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WELL - LOGGING STUDY
OF UPPER JURASSIC
FORMATIONS
1/3 - 3 BORE
(NORWAY)

- - -

DIRECTION EXPLORATION

division
recherches et applications
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WELL - LOGGING STUDY OF UPPER JURASSIC FORMATIONS 1/3 - 3 BORE (NORWAY)

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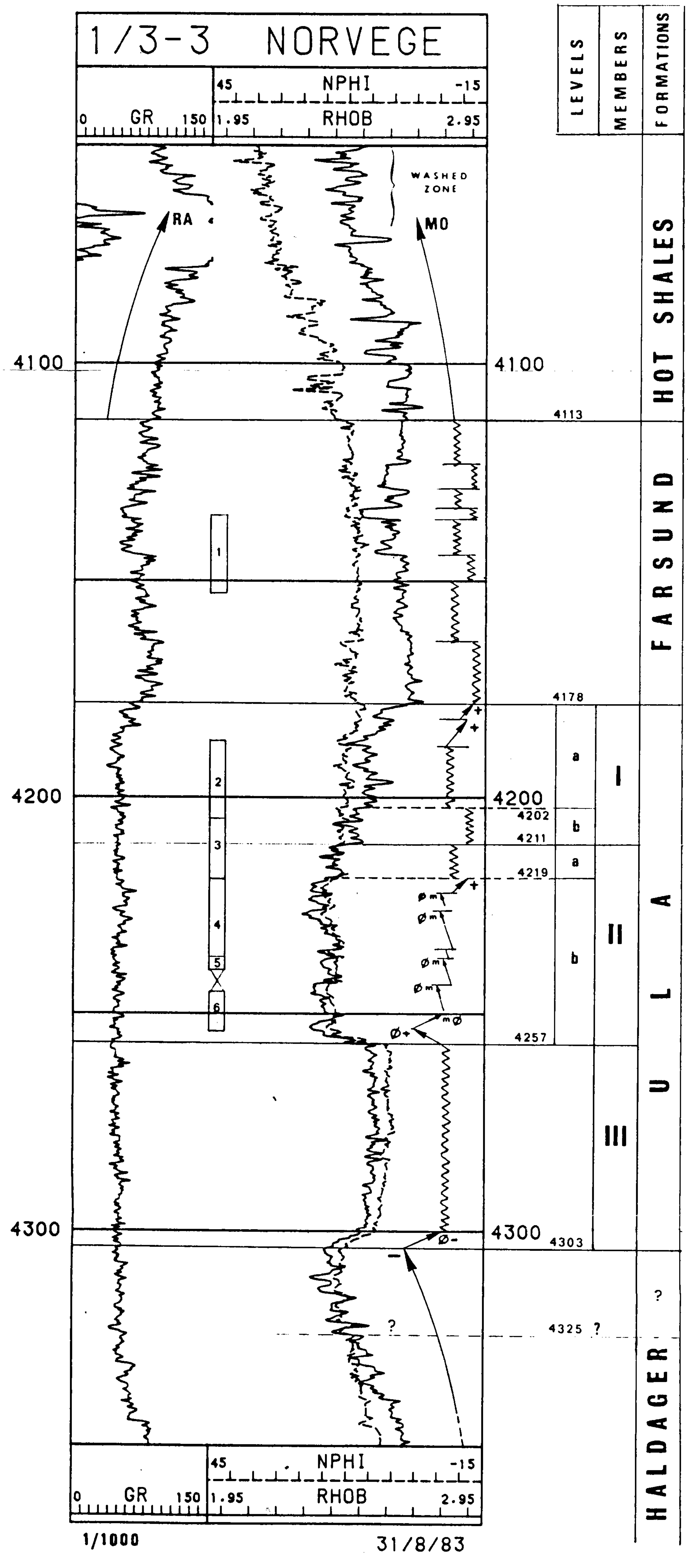
ABSTRACT

The partial well-logging study of 1/3-3 bore has been carried out for the purpose of interpretation of an apparently "abnormal" result, or at least difficult to understand. Indeed, a notable quantity of anhydrous oil has been yielded by a zone which show all the characteristics of an aquiferus or highly water-satured reservoir ($Sw \geq 50$ %; $Rt < 3$ Ohm).

