy to be measure and may invalidate the results obtained by means of the methodology given by Parchure and Mehta (1985).

As the bed used in the experiments described above was 1.9 cm thick, it was noticeable that the sediment surface was highly affected by dewatering from buried sediments. The surface, instead of been smooth, shown a series of bumps of variable diameter (up to 4 mm), usually with a small hole in the centre, and with a density of the order of $10/cm^2$. These changes in bed roughness may have an affect on erosion threshold. Four experiments were carried out to determine the effect of dewatering of the buried sediments on ϵ. The procedures followed in these experiment were:

Experiment 1: Total resuspension (19 mm depth), 20 h of compaction time, erosion. CAO2.020

Experiment 2: Total resuspension (19 mm depth), 20 h of compaction time, 30 minutes of $\tau_{sbcr}=0.1896 N/m^2$, erosion. CAO2.023

Experiment 3: Resuspension until 2.5 g/l (2 mm depth) , 20 h of compaction time, erosion. CAO2.024

Experiment 4: Resuspension until 2.5 g/l (2 mm depth), 20 h of compaction time, 30 minutes of τ_{sbcr}=0.1896N/m^2, erosion. CAO2.025

The results of these four experiments are shown in figure 24. From these time-series, it is easy to observe that the results from experiments 3 and 4 are almost identical. There are some differences between them and experiment 2, but the greatest change in the erodibility was in experiment 1. From these results, it is possible to conclude that the greatest changes in ϵ (caused by the applied stress history) is caused by the buried sediment dewatering.

However, with the resources available it is not possible by the moment to evaluate the direct effect of τ in the sediment bed compaction. Then, in order to make that effect as small as possible, it is recommendable to use a small sediment bed thickness to make insignificant the physical alterations due to dewatering. At the same time, the use of a small settled sediment bed thickness in lab experiments could be more representative of what occurs in natural tidal environments, where the sediment layer thicknesses involved in a tidal cycle (eroded and deposited) are usually of the order of millimetres.

4. DISCUSSION

The experiments carried out during the present investigation have made it possible to point out the importance of certain aspects about cohesive sediment behaviour under unidirectional currents. Very often, such aspects are omitted or simplified, and this could lead to incorrect interpretations of the factors involved in the erosional behaviour of cohesive sediments.

In first place, it is necessary to point out the importance of the effect of the applied τ on the physical proprieties of the topmost sediment layers, which leads to measurable changes in the erodibility. This effect has been analyzed before by Kusuda et al. (1985), on placed mud with different water contents, from the Chikugo Estuary in Japan. Those authors have shown that, under a constant τ the rapid decrease in ϵ after 10 to 30 minutes from the test start is caused mainly by the hardening of sediment due to the applied shear stress, and that the selective erosion has not much influence in ϵ of silty-clay sediments. The results obtained here are in total agreement with the observations of those authors, and show that to ignore this effect can lead to great mistakes in the interpretation of the behaviour of the top bed layers because their analysis could be most of the time experimental-dependent. The compressive effect due to the applied τ is probably always involved, particularly in soft mud which are mainly the materials in estuaries.

However, we do not have the technology necessary to be able to measure the physical changes that occurs in the sediment bed, at the same time that the experiments are being carried out. So there is no way to evaluate the influence of this effect properly in a settled cohesive bed, which has variable physical proprieties with depth (i.e. water content). In order to be able to obtain more comparable results, and according with the observation done in the present study, it is recommended to use a small bed thickness to prevent physical bed alterations due to dewatering processes.

The results obtained here show that the experimental procedure given by Parchure and Mehta (1985) do not adequately characterize the erosional behaviour of the top layers of a cohesive settled bed. This is not only because the compressive effect of τ, but also because of the long duration involved with that method (especially important when the measures has to be done in the field). In the experiments done by those authors, each speed increment lasted during one hour, and the whole experiment took up to 1.7 days. Another limitation of this methodology is that to be able to measure the τcr values, it is necessary to have a "Type I profile", which means a noticeable downwards increase in the bed erosional resistance or shear strength. If a "Type II profile" exists (constant erodibility with depth) the method does not work. This leads to the necessity of setting up an experimental method that would allow, during a single experiment and within a reasonable small period of time, the measurement of the relationship between erodibility and current speed at different depths in the sediment bed.

First, it was necessary to determine the τ-ϵ relationship, and in order to accomplish it, three series of experiments were carried out. The results from those series, within the range of τ used here, have shown the existence of a relationship of the form:

$$\ln(\epsilon)=\alpha\tau+\beta \quad [2]$$

This kind of relationship has been pointed out before by Gularte et al. (1980); note it does not include an erosion threshold. Under this kind of relationship, erosion would be taking place at any current speed.

Then, the behaviour of a particular inorganic cohesive sediment bed under the action of any value of τ, instead of being characterized by τ_{cr} and its variation with depth, can be described and forecasted by finding a way of measuring the values of α and β (and their variation with depth). Amos (1992a and b) have shown that for an annular flume (Sea Carousel) of the same dimensions as the one used here, the turbulence caused during the current speed changes does not affect significatively the value of ϵ. Within the range of change of current speeds used in this investigation, we come to the same conclusion. When ϵ is constant (or almost constant) with depth, the change in SSC with time is constant, and if the turbulence of the changing speed does not affect the ϵ, the linearity in the increment of SSC will be maintained after the speed change, as is observed in the experiments shown in figure 25.

Then, the values of α and β could be obtained measuring the change in ϵ when the change in the applied τ occurs. At the point where the current speed changes, it would be possible to assume that we have submitted the same sediment depth to two different τ's, which give as a result two different ϵ's at the equivalent depth. This means that we have two (x,y) points for that sediment depth, and then, it will be possible to obtain the α and β values to be able to describe ϵ as a function of τ for that depth. Measuring the changes in ϵ at different depths where the τ has been changed, it would be possible to obtain the α and β values, and their variation for the entire sediment bed, and then it would be possible to forecast its erosional behaviour under any applied current.

To test the accuracy of this method, three experiments were carried out (fig. 26), two of them (ca3.009 and ca3.011) applying a 30 minutes of pre-erosional current speeds (13.9 cm/s), and other (ca3.010) with out the effect of those currents. The values for α and β calculated from experiments ca3.009 and ca3.011 are very close to those values obtained from the experimental series CA3 (fig. 27). However, the values of α and β obtained from the experiment without 30 minutes pre-erosional τ are higher than those from the series CA3 (fig. 27). The results of the last experiment means that, even without the dewatering alterations, the compressive effect of the applied currents is still important.

The results obtained above, show that the proposed method seems to work correct, having at the same time the advantages that it describes the erosional behaviour of a cohesive bed (inorganic, and under unidirectional flow) in a reasonable short period of time irrespective of the erodibility profile type. Once the α-β values are known at the depths of the current speed changes, it is possible to find a function relating them to sediment depth, and then to forecast the erosional behaviour of the entire bed under any current speed.

However, there are certain aspects related with the relationship ϵ-τ that needs a physical interpretation. The relationship suggests that erosion would occur at any current speed. From figures 13, 17 and 20, it is evident that the α and β values are dependent, showing a linear inverse relationship in their distribution with depth. The regression of those values for kaolinite (series CA2 and CA3), and natural sediment (fig. 28, 29 and 30, respectively), show that the relationship between α and β is of the form

$$\beta = a\alpha + b \quad [3]$$

what means that all the ϵ-τ curves from different depths intersect at the point where τ = a, which is in the positive side of τ. If the β value would have been constant with depth, it would have meant that the intersection of the curves are at $\tau=0$ (a=0). If the α-β relationship with depth would have been linear direct (i.e. α and β decreasing both with depth), the intersection would be in the negative side of τ, which has not physical meaning because erosion would be taken place at negative values of τ (which by definition, does not exit).

Coming back to the results obtained here (β inverse to α), the curves below τ=a have no physical meaning because the ϵ-τ relationship with depth becomes inverse: at a given τ (smaller than a), the top layers would be eroding at a lower rate than the deepest layers. Then, the ϵ-τ relationships obtained here for each depth, should be valid only for τ equal or greater than the intersectional τ (a). Then, from [3], the function [2] for ϵ can be rewritten in the following way

$$\ln(\epsilon)=\alpha(\tau+a)+b \quad [4]$$

and as when τ=a, $\ln(\epsilon_f)=b$

$$\ln\left(\frac{\epsilon}{\epsilon_f}\right)=\alpha(\tau+a) \quad [5]$$

Notice that as a is a negative value it defines an excess shear stress, and the form of the relationship for ϵ is the same as that of Parchure and Mehta (1985) [1], but in our case n=1. However, conceptually this relationship is different from equation 1. If the value a is something that can be considered as τ_{cr}, where does erosion start, the τ_{cr} of certain cohesive sediment (homogeneous grain size and mineralogy) would be constant for such sediment, not changing with the downwards change in the physical properties (i.e. water content). Moreover, α instead of being a constant value for a given sediment as assumed by those authors, would be a variable, and its change with depth would represent the physical changes in the sediment. It is possible that the value of n=0.5 obtained by Parchure and Mehta (1985), could be a consequence of the compressional effect due to the applied currents. However, in order to obtain a, it is necessary to have a variation in α with depth, and even though in an ideal "Type II profile" (constant erodibility with depth) it is possible to calculate α and β, there is not any curves intersection (or α-β relationship) to obtain a.

As β is a function of α in the form

$$\beta=a(\alpha)+b$$

and α can be described as a certain function of depth (z), in order to simplify in a linear form (fig. 31)

$$\alpha=c(z)+d$$

and because ϵ is a function of α, it would be possible to describe the erodability of the entire bed in the form

$$\ln(\epsilon)=c(\tau+a)z+(d(\tau+a)+b)$$

which for a fixed given τ leads to a function of the form

$$\epsilon=Be^{A(z)}$$

where B and A are constants defined by τ, a, b, c and d. Even though here the τ_{cr} (a) does not vary with depth, the erodibility of the sediment decreases (Type I Profile), and will behave in the same way that those experiments described by the methodology given by Parchure and Mehta (1985): for a given value of τ, the SSC variation (ϵ) will decrease asynthotically with time.

As the method proposed here is based in applying two different τ values at the same sediment depths, it is obvious that several possible errors in the measures could be avoided if it were possible to measure directly and simultaneously, the ϵ of certain sediment under the action of two current speeds. As a possibility, a double device could be constructed in order to make possible to apply simultaneously two different current speeds at the same sediment bed. In the case of the carousel (lab and sea versions), it could be possible to build two parallel annular flumes (different radius). Then, the same angular speed of the lid would be generating different azimuthal current speeds in each flume, being the relation between both ϵ, done by the equivalence between SSC (eroded depth). In this way, the derivation of the α and β values and their variation with depth, would be continuous. Also, there would not be the possibility that the macroturbulences generated at current speed changes could affect ϵ. Even thought this last effect (as was explained above) could be neglected, there exist the possibility that very soft sediments (i.e. upper layers) can be sensitive to this effect.

Finally, it is possible to say that the proposed experimental methodology given here for the analysis of the erosional behaviour under unidirectional flow of an inorganic cohesive bed, seems to be adequate. However, it is clear that in order to be able to prove its general application (and the theoretical implications outlined here), it is necessary to obtain more experimental information and a more profound physical analysis of the results.

5. CONCLUSIONS

The importance of the compressive effect due to the applied τ, which modifies the erosional behaviour of a inorganic soft cohesive sediment bed, have been demonstrated. The dewatering of buried sediments have shown a major influence on the erosion rate. Then, in comparative experiments to be carried out in laboratory, it is recommended to diminish the dewatering effects by using sediment bed thickness as small as possible. However, in order to get comparable results, either in the field or in laboratory, it is absolutely necessary to develop an instrument that could allow to measure the changes caused by the applied τ in the sediment bed at the same time that the experiments are taking place. This kind of information will be particularly important in such cases where the results are necessary to forecast the sediments behaviour in a real environment.

A new experimental methodology to measure the erodibility of a soft cohesive sediment bed is proposed. This methodology significatively differs from that proposed by Parchure an Mehta (1985) because, instead of being based on measuring the critical shear stresses, it is based on the change in the erosion rate caused by changes in the shear stress. The methodology proposed here has the advantage that it measures the erodibility of any type of bed profile, and within a reasonable short period of time.

The analysis of the results that led to the experimental methodology proposed here, has also led to the same general equation as given by Parchure and Mehta (1985) for erosion rate-shear stress. However, the conceptual meaning of the terms involved is different. The critical shear stress, instead of being a variable within the sediment bed, is showing to be a constant. The α value, instead of being a constant for a given sediment, is variable, and its variation exhibits the changes in erodibility within the sediment. Under this stand point, a change in the critical shear stress would reflect changes in the sediment grain size or mineralogy, but not necessarily a change in its erodibility.

According with the fundament of the proposed methodology, and as a way of measuring the erodibility of the sediments with depth in a continuous way, the construction of a double carousel (sea and lab versions) is recommended.

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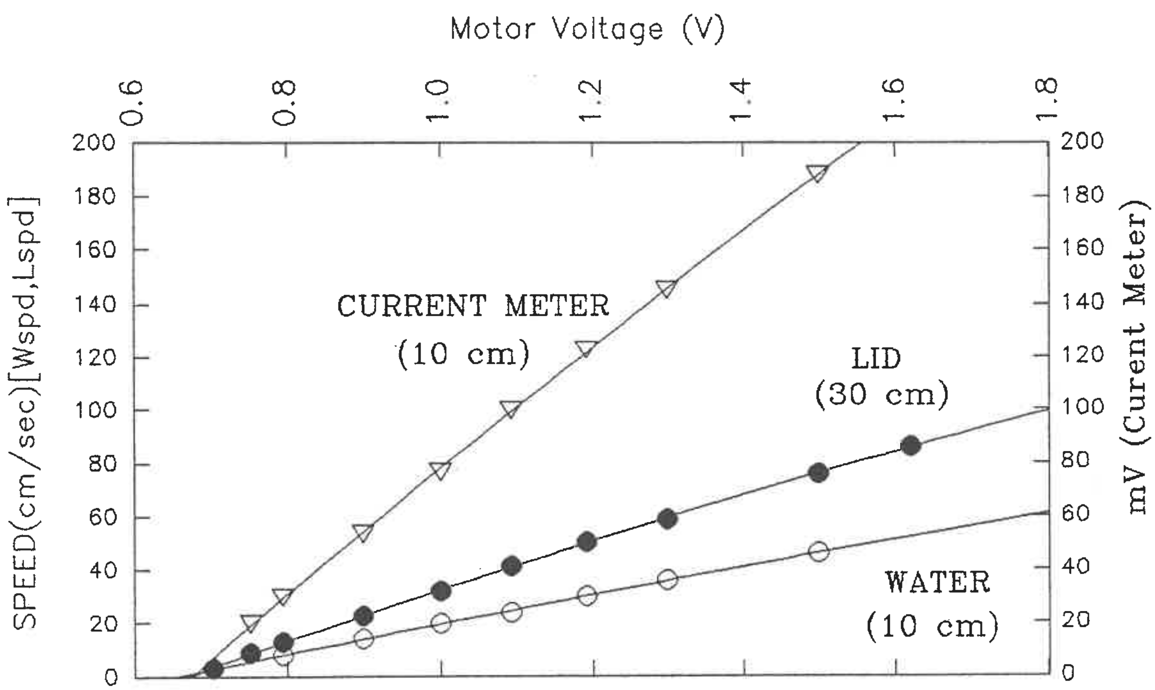
8. FIGURES



a) Water Speed: $Wspd = -4.121\ (V)^2 + 63.528\ (V) - 39.923$

b) Lid Speed: $Lspd = -12.33104(V)^2 + 118.2355(V) - 73.6058$

c) Current Meter $mV = -21.47298(V)^2 + 274.1525(V) - 174.8218$

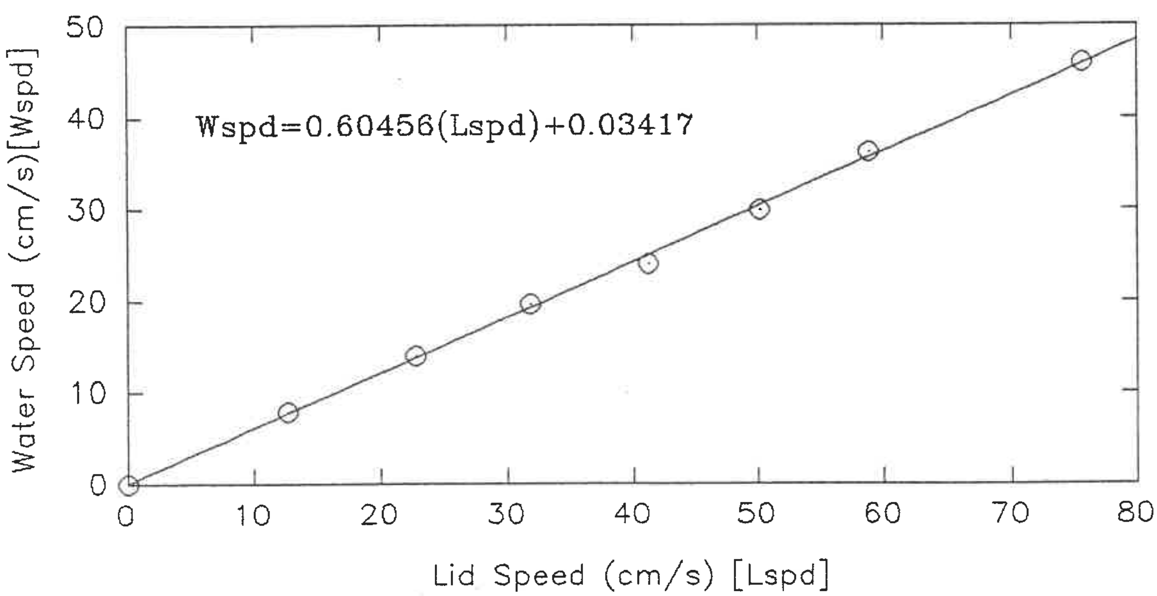


Fig. 1. Calibrations for water speed (Wspd) and current meter (mV) at 10 cm height, and lid azimuthal speed (Lspd) against motor input voltage. The relationship between Wspd and Lspd is also shown.