A solution to this detection problem can be propounded, by the means of a detailed facies sequential analysis centred on sedimentology, which leads to gather, as a preliminary, the greatest number of data concerning the lithological characters and the log-facies.

While still hypothetic, all the obtained results converge towards the determination of a double permeability matrix network.

FIG.1



1/3-3 NORVEGE
0 GR 150
45 NPHI -15
1.95 RHOB 2.95
WASHED ZONE
RA
MO
4100
4200
4300
4113
4178
4200
4202
4211
4219
4257
4300
4303
4325 ?
?
1
2
3
4
5
6
a
b
a
b
I
II
III
LEVELS
MEMBERS
FORMATIONS
HOT SHALES
FARSUND
ULA
?
HALDAGER
0 GR 150
45 NPHI -15
1.95 RHOB 2.95
1/1000
31/8/83

The study carried out on 1/3-3 has been restricted to the 4050-4300 m. interval : it widely covers the upper jurassic detritics reservoirs, almost entirely cored, and the zone which, between 4202 and 4214 m. (DST n° 3B), has shown oil seepages.

After a generalities chapter, the well logging study will be divided into three main parts :

- facies analysis
- sequential analysis
- hydrocarbon detection

Available documents

- complete pack of logs
- summarized card of the well (1/5000 scale)
- results of laboratory analysis carried out on six cores (*)

I - ELECTROFACIES BLOCKS AND GENERAL VIEWS

1.1 - General definitions

A facies log, which conception is now classical, has been drawn along the studied interval at the 1/1000 scale (Fig.-1), due to the juxtaposition/superposition of three basic logs : GR - FDC - CNL.

It gives, before any detailed analysis, a broad idea of the log characters : among these, the couple of records FDC/CNL leads to direct observations connected with the three following variables;

- polarity of the two curves (FDC fluctuating left and right from CNL);
- their relative spacing (usually maximum in clayey zones);
- absolute values of the records.

(*) - G. SAMBET - J.P. SEVERAC : Etude sédimentologique et minéralogique des carottes 1 à 6 du puits 1/3-3 (Norvège) DEX/RAG - Labo Boussens N° 83/035 N-24/05/1983 : Sedimentological and mineralogical study of cores 1 to 6 in the 1/3-3 well (Norway). DEX/RAG - Labo Boussens N° 83/035 N - 24/05/1983.

It is therefore already possible to separate 1/3-3 series into several fairly well distinguished electrofacies blocks. More, it is easy to set up the relationship with the formations which characterize this part of Central Graben :

- Hot Shales (above 4113 m); essentially clayey formation : maximum CNL-FDC spacing. Radioactivity.

- Farsund (4113 to 4178 m.); gritty clayey formation : decreasing of relative spacing - ØN plateau of about 15 %.

- Ula (4178 to 4303 m.): sandstonelike formation; relative spacing becoming minimum to zero.

N.B. : On the 1/5000 scale card, the lower boundary of Ula fm has been set at 4320 m. (4325 m. logs ?), just in the middle of a sequential and gradual evolution of gritty-facies. This choice seems to be somewhat arbitrary. It would be better:

- to move upwards this boundary till the end of the evolution, near 4303 m,

- or, on the contrary, to move it downwards;

but we should then have to define again the lithostratigraphy of Haldager formation and this would get out from the restricted scope of this study. Consequently, the first way will be provisionally adopted.

The so-delimited Ula fm may be divided into three members :

- Ula - Zone I (4178 to 4211 m.) or upper Ula : minimum spacing of the curves in the CNL-FDC polarity system (FDC moving right from CNL).

- Ula - Zone II (4211 to 4257 m.) or middle Ula : change of polarity: FDC-CNL.

- Ula - Zone III (4257 to 4303 m.) or lower Ula : same polarity but quick simultaneous changing of the absolute values of the two records.

More, if we take into consideration an hydrocarbon problem near the boundary between Zone I and II, we may divided again these members into levels: respectively at the floor of Zone I and at the roof of Zone II, as follow :

. Ula - Zone Ib (4202 to 4211 m.) : minimum spacing in the CNL-FDC polarity system and slight plateau in the measured absolute values.