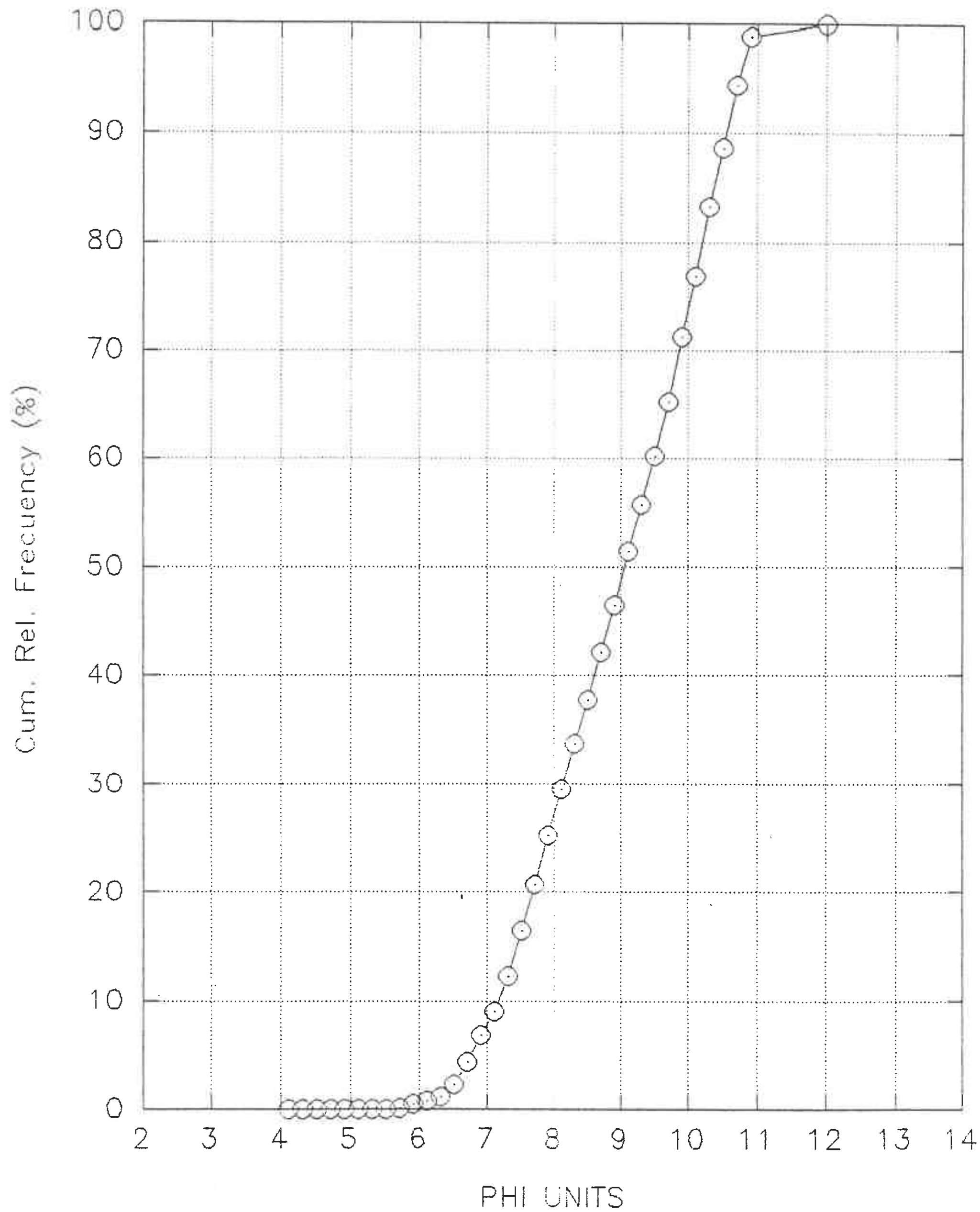


Fig. 2. Grain size distribution for Glomax kaolinite.

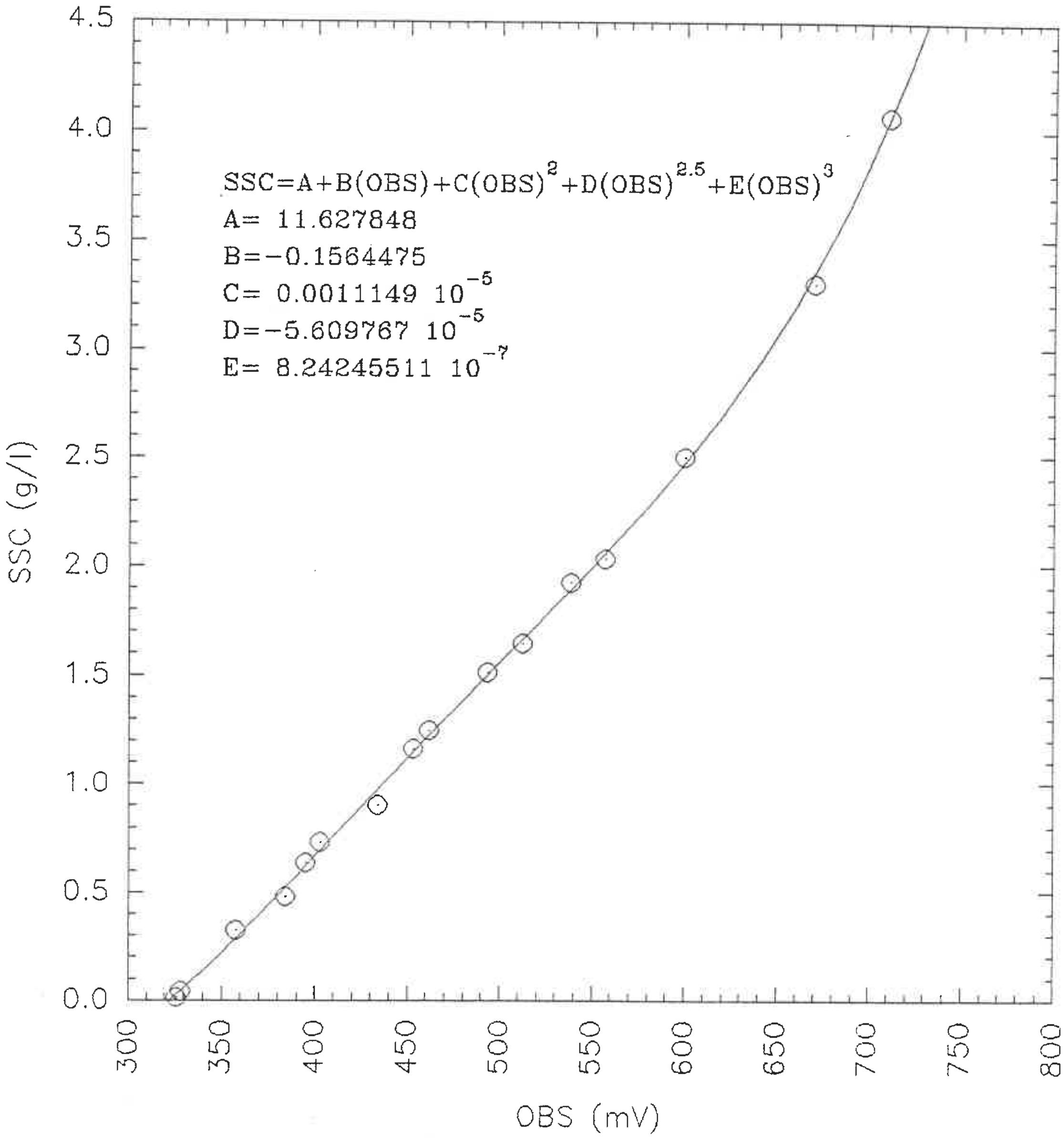


Fig. 3. Example of calibration between OBS lectures and suspended sediment concentration..

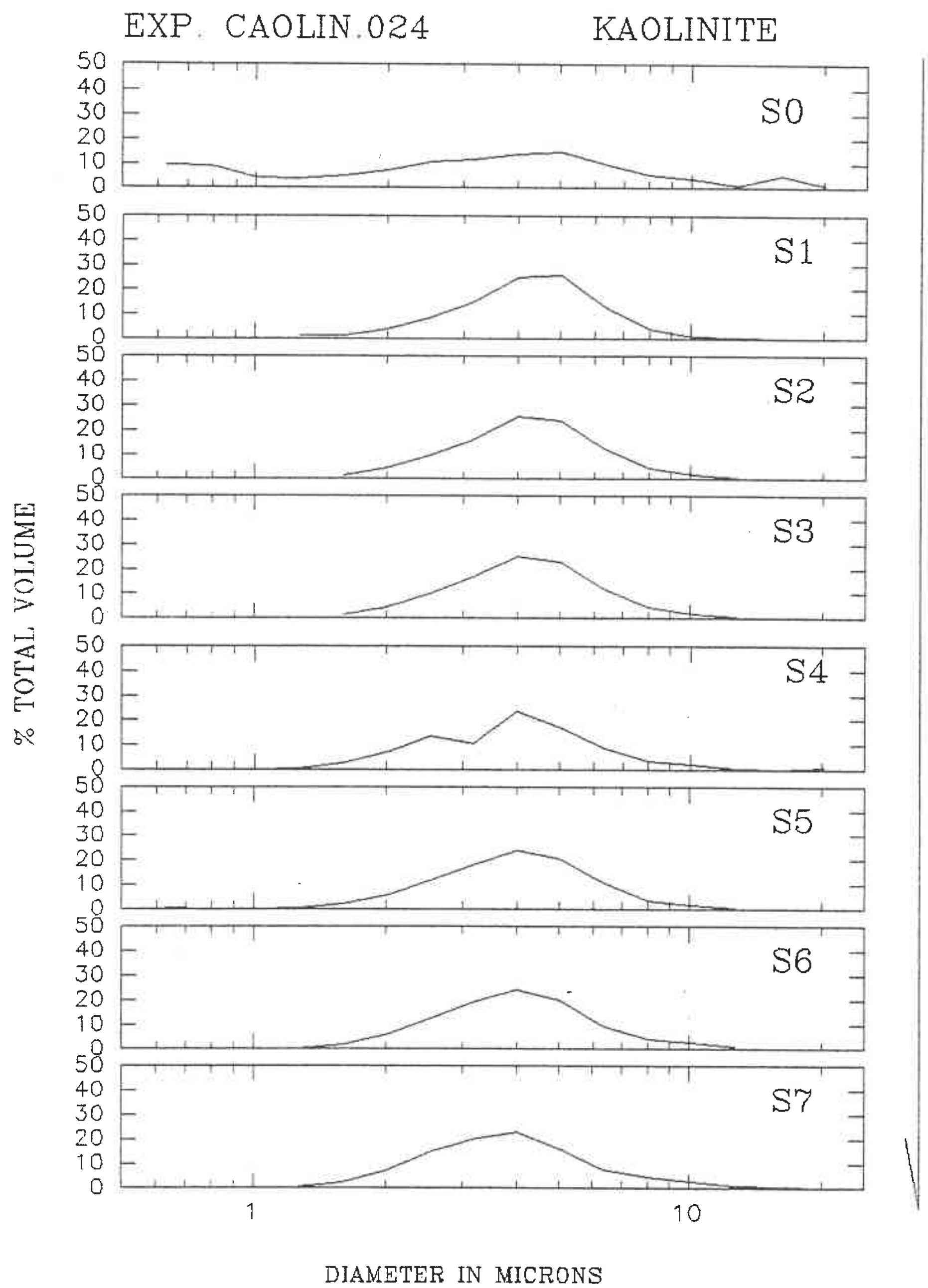


Fig. 4. Grain size distribution in suspended sediment. Each graph corresponds at eroded sediments from supralaying layers. S0 is the environment sample.

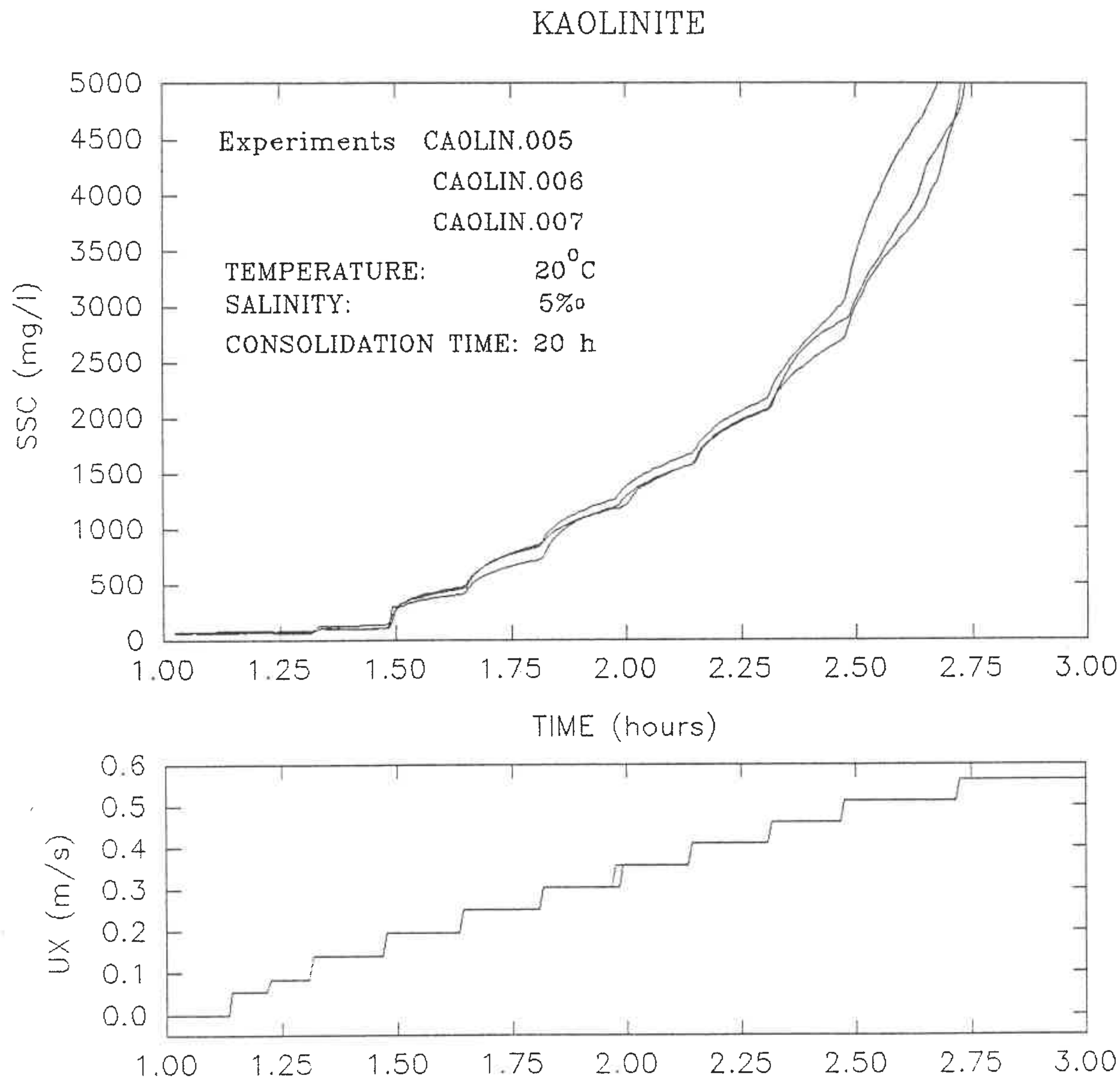


Fig. 5. Experiments to evaluate repeatability.