. Ula - Zone IIa (4211 to 4219 m.): the two records run concurrently.

Consequences and preliminary observations : Provided that, usually, the development of the clayey character in detritic series follows the relative spacing of the two curves in a CNL-FDC polarity, we may observe that :

- by their superposition, the two preceding levels draw a transition between the gritty. Ula and the gritty-clayey Ula.
- following the normal direction of deposits, the succes-ion of blocks that me have described from lower Ula up to the Hot-Shales is a normal-decreasing grain-size-megasequence.

1.2 - Global radioactivity and spectrometry

G.R. reveals a somewhat high radioactivity for sandstones, which is rather constant along Ula fm (approximately 50 API). As Vsh may change, we have to admit the existence of complementary and compensating sources - feldspars, heavy minerals ... - which are not organic - zero U component of spectrometry - the whole exerting from a residue associated to the Quartz in little amount - Th. and K. values being respectively 4 ppm and 2 % - but GR may not be taken into account for even a rough estimate of the clayey character of the sandstones. This is a general fact for complex matrix.

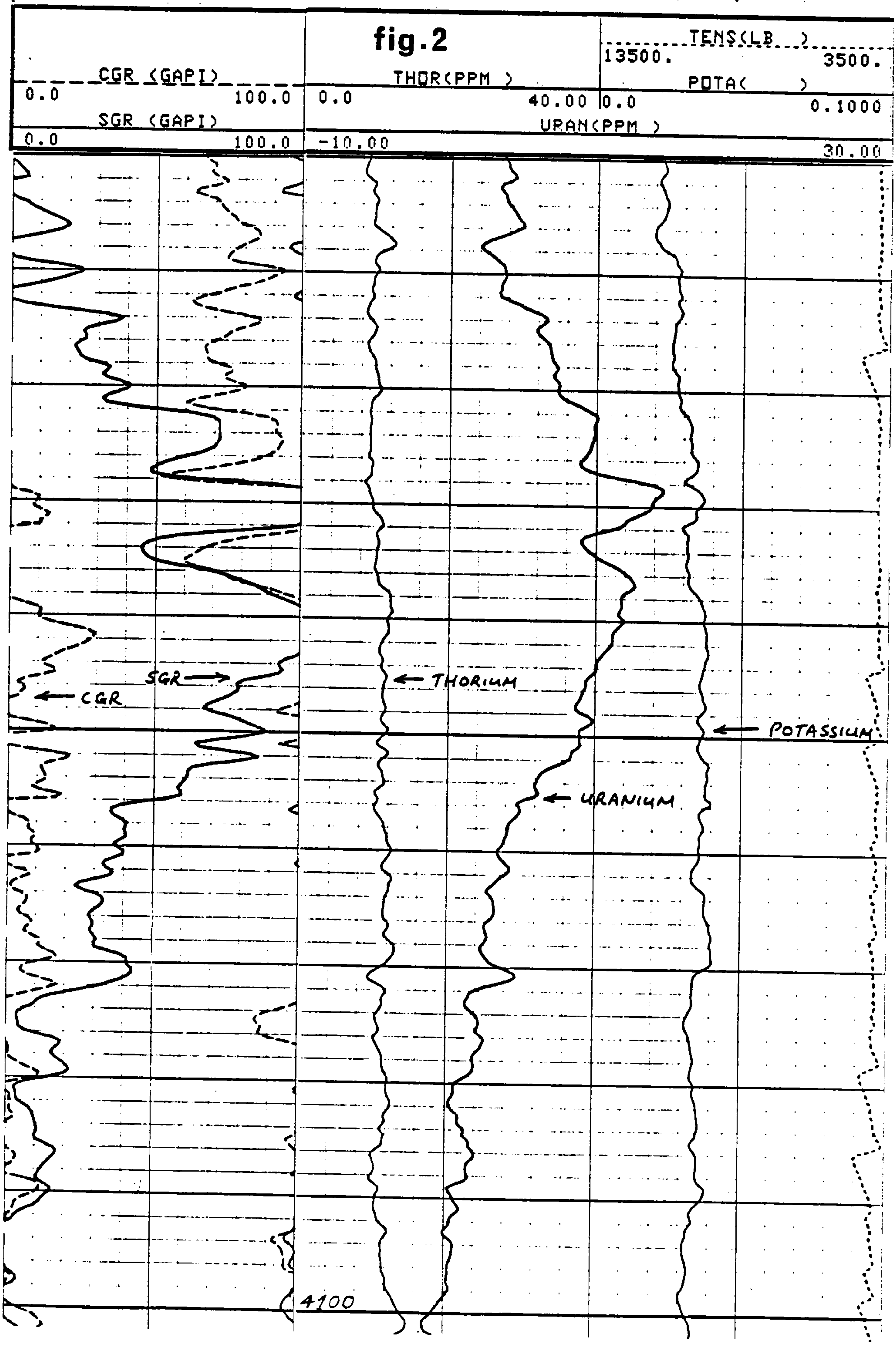
Along overlying formations which are very clayey (Farsund) or many clayey (Hot Shales), the global radioactivity normally increases and may be greater than 200 API at the end of the evolution. Spectrometry shows that the main cause is the development of the uranium component, while concurrently Th. and K. rates reach 8/12 ppm and 3/4 %. This is a very well known characteristic of the organic clays which are these Hot Shales (Fig. 2).