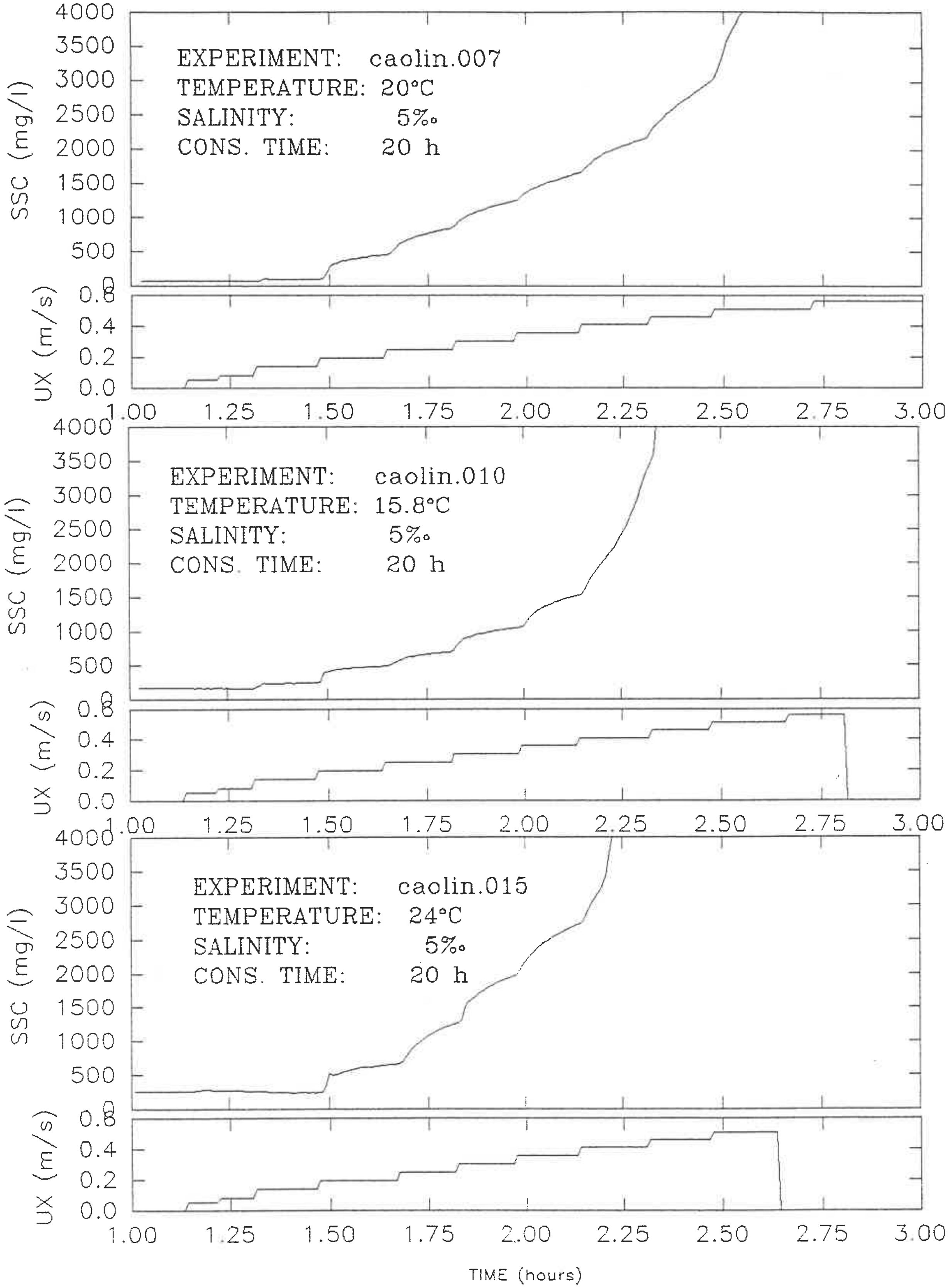


Fig. 6. Experiments with kaolinite changing water temperature and salinity. Same consolidation time.

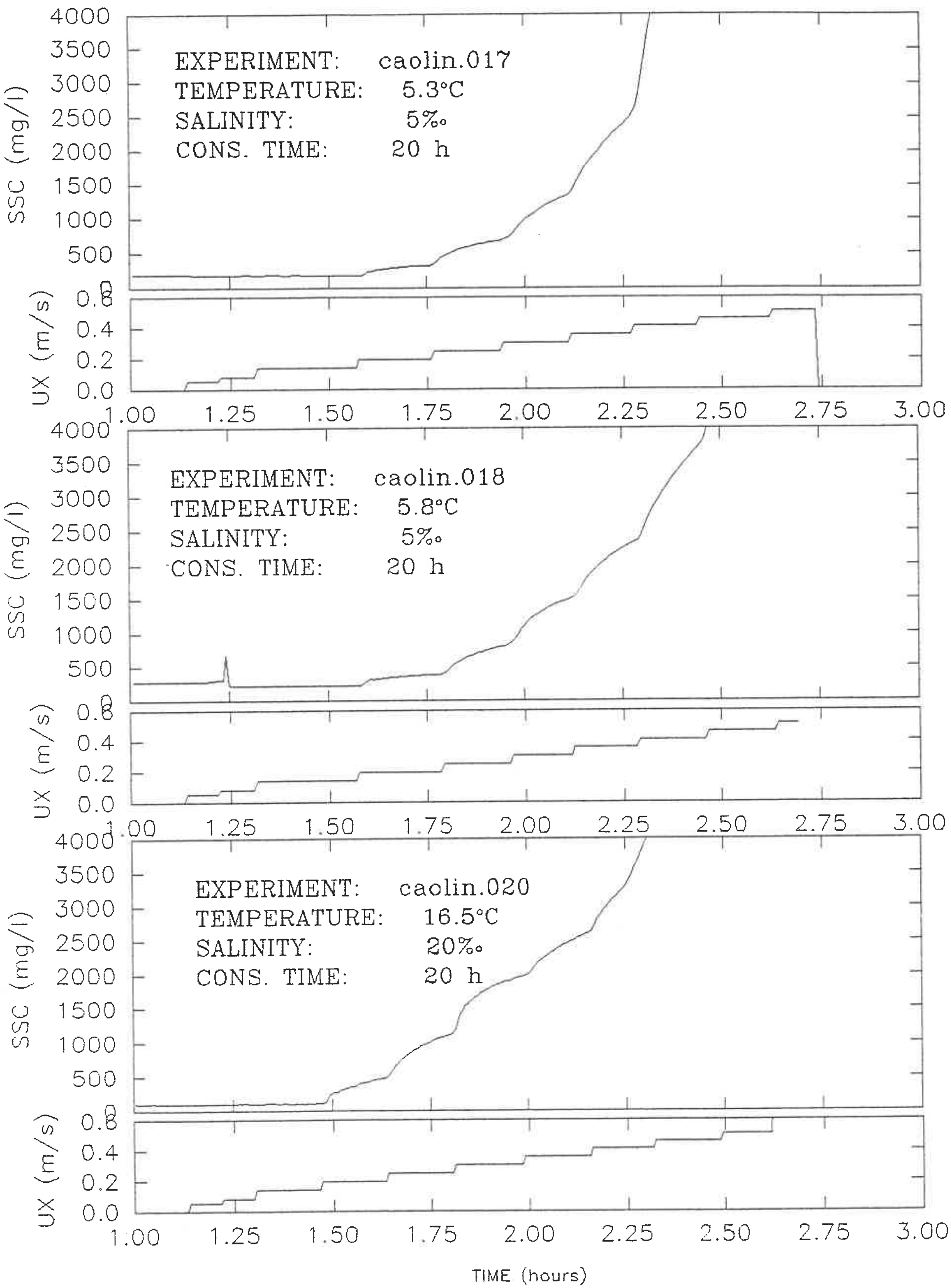


Fig. 7. Experiments with kaolinite changing water temperature and salinity. Same consolidation time.

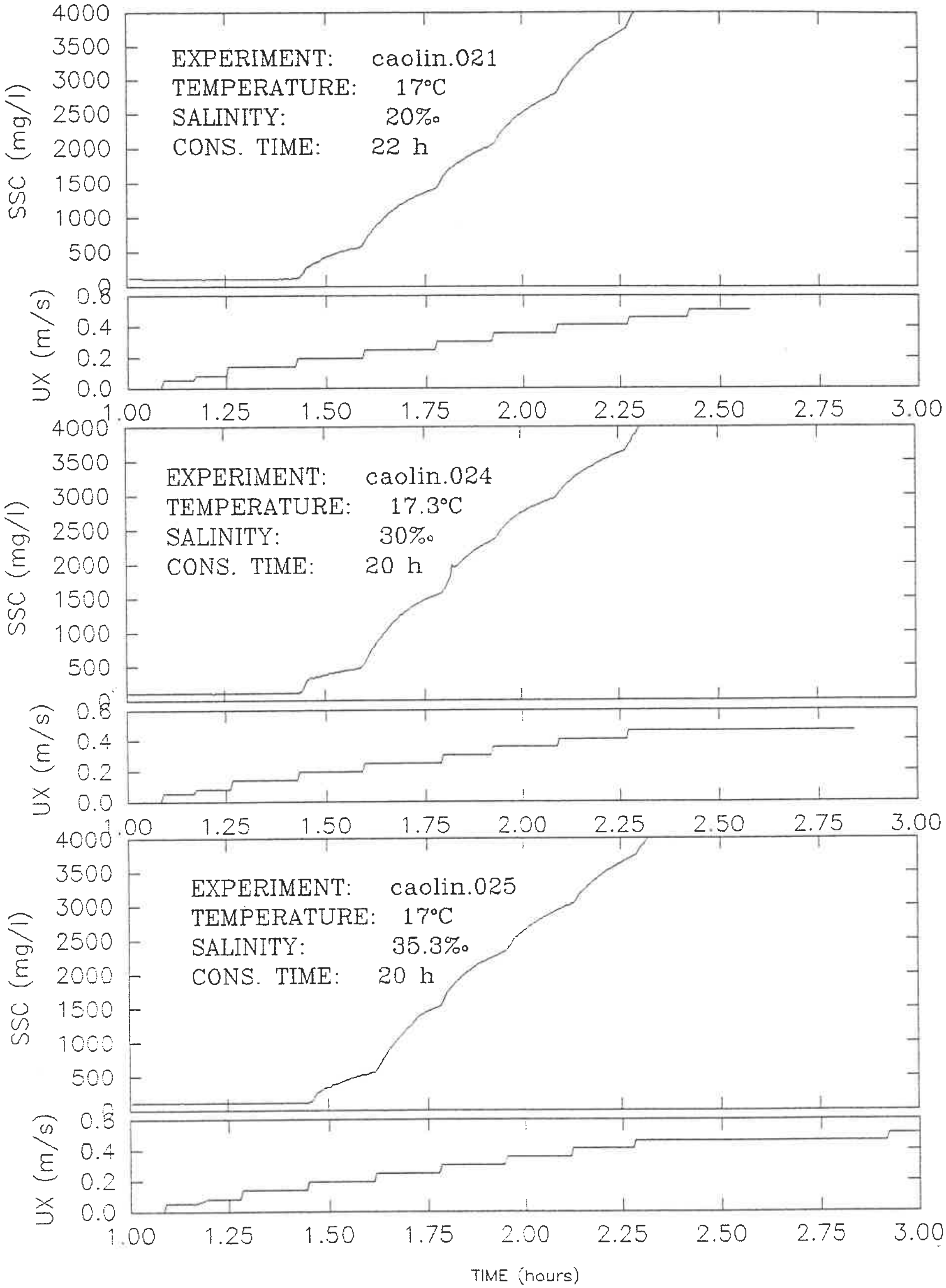


Fig. 8. Experiments with kaolinite changing water temperature and salinity. Same consolidation time.

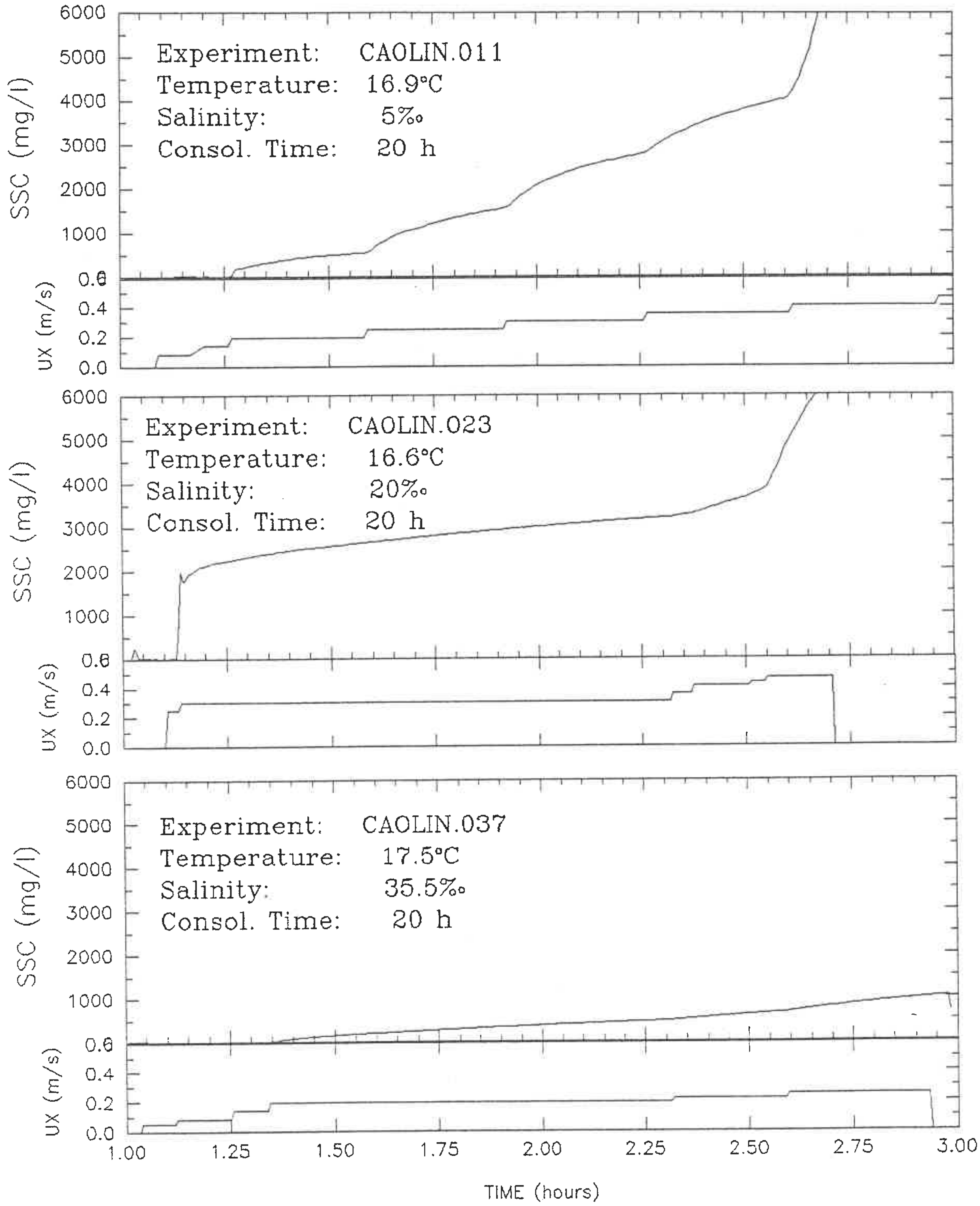


Fig. 9. Erosion rate with different time intervals.

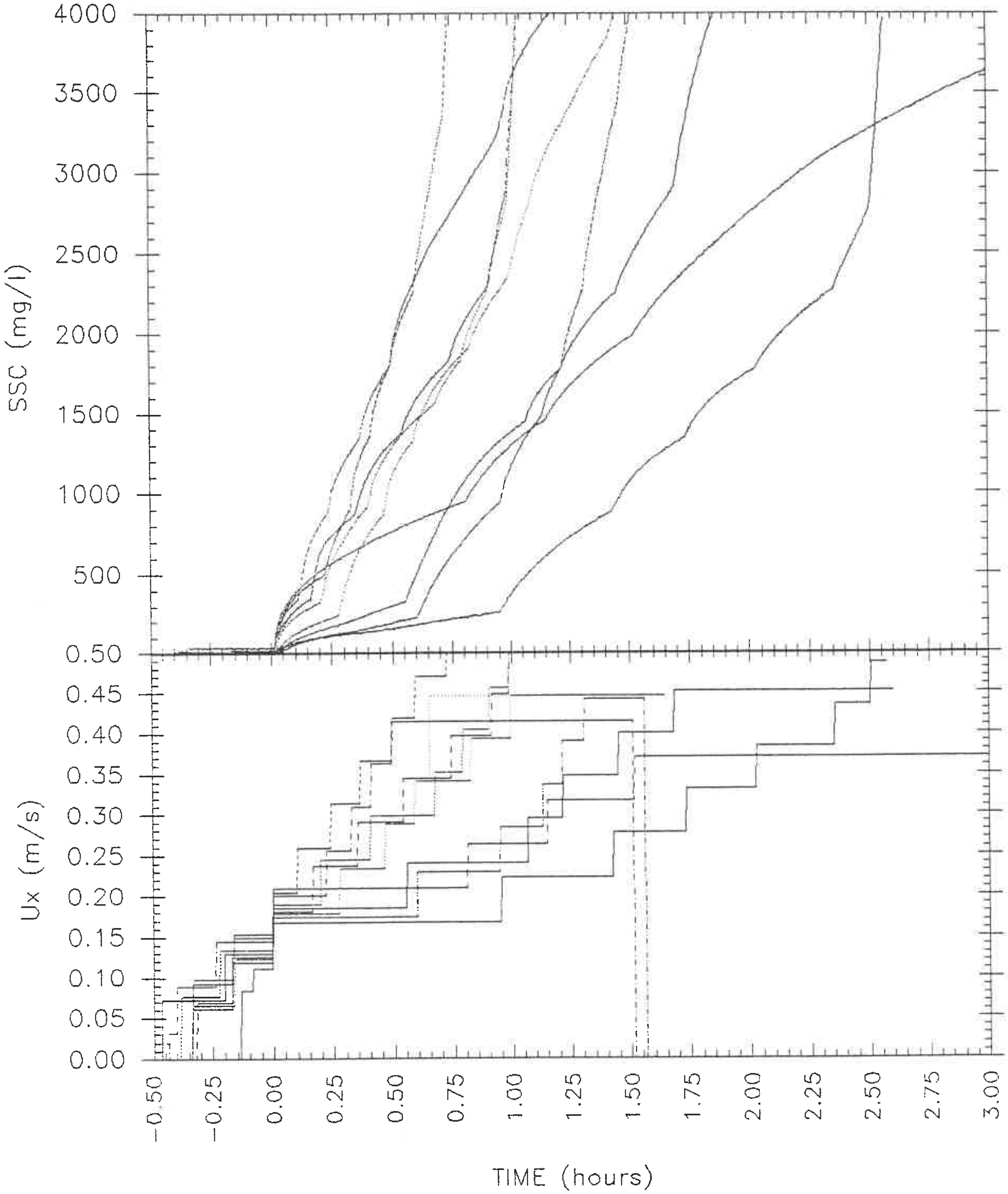


Fig. 10. Time-series for the set of experiments CA2.

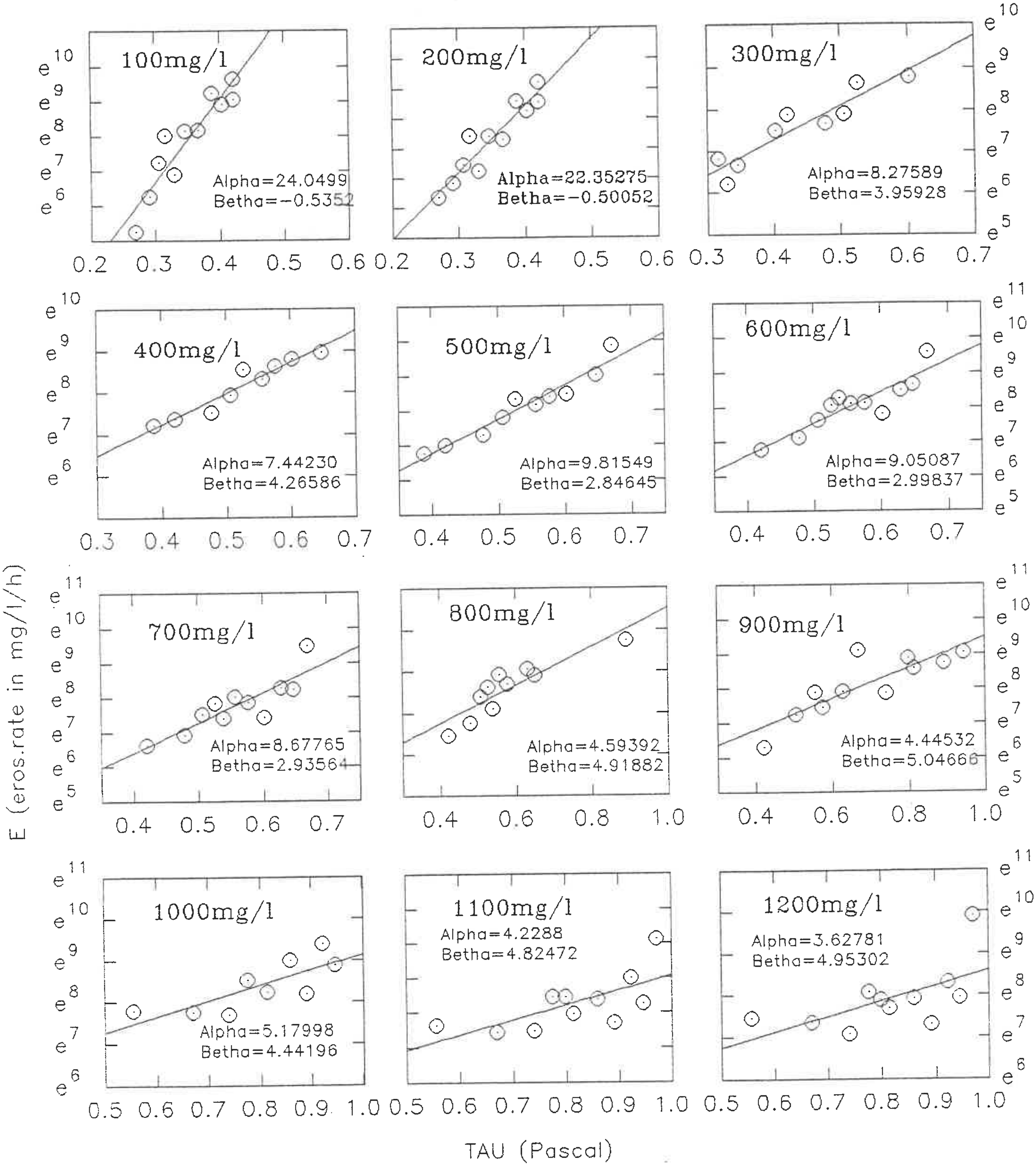


Fig. 11. Relationships between erosion rate and shear stress for the experiments from serie CA2.

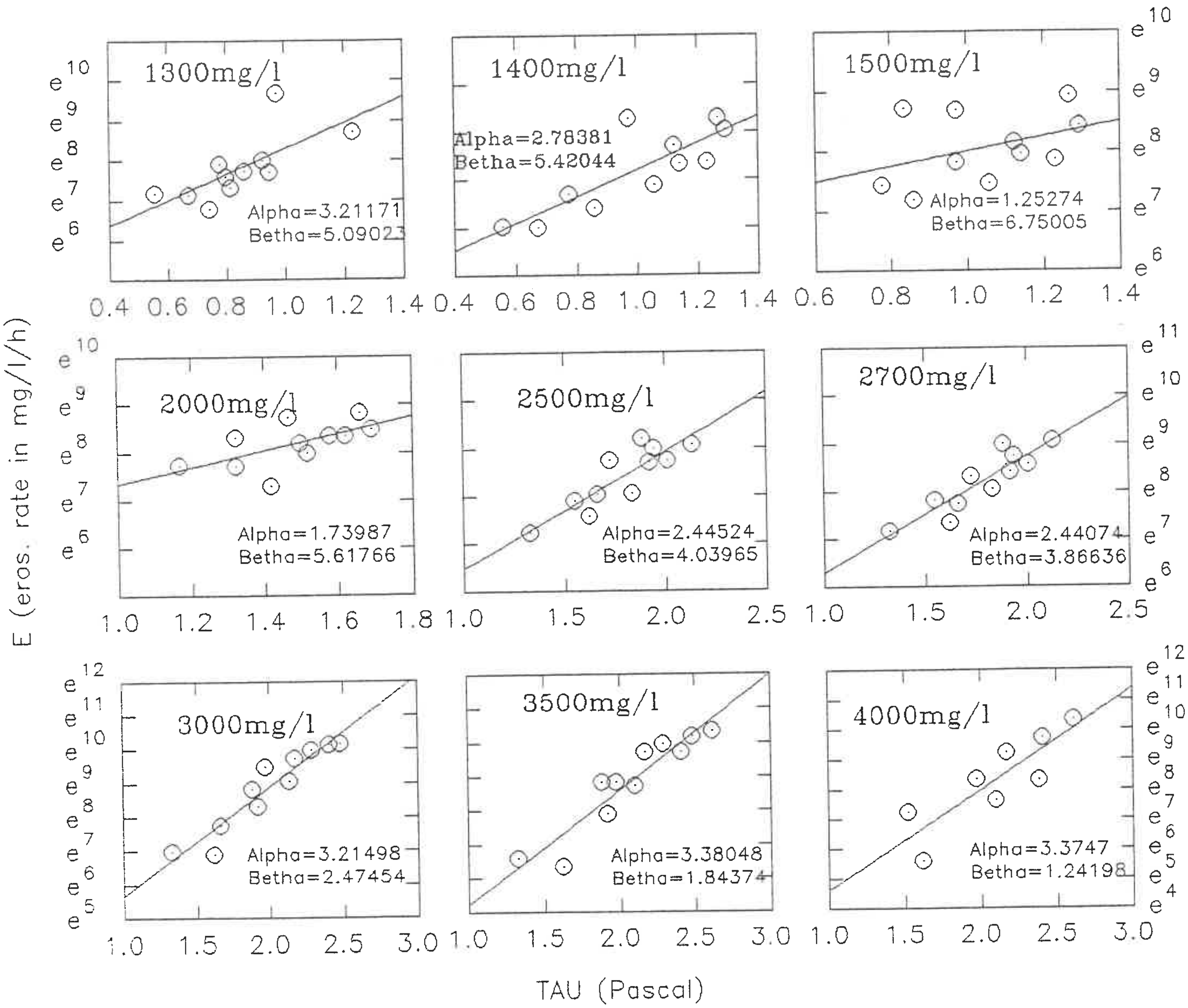


Fig. 12. Relationships between erosion rate and shear stress for the experiments from serie CA2.

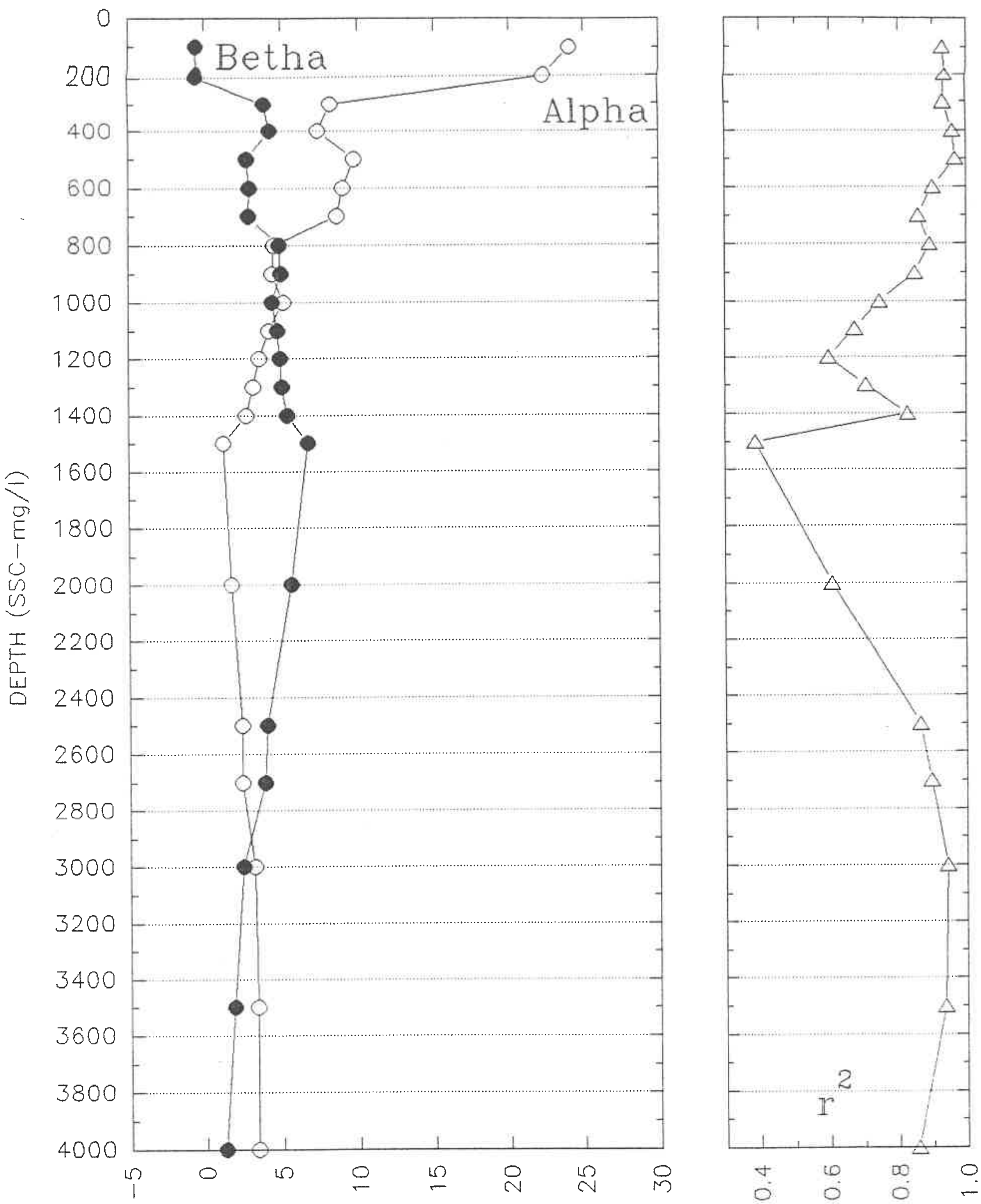


Fig. 13. Variation of Alpha and Betha values with sediment depth for experimental serie CA2 (kaolinite). Sediment bed depth 19 mm, Consolidation time: 20 h, water temperature between 18 and 22.9 °C, salinity 30‰.

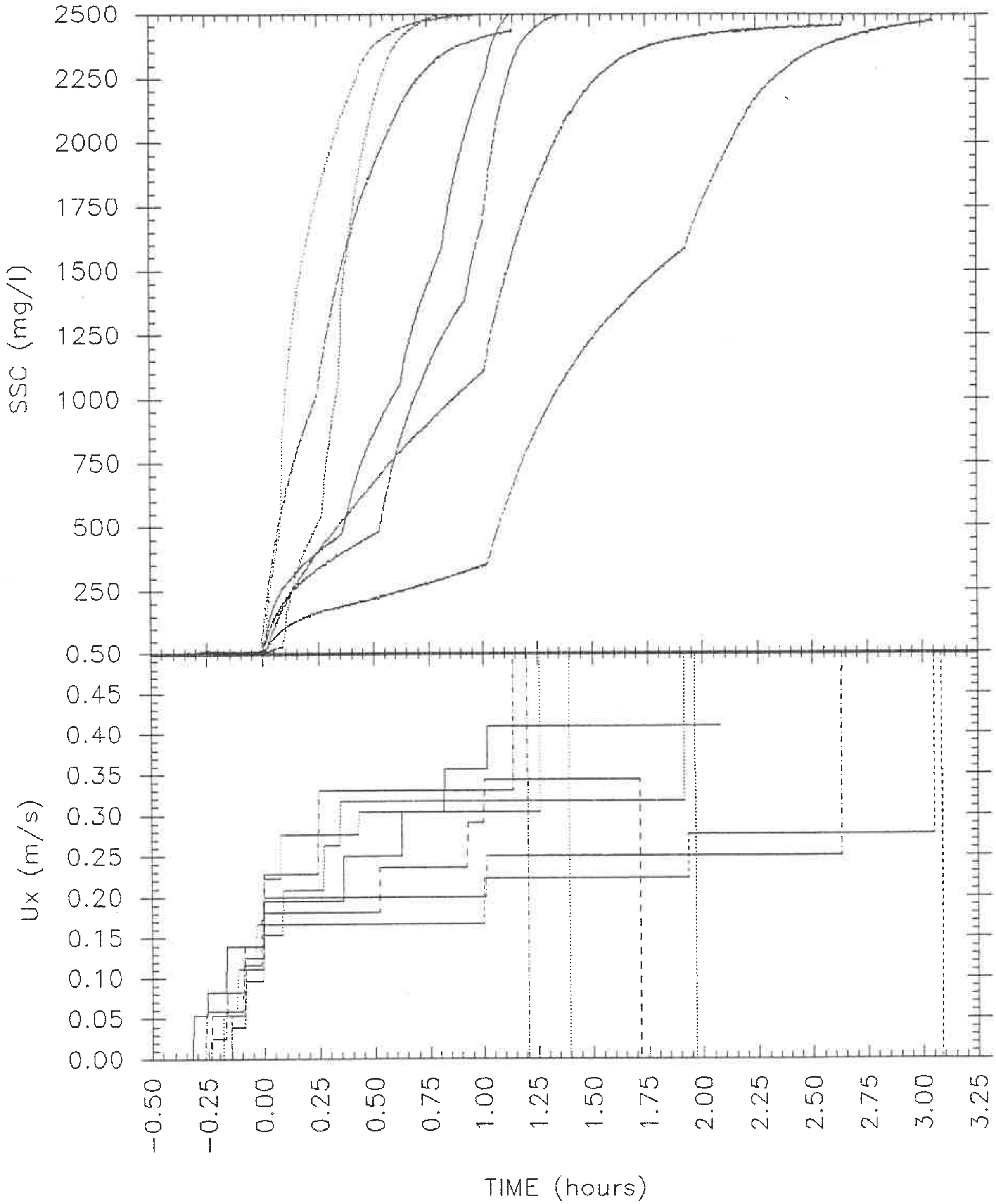


Fig. 14. Time–series for the set of experiments CA3.