Consequently, for studying the argillaceous poles, we have to take care and try to isolate this organic component because :

- on the one hand it does not seem to concern the gritty underlying reservoirs
- on the other hand, the most clayey - or the least gritty - seems which may be used as a reference for qualitative and quantitative Vsh estimates are only found in the Hot Shales.

Important remark : usually, spectrometric data and more particularly K. rate or Th/K. ratio are associated to the photoelectric Index value for a more accurate estimate of - among others - the clay parameter by logging techniques. In the 1/3-3 case, this is not possible because of the use of a barytic drilling mud. For instance, one can observe the bad influence of the latter near 4185 m., at which level cake spreads out.

fig.2


CGR (GAPI)
0.0 100.0
SGR (GAPI)
0.0 100.0
THOR(PPM)
0.0 40.00
URAN(PPM)
-10.00 30.00
TENS(LB)
13500. 3500.
POTA( )
0.0 0.1000
SGR
CGR
THORIUM
POTASSIUM
URANIUM
4100

II - FACIES ANALYSIS

As the argillaceous blocks from which we shall get the greatest number of data concerning the clay parameter is situated at the top of the series, the analysis will be exceptionally carried out from top to bottom.

2.1 - Hot Shales (till 4113 m.) : not cored

We may divide the long gradient of evolution connected to organic matter into 4 successive blocks, especially using the latter well-marked plateau on the CNL (cf. caption an. 1)

Iteration between the main basic charts : DENS/CNL (an. 2), DENS/DT (an. 3), and the determination chart Mvs P (an. 1) reveals the specific orientation and the good characterization of the gradient due to the organic matter.

The most interesting plots for our study are those (circles) grouped near the origin of the trend. They logically fit with the electro-beds which are not - or not yet - affected by the o.m. and are situated near the floor of the formation between 4095 and 4113 m. Samyles 39 near 4106 m. (Reference A2) and 42 near 4110 m. (Reference A 1) are the most clayey and may be chosen as reference poles : especially A 1 which is more bound up with the trend than A 2.

They enclose the other plots which are more or less grouped in the median sector of the chart. This rather large spectrum of the clayey character means that we probably have a mixture of clay minerals from the "heavy" phase (Illite, chlorite ...) as well as from the "light" phase (Kaolinite, smectite ...) including the interstratified minerals "intermediary" one. As we may not use the PET informations, logging techniques are not sufficient to choose between this large number of solutions.

In conclusion, the Hot Shales may be described by logging techniques in 1/3 - 3 well as more or less rich in radioactive organic matter silty-clays - The two defined argillaceous poles A 1 and A 2 may be also used as a reference for the underlying blocks which do not contain "pure" clayey seams and, above all, are situated at the end of the megasequential evolution of clayey development.

Finally, the ternary diagram Q, MU (muscovite), KA (Kaolinite) has drawn by computer plotting (an. 1) takes into account the evolution of depth and temperature. It seems to suit with the whole of the plots.

2.2 - Farsund (4113 to 4178 m.) - partially cored (K 1)

The plots are well alined in the median zone of the Mvs P diagram (an. 4) between the so-called A 1 and A 2 poles. We have therefore very clayey silts alternating with very silty clays. The clayey character ranges between 28 and 60 % and the mixture would have the same characters than previously.

The core n° 1 has been sampled near the middle of the formation in its most silty part. Lithofacies analysis give a clay proportion ranging between 25 and 45 which we can compare to the 28-45 % values directly got in the same zone by logging techniques. The similarity of the results confirms the reliability of the ternary diagram, at least concerning the clayey rate.

X-ray analysis of the clays shows the following composition - in decreasing order - : illite, chlorite, interstratified minerals (illite - smectite). This result conveniently fits with previous estimates by log techniques. We have indeed an association of several clay minerals.

Among the accessory minerals of the detritic phase, the laboratory analysis shows the presence of a little amount of carbonate (dolomite) and feldspars, which proportion does not exced 10 %; the mean value is 3 to 5 %. The log characteristics of these minerals may be counterbalanced with respect to silica, especially from the density point of view, and their proportions are too low to have a decisive influence on the records. This is shown by an iteration between the two basic charts (an. 5, an.6): the moving of the plots is strictly linked with the one of A 1 or A2 argillaceous poles.

In conclusion, only the clayey rate has a decisive influence on log-facies along the Farsund.

Porosity estimate - Øu calculation : this has only a symbolic interest for this still very clayey block; but we have a first comparison opportunity with the values measured on core n° 1.

Computation method uses a Nvs DPRIM (*) (an. 7) chart where Ø influence is exerting only horizontally by a moving of the plots to the left part of the chart with respect to a director straight line Øx, locus of the points having a zero porosity matrix, which is centred on a reference argillaceous pole; the one which is

(*) DPRIM = density (Prime) $= \frac{\rho_B - 1}{\rho_B + 1}$

considered to be associated to the reservoir.

Here, the plotting of this straight line leans on sample 43 which is at one and the same time :

- one of the most clayey (Vsh > 50 %);
- very near the Al reference pole ;
- best optimizing the Øu estimates (by projection on the "pure" sandstones straight line).

Following this construction, the Farsund Øu are spread out over the interval 0-12 % with a mean value of 5 %.

Along K1, their fluctuation between 3 and 12 % is to be compared with the 5-14 % extreme values got in the core. The slight deficit of log estimates may be explained by a preponderant influence of clay in the integrated measurements, a fortiori if the series are still very clayey.

2.3 - Ula - Zone I

(4178 to 4211 m.): almost entirely cored : (K2 and one half of K3). According to Mvs P. (an. 8): clayey sandstones with : 20 < Vsh < 40 % Logically, the floor of the block previously distinguished (Zone Ib) is identical with the least clayey level (20 to 28 %).

Several core samples contain up to 50 % of clay; but the most clayey seams are described as lamines or thin discontinuous joints. It is therefore not surprising at all that the integrated log measurement privileges the silica rate, contrary to what would happen in more clayey blocks.

We have thus a light and global decrease of the clayey rate. But the new phenomenon is the general moving of the plots towards the NW part of the chart. This may be explained in two ways;

- a great influence of carbonates (at least 20 to 30 % of the matrix)
- SPI (secondary porosity Index = log Index of heterogeneity or anisotropy) effect.

An iteration between the two basic charts (an. 9 and 10) leads to quickly cancel the first hypothesis. Indeed, neither the calcite pole nor the dolomite one does have any influence on the moving of the plots. On the contrary, the latter is always in agreement with the simultaneous and almost horizontal moving of the clayey poles. At the utmost should we notice a more rapide shifting due to the DT on the second chart (an. 10). Thus, if we compare with the data given by the CNL/FDC, the obtained DT seem to be low; we have there the explanation of the SPI phenomenon and can choose the second hypothesis. This implies the presence of a matrix heterogeneity, which is nevertheless, moderate.