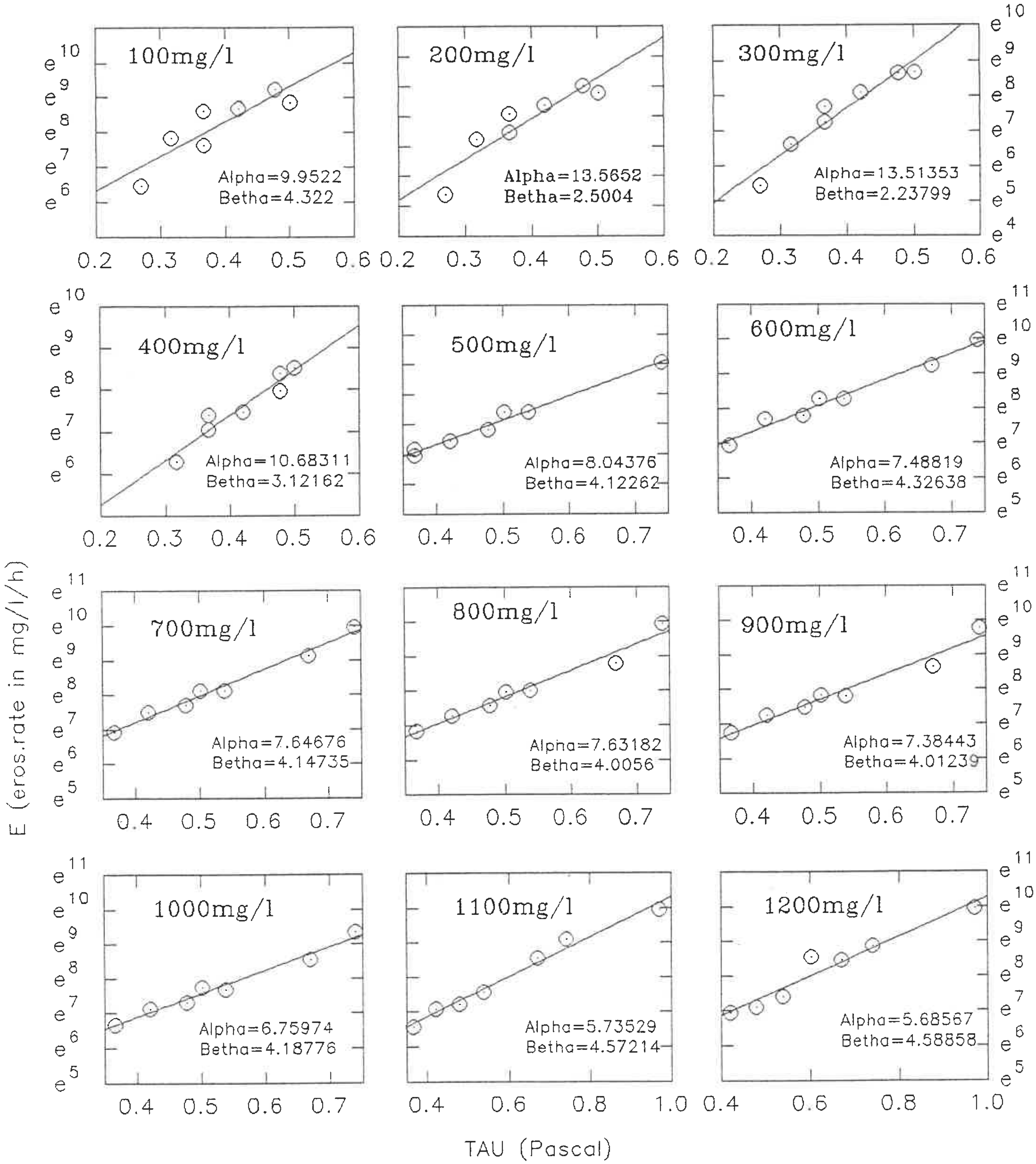


Fig. 15. Relationships between erosion rate and shear stress for the experiments from serie CA3.

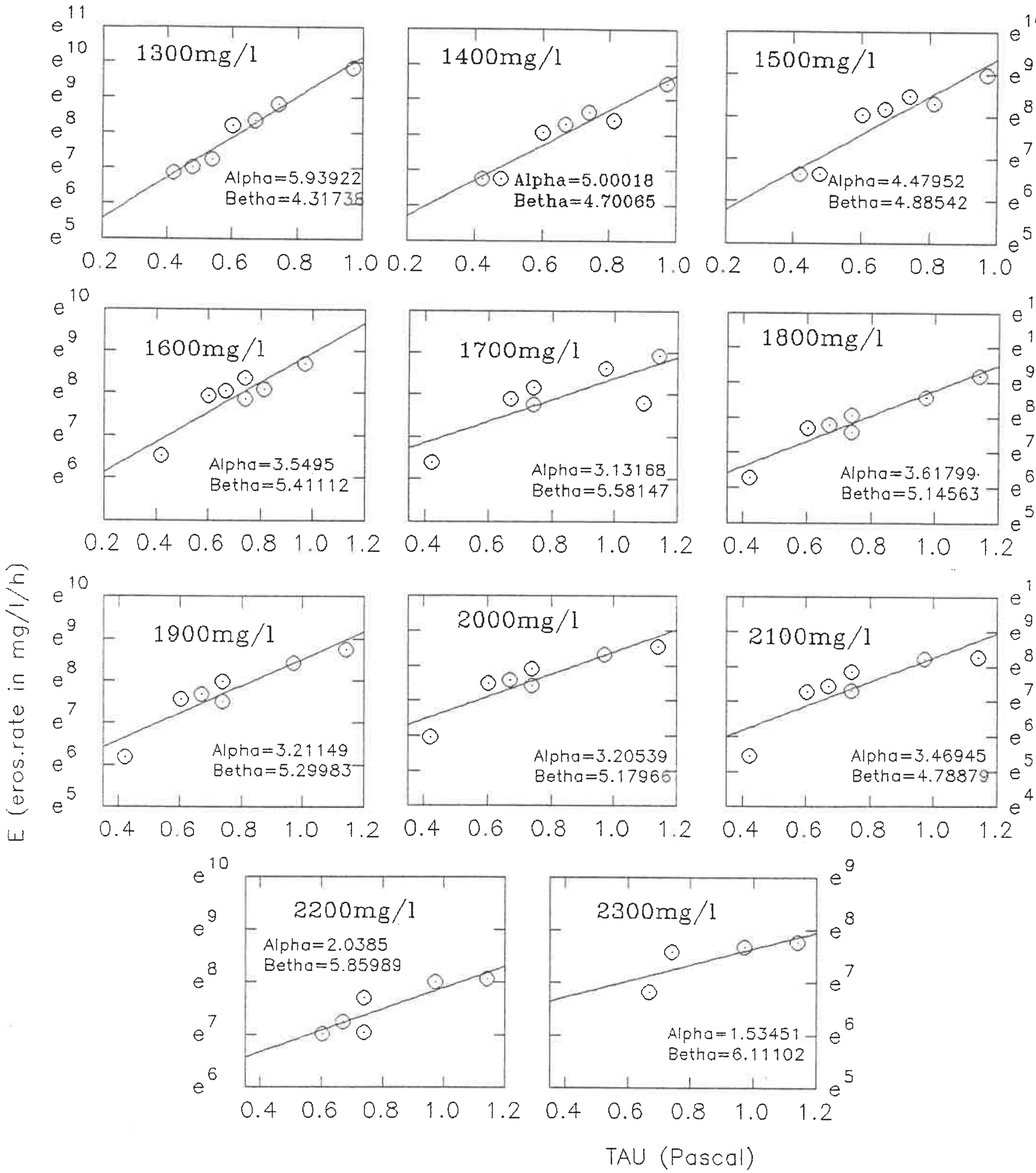


Fig. 16. Relationships between erosion rate and shear stress for the experiments from serie CA3.

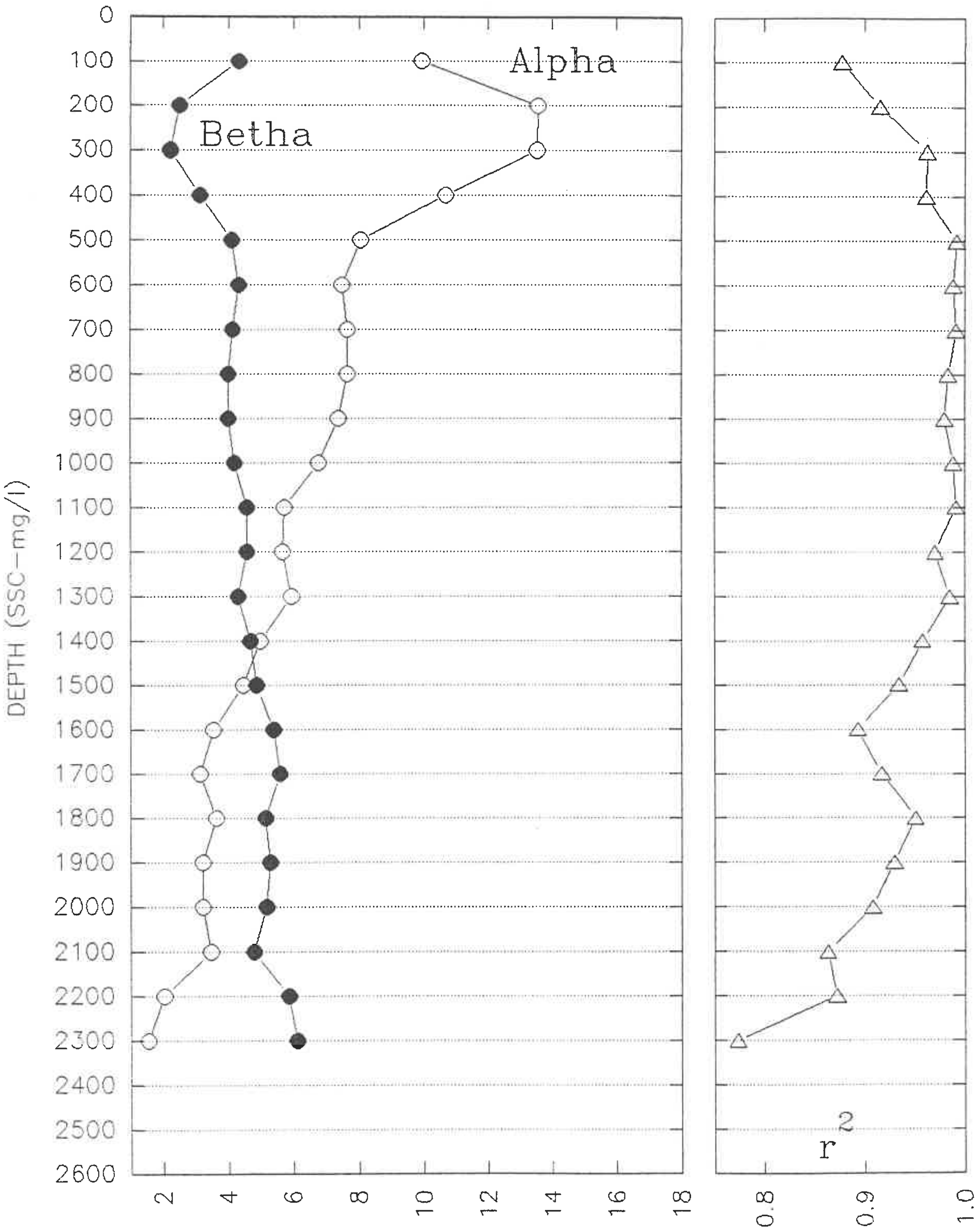


Fig. 17. Variation of Alpha and Betha values with sediment depth for serie CA3 (kaolinite). Sediment bed depth 2 mm, consolidation time 20 h, water temperature between 21 and 17 °C, salinity 30‰.

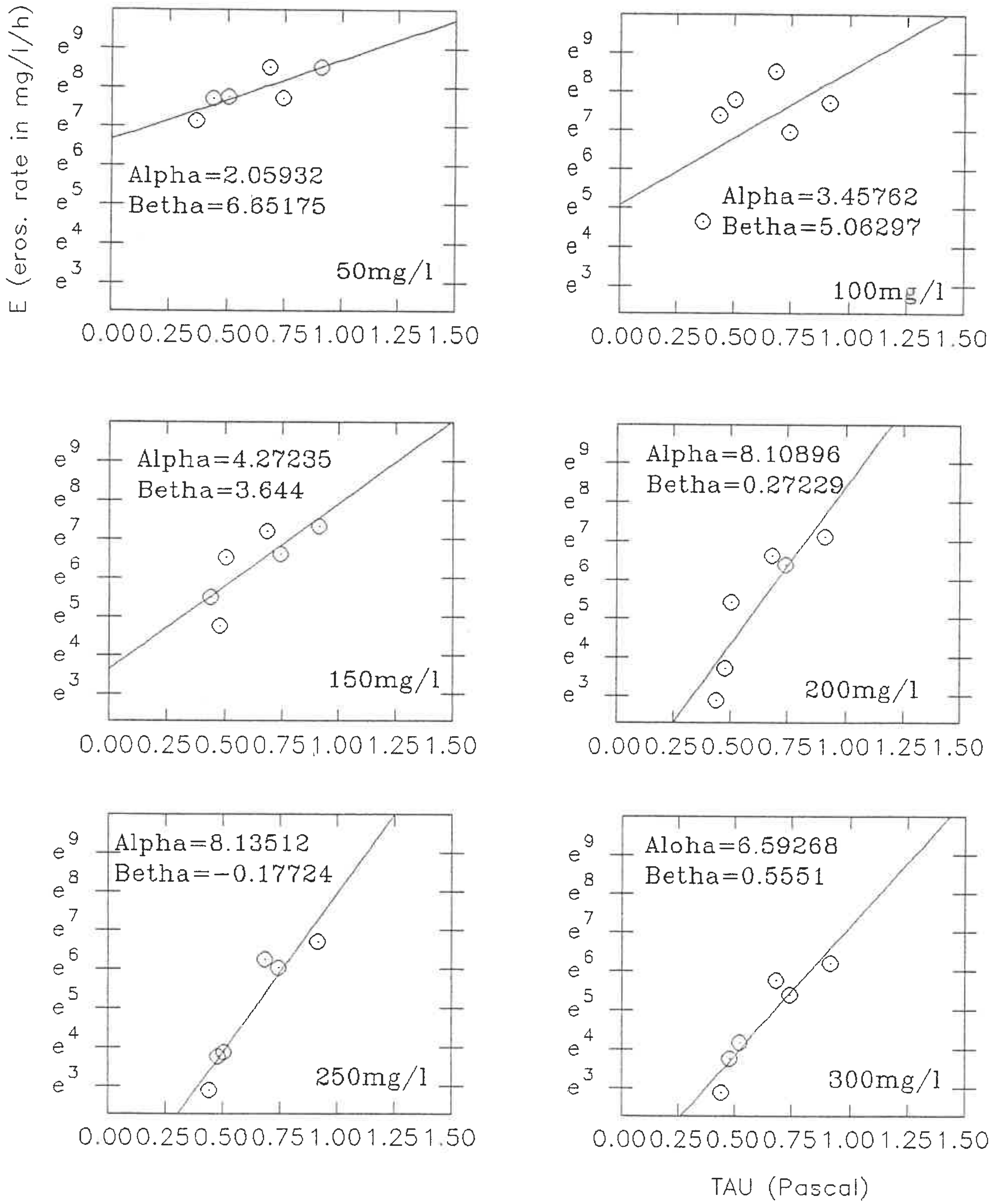


Fig. 18. Relationships between erosion rate and shear stress for the set of experiments NATAU.(natural sediment).

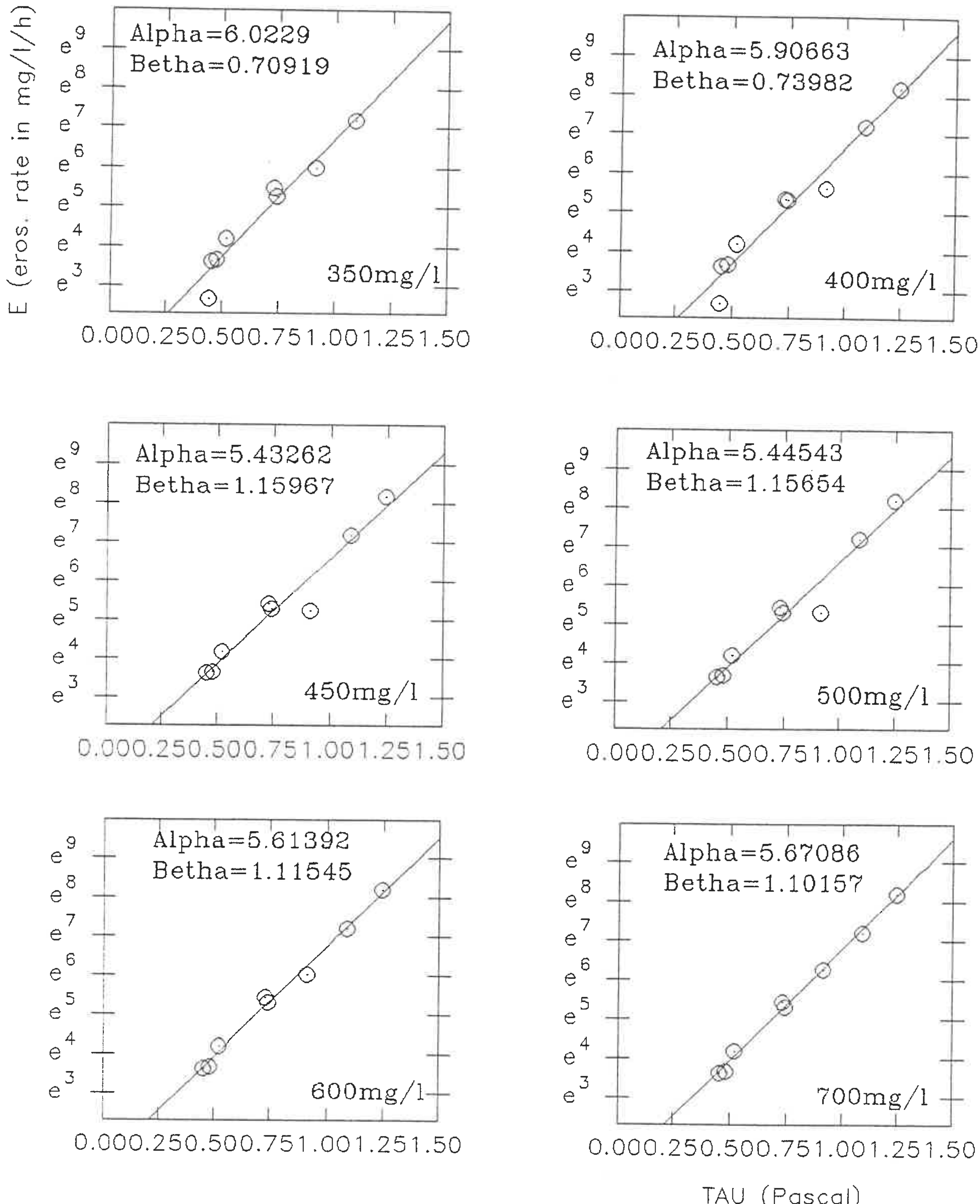


Fig. 19. Relationships between erosion rate and shear stress for the set of experiments NATAU (natural sediment).

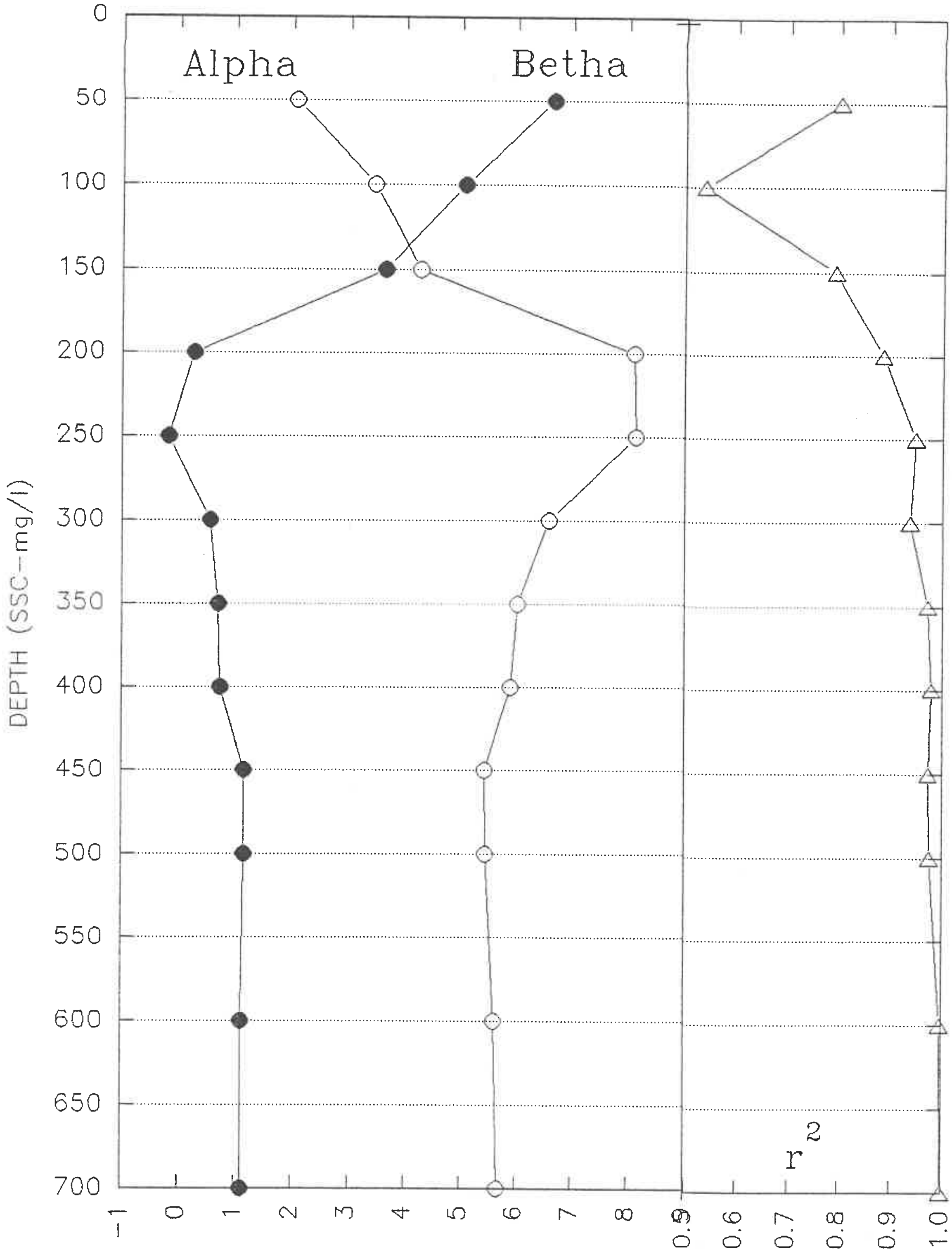


Fig. 20. Variation of Alpha and Betha values with sediment depth for experiments NATAU (natural sediment). Sediment bed 3 mm, Consolidation time: 44 h, water temperature between 18.5 and 17.3 °C, Salinity : 30‰.

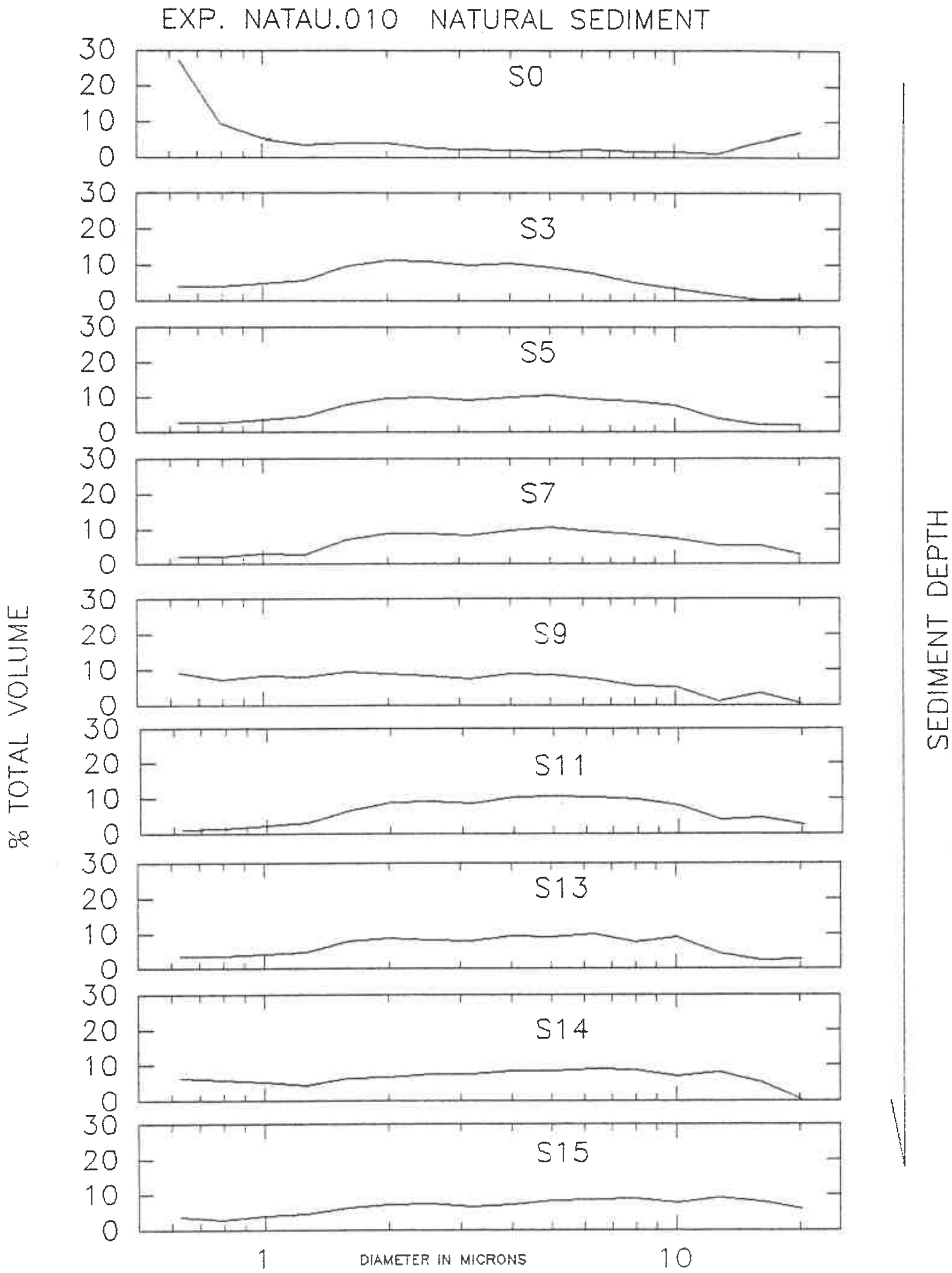


Fig. 21. Grain size distribution in suspended sediment. Each graph corresponds at different eroded depths. S0 is the environment sample.

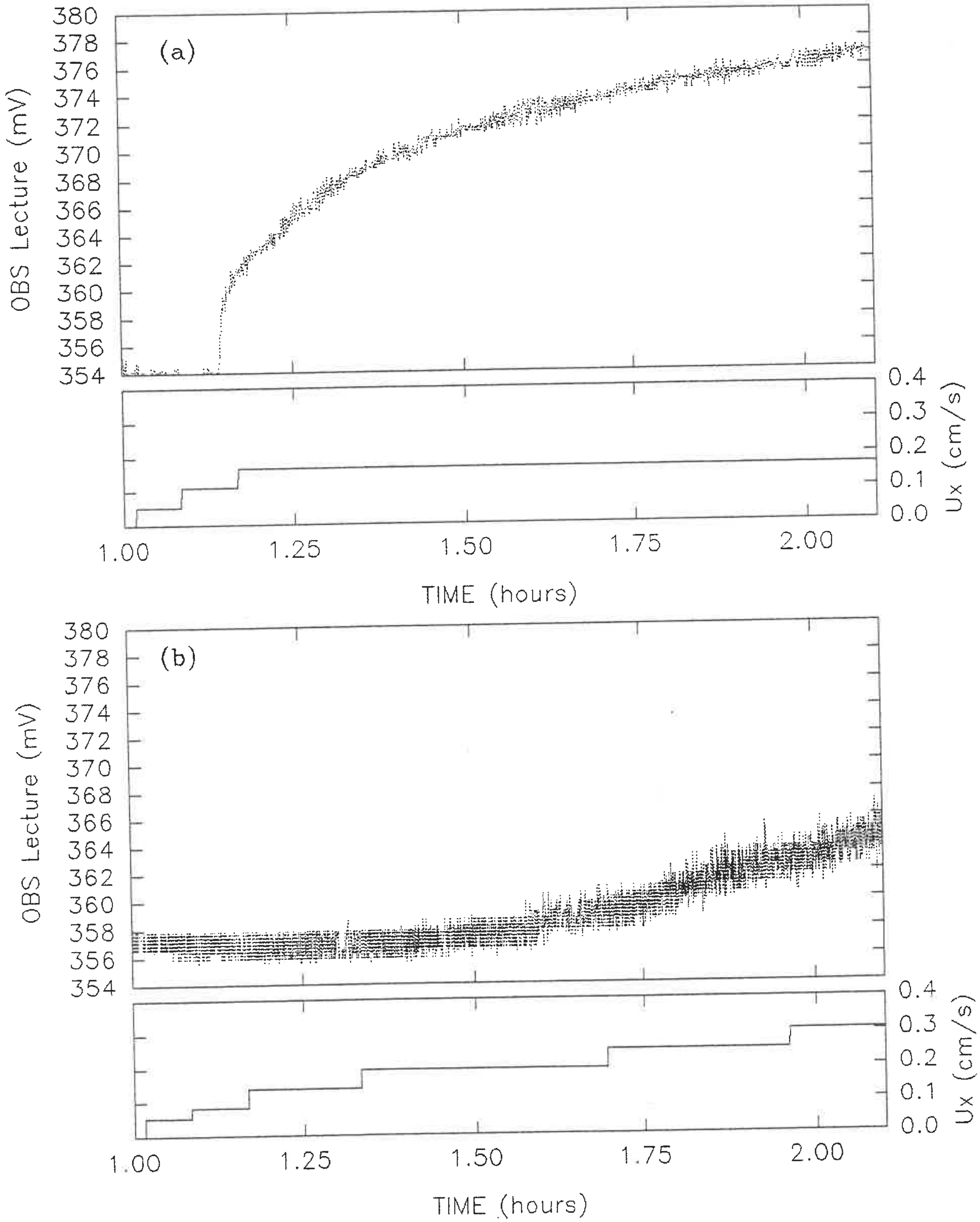


Fig. 22. Deviation in OBS lectures in experiments done with natural sediments: a) inorganic, b) abiotic with organic. 1 second interval time for plotting. Data not averaged.

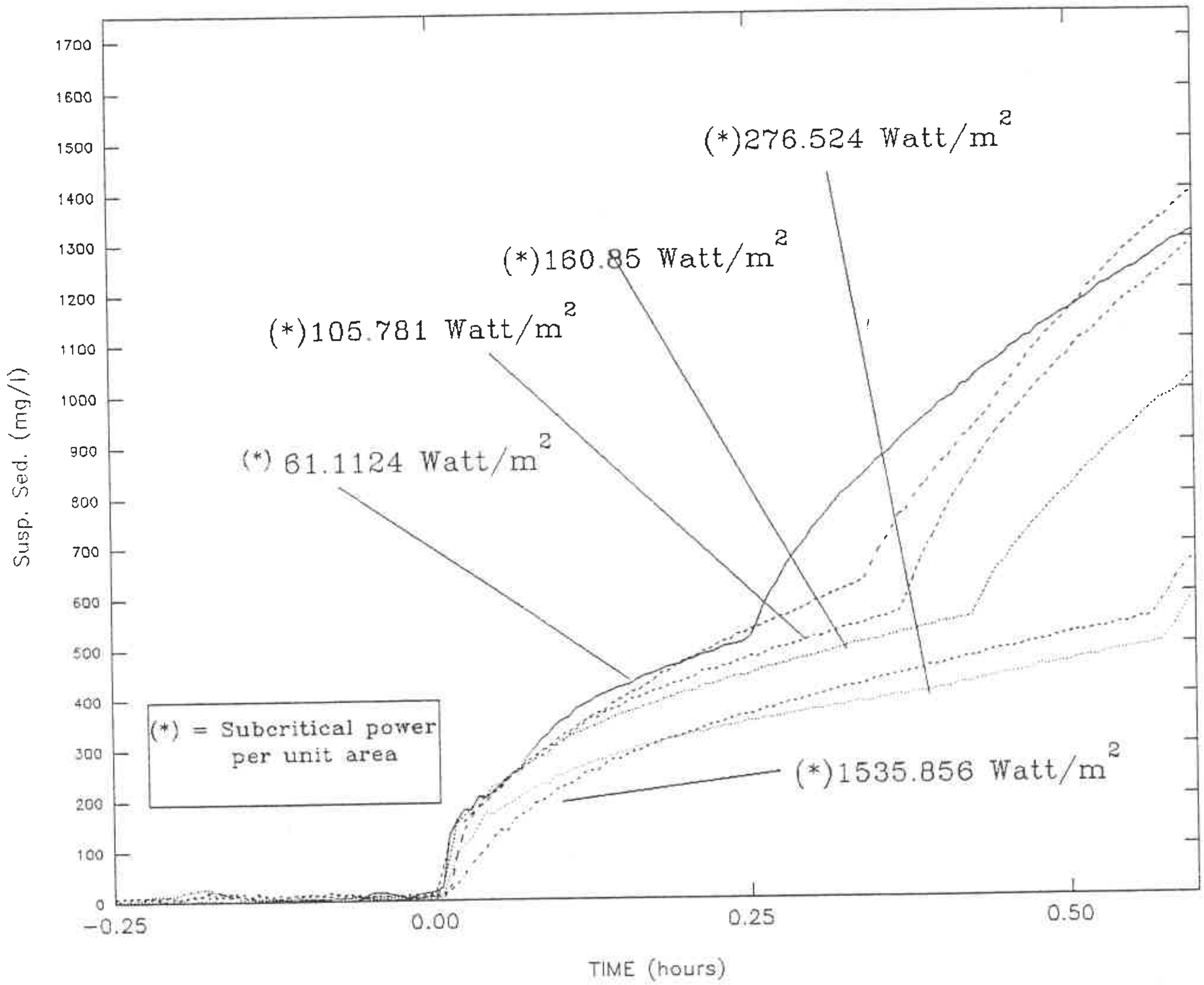


Fig. 23. Variation of erosion rate related with subcritical power. The subcritical power is calculated by the summatory of the subcritical applied TAU times the application time.

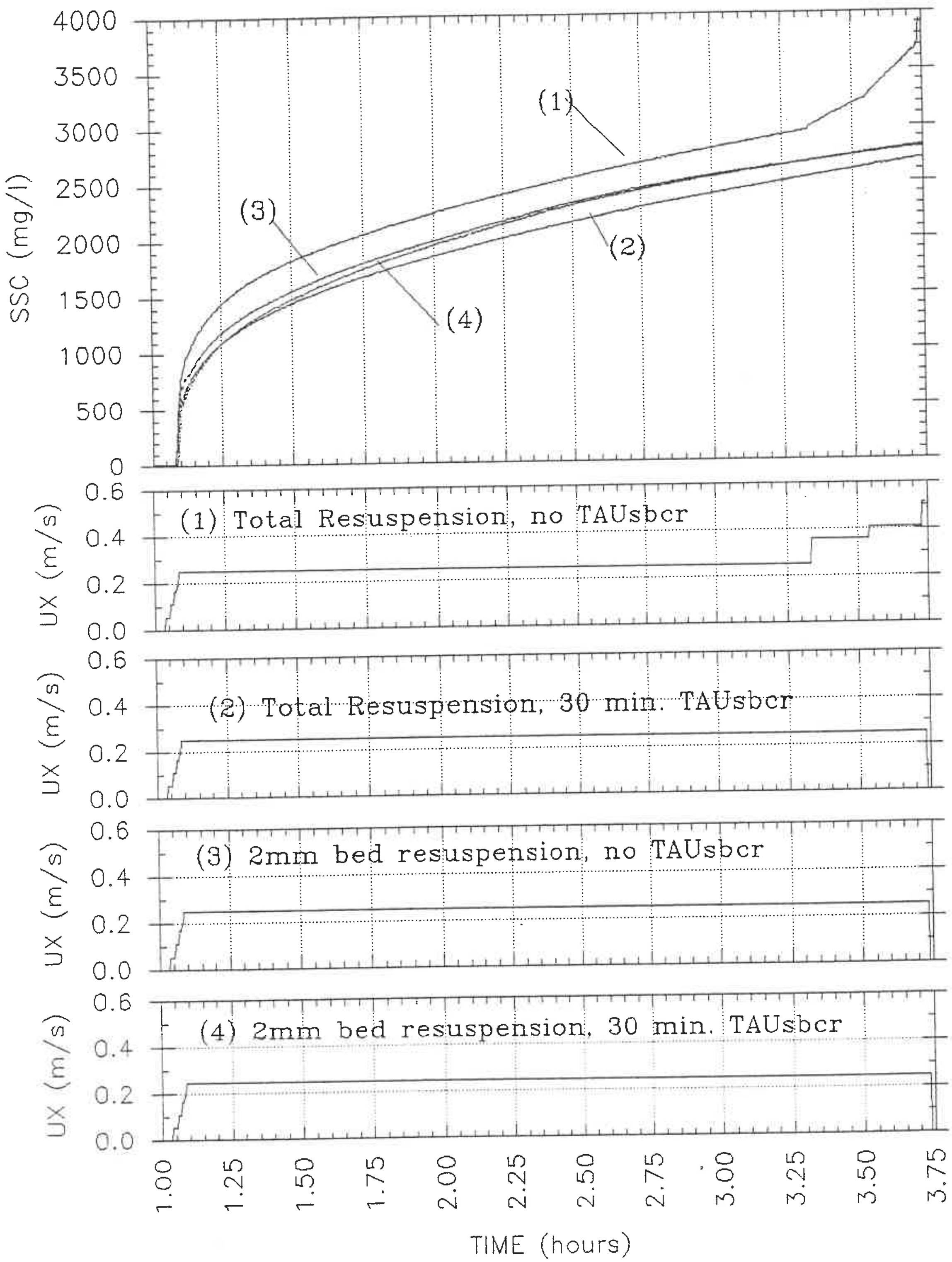


Fig. 24. Dewatering effect on compaction caused by subcritical currents.

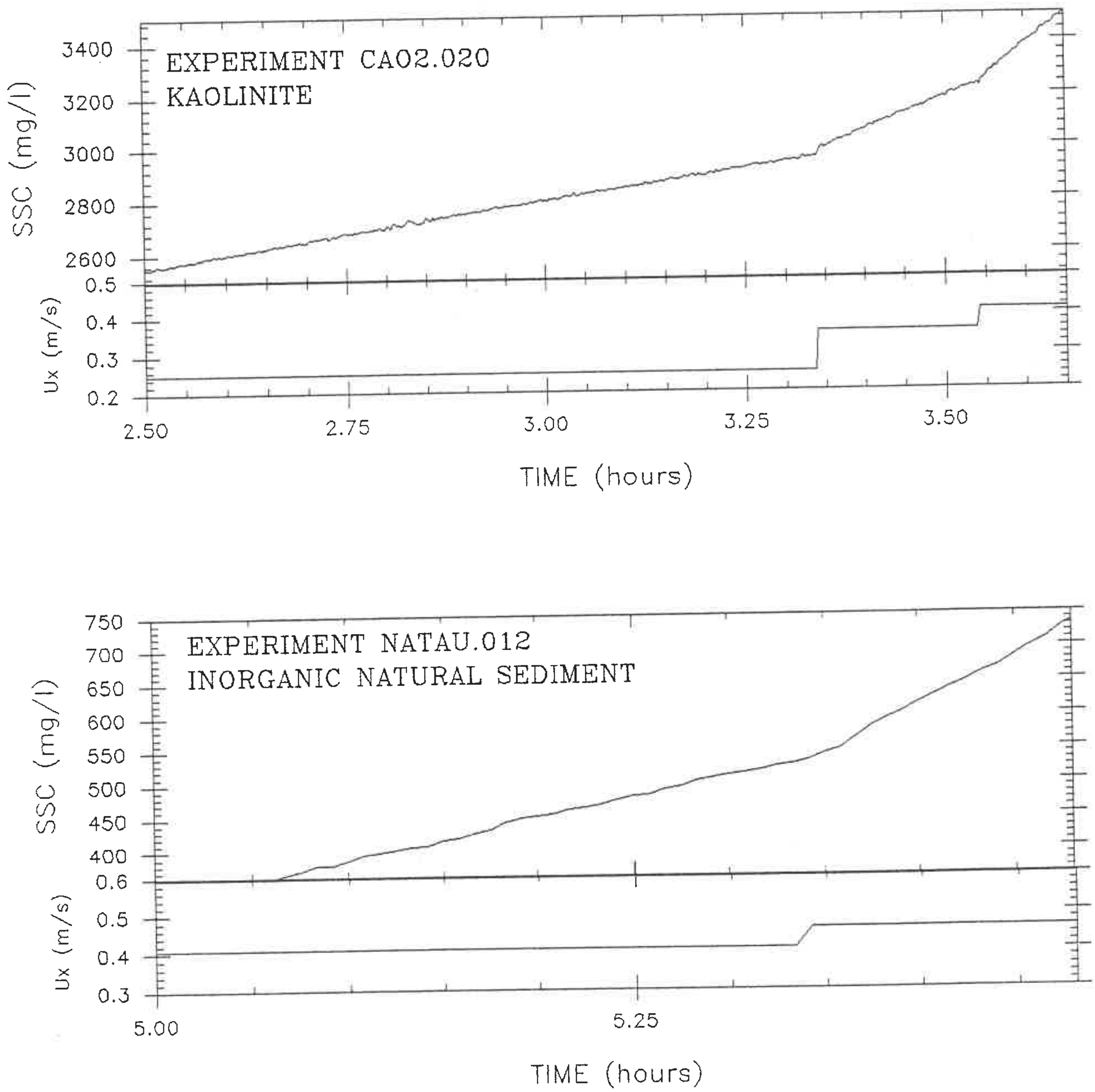
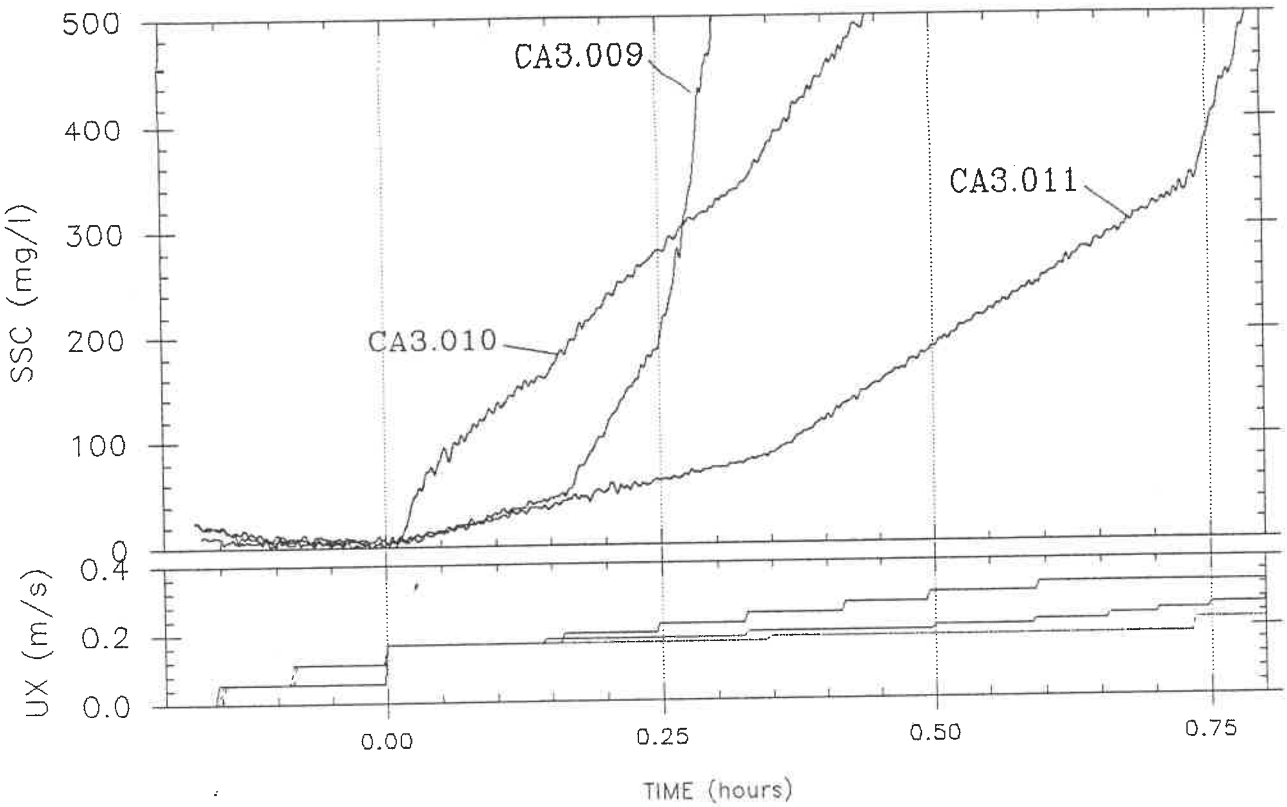


Fig. 25. Examples of constant erodability with depth (Profile Type II). The continuity in the linear trend after the change of Ux, shows no change in erosion rate produced by turbulences.



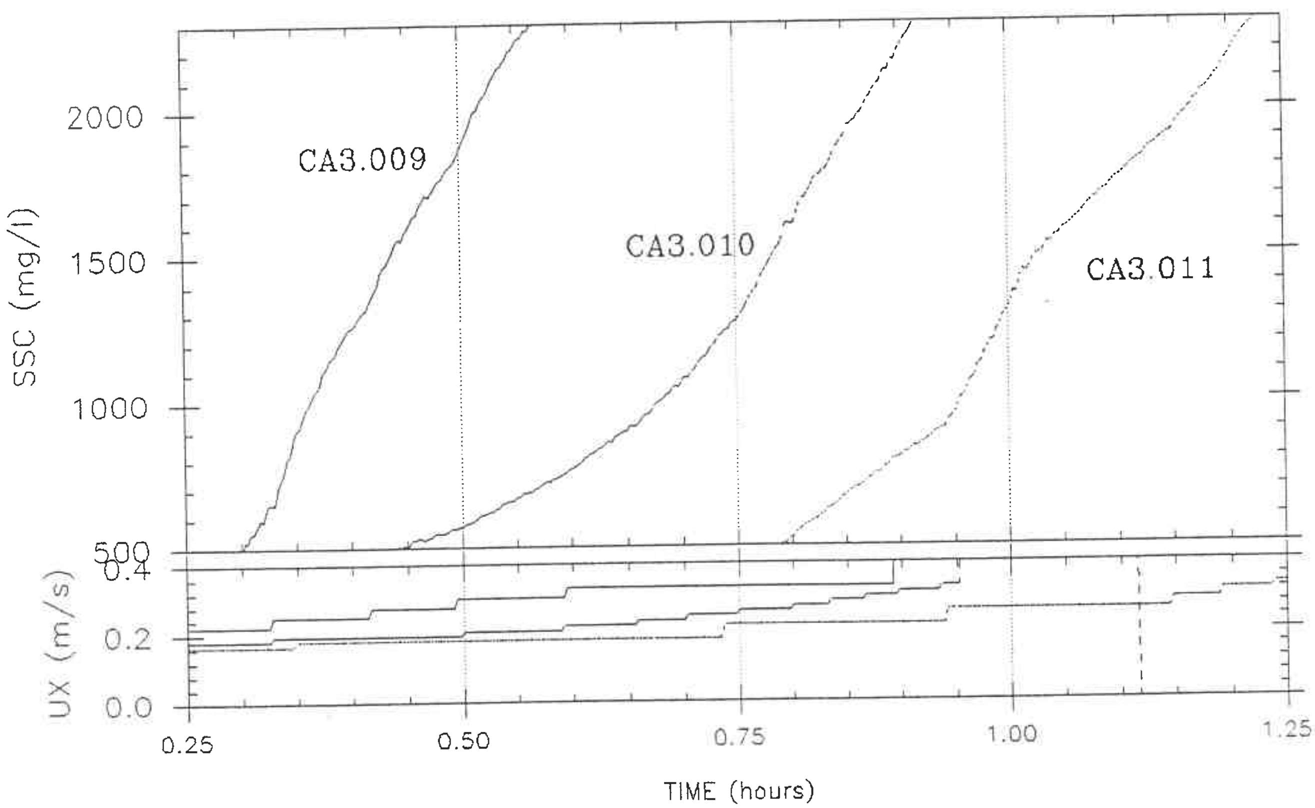


Fig. 26.. Experiments CA3.009, CA3.010 and CA3.011. In CA3.010 no pre-erosional currents were applied before the beginning of the experiment.

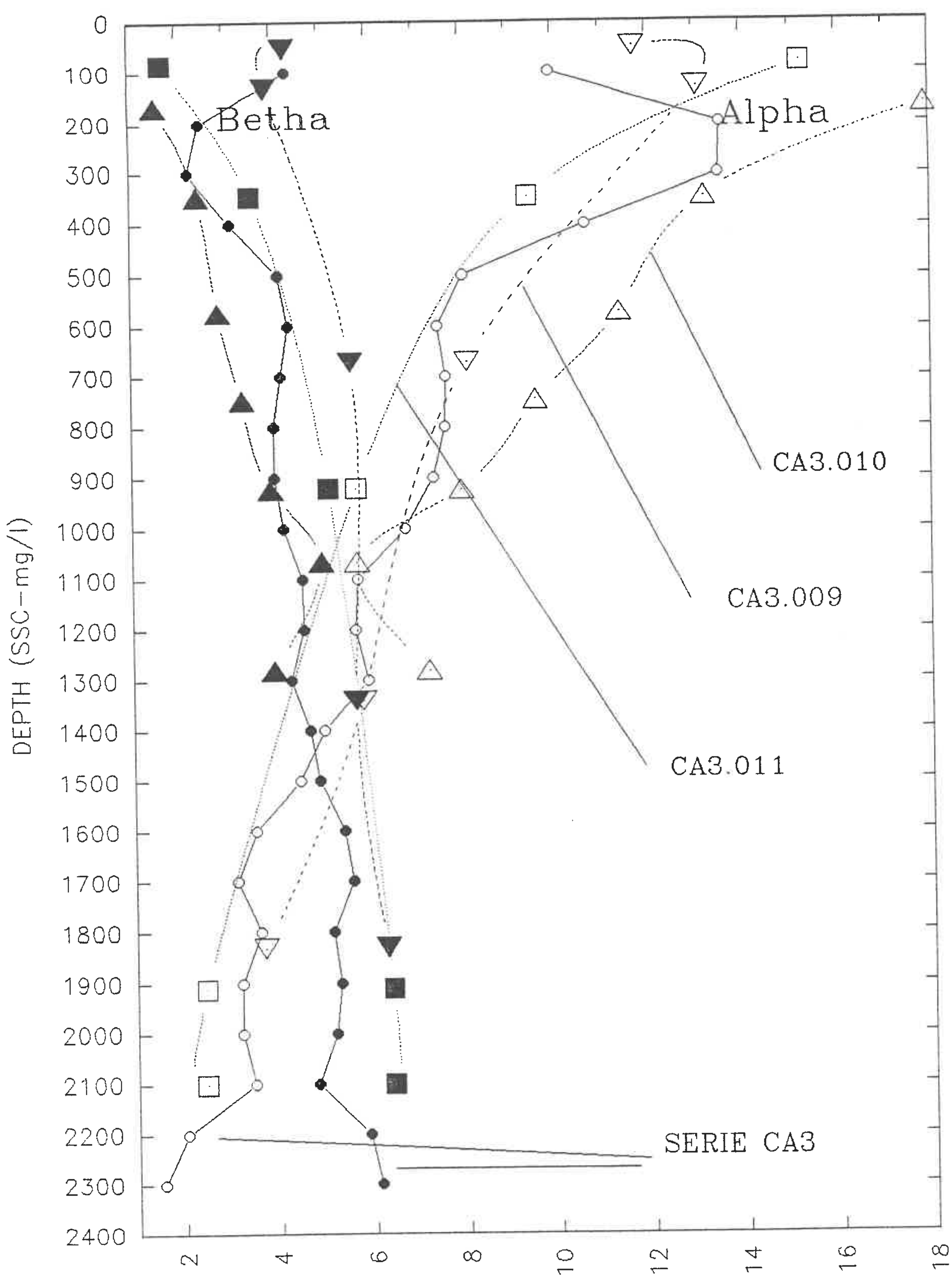


Fig. 27. Comparition between Alpfa and Betha from serie CA3, and the values obtained from experiments CA3.009, CA3.010 and CA3011. The values for CA3.009 and CA3.011 are very close to those from serie CA3. Superficial layers in CA3.010 are more erodible.

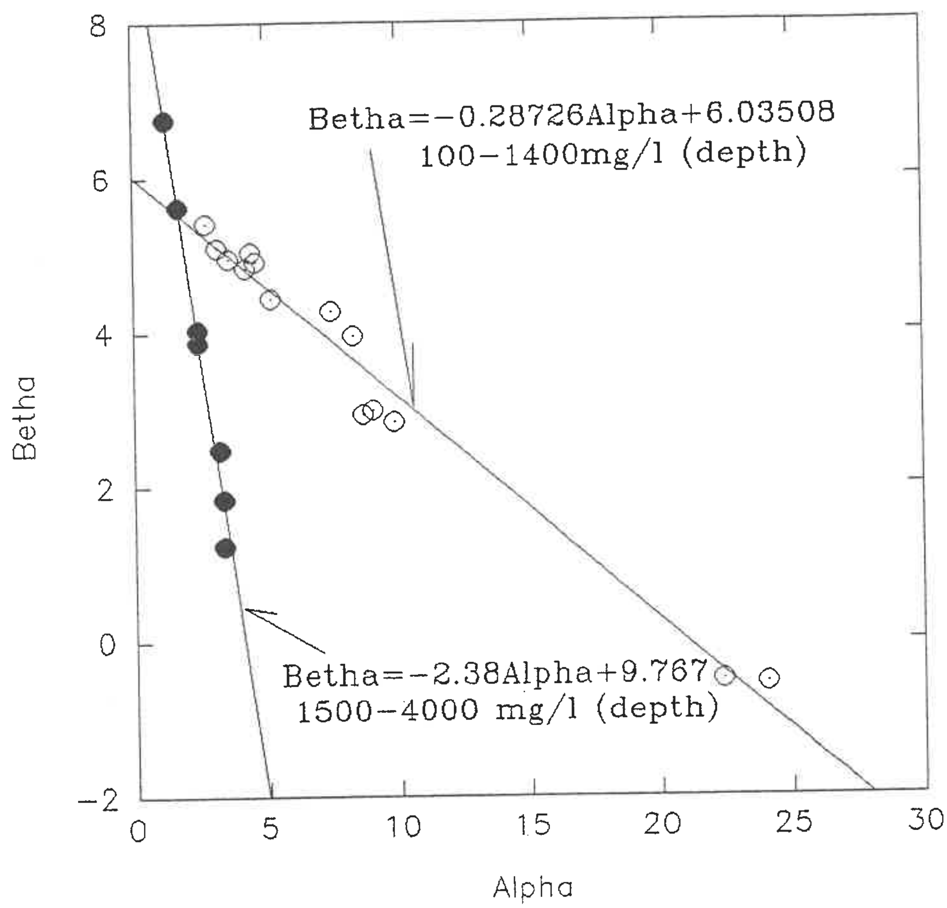


Fig. 28. Relationship between Alpha and Betha for experimental serie CA2 (kaolinite). The high steep at depths greater than 1400 mg/l could be related to a change in flow characteristics. Notice that the relationship between Alpha and Betha for depths lower than 1400 mg/l is almost identical to that obtained for serie CA3.

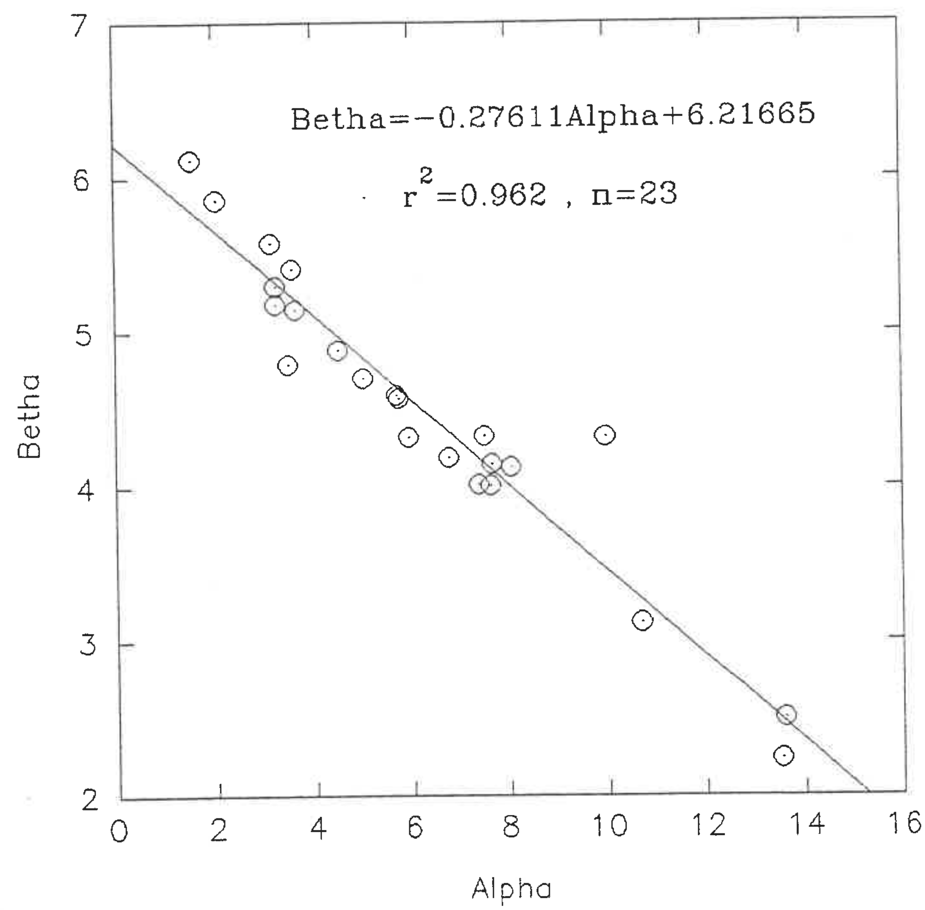


Fig. 29. Relationship between Alpha and Betha for serie CA3 (kaolinite).

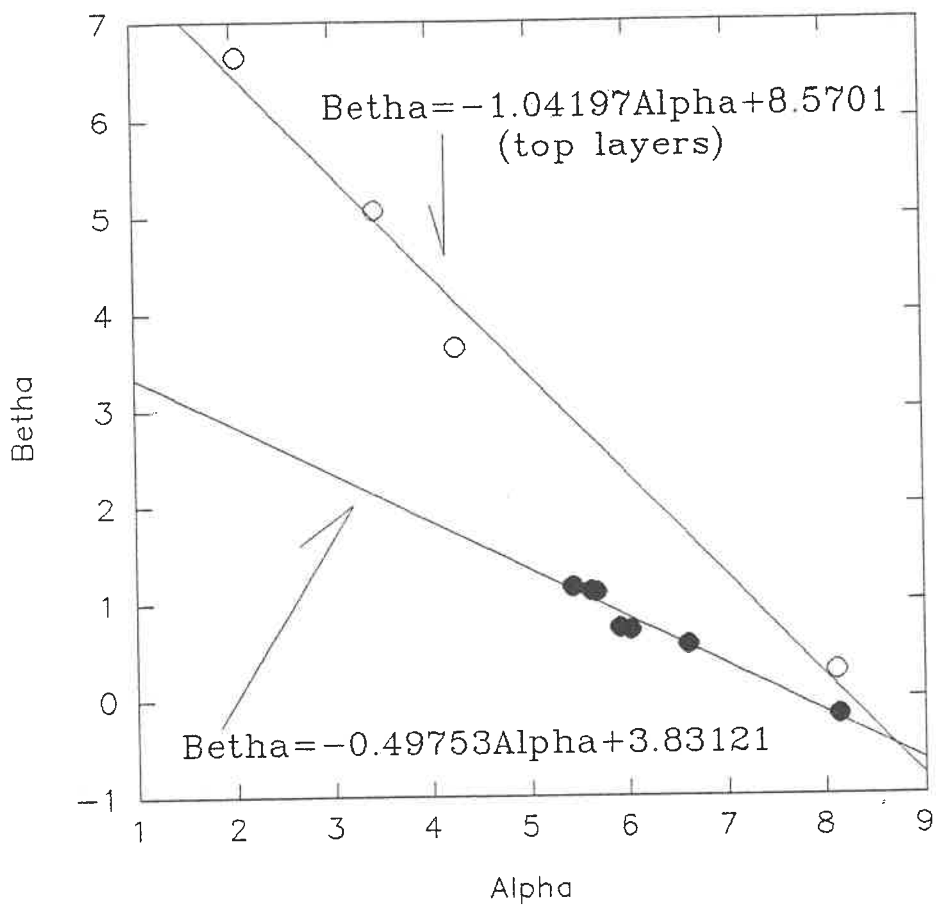


Fig. 30. Relationship between Alpha and Betha for experimental serie NATAU (natural sediment). The diferences between top layers (white circles) and down layers (black circles) are probably related with a low correlation between erosion rate and shear stress for depths lower than 250 mg/l.

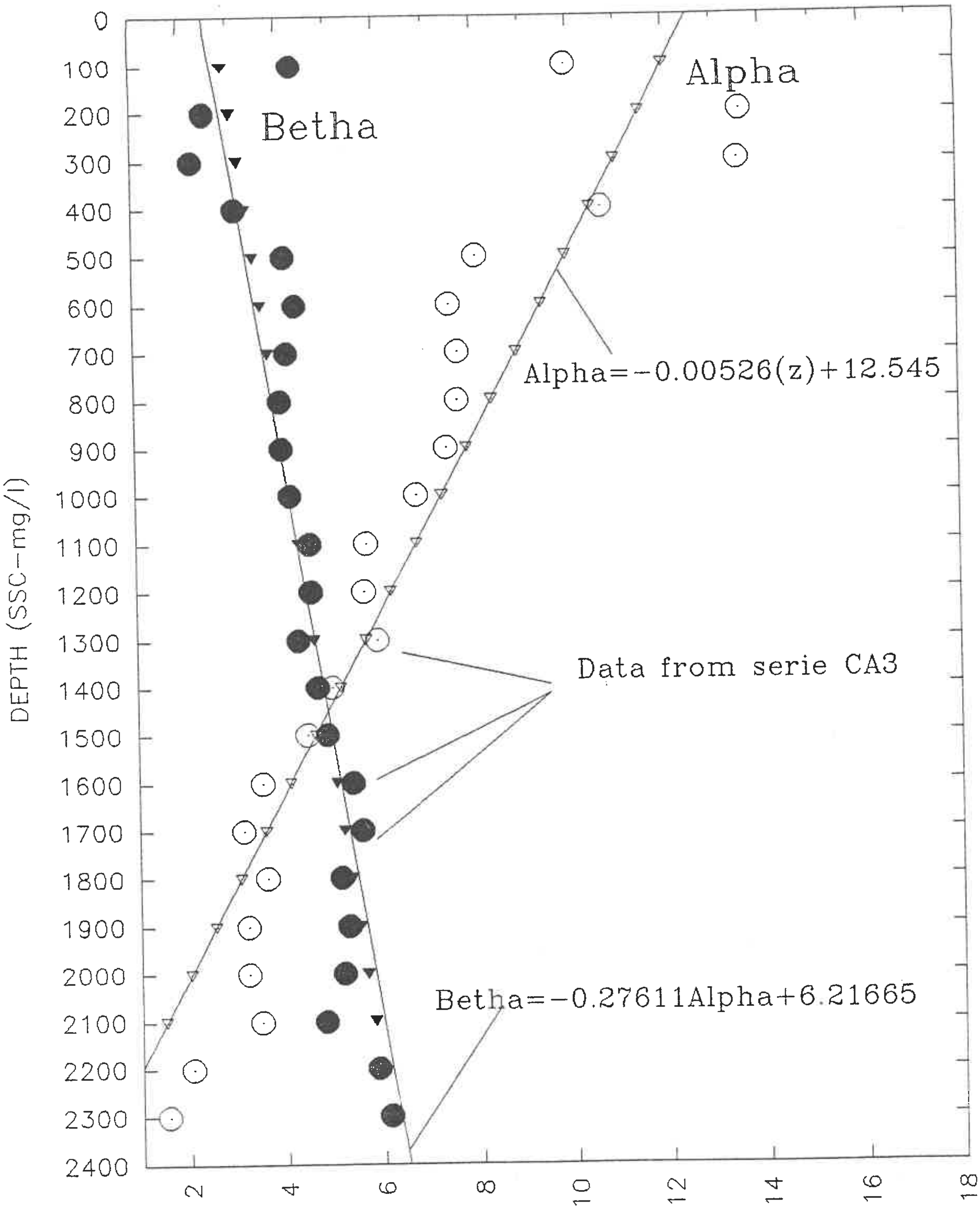


Fig. 31. Linear regression for Alpha with depth (z). Betha obtained from Alpha-Betha linear regression.