N.B. :

1) The macrolithological description of the cores makes mention of various sedimentary structures : mainly bioturbations, but also shell remains, spheroïds and aggregates of micritic mud, irregular laminations, ... amply sufficient to explain the phenomenon suggested in the logs. We find, here at least, a satisfying convergence of the observations.

2) The microlithological description mentions the presence of accessory mineralizations, for instance dolomite and feldspars. While slightly increasing (5 to 10 % for the first one, approximately 10 % for the second), and as the iteration between the basic charts still suggests, a counterbalancing phenomenon covers up their coming out on the logs.

In conclusion, the log-facies of Ula-Zone I looks like a clayey and fairly heterogeneous sandstone. Clay and SPI have a preponderant influence on the only three porosity tools that we may use for facies determinations.

Porosity estimate - Øu calculation

Keeping the same director straight line as for the Farsund, we obtain from the Nvs DPRIM (an. 11) chart a good spreading out of the values over the interval 2 to 16 %. For the only zones which have been cored - which do not include the top of the member - value ranges obtained by the two techniques are the same :

$$5 < Øu \text{ or } Ø k < 16 \%$$

2.4 - Ula-Zone II (4211-4257 m.)

Almost entirely cored (one third K3 to K6).

Compared to the previous block (see an. 8 and 12), the most marked change is the decrease of the clayey rate which is now in the 10-20 % range. We make the same observations than previously concerning the accessory minerals (dolomite, feldspars ...) counterbalanced by a still preponderant matrix homogeneity (SPI) (see iteration an. 13 and 14).

The level (Zone IIa) distinguished at the roof of the member is logically the most clayey (18 to 20 %). Two new facts have to be noticed:

- The heterogeneity is less systematic than in Ula-Zone I. Several plots are situated again in the chart sector enclosed by the reference clayey poles, the clayey character still being connected with a mixture (Illite, chlorite, interstratified minerals ...). Now according to the core observations : ... "bioturbation does affect the sediment to a lesser degree" ... This is in good accordance with a SPI decrease.
- Among the concerned plots, two samples : 13 near 4224 m. and 32 near 4243 m. correspond to beds which clay component is very close to the "light" phase - kaolinite/smectite -.

If the second sample is situated in a zone where K5 has not been recovered, the first one, near the top of K4, (at 4218 m. depth - reading K) coincides with the single microlithological analysis which makes mention of a notable amount of smectite beside the usual mixture.

In conclusion, the log-facies of Ula-Zone II member looks like a not much clayey and more or less heterogeneous sandstone.

Porosity estimate - Øu calculation : According to the Nvs DPRIM (an. 15) chart, Øu is comprised between 11 and 22 % with a mean value of approximately 18 %, still keeping the same director straight line, reference basis for the compact matrix of zero porosity, as for other previous units.

Comparison with core analysis : The clayey rate - 10 to 20 % - given by log interpretation has to be compared to the 10/30 % values measured on the cores. Now,according to the macrolithological analysis of the latter, below 4205 m. (K) - approximately 4211 m. log - ; that is to say really in the concerned block, the clay seems to be ... "concentrated in irregularly laminated beds" ...

Provided these conditions, it is absolutely normal that the integrated log measurements give lower clayey rates for the maximum content.

For the same reasons, Øk measurement are a little greater : from 15 to 25 %, to be compared to the 11 to 22 % Øu values. In this case, the integrated log measurements necessarily include all the clay components, while the sampling for Øk measurements has been of course carried out outside the clayey laminations. Nevertheless, and this should be a general rule in such a case, we recommend to carefully take into account the log estimates: while they are less accurate for absolute values, they automatically include the splitting of the reservoir into several portions due to the clayey bedding - however slight this phenomenon may be - and quantify therefore an important parameter.

However that may be, we shall notice for that unit again a good convergence of the results obtained by both logging and laboratory techniques.

2.5 - Ula - Zone III (4257-4303 m.) - Block not cored -

As we could anticipate from the facies-log (Fig. 1), the evolution observed till now is completing. The log-facies (an. 16) looks like a sandstone with the lowest clayey rate : 3 to 10 %. That is almost a "pure" sandstone in the logging sense of the word.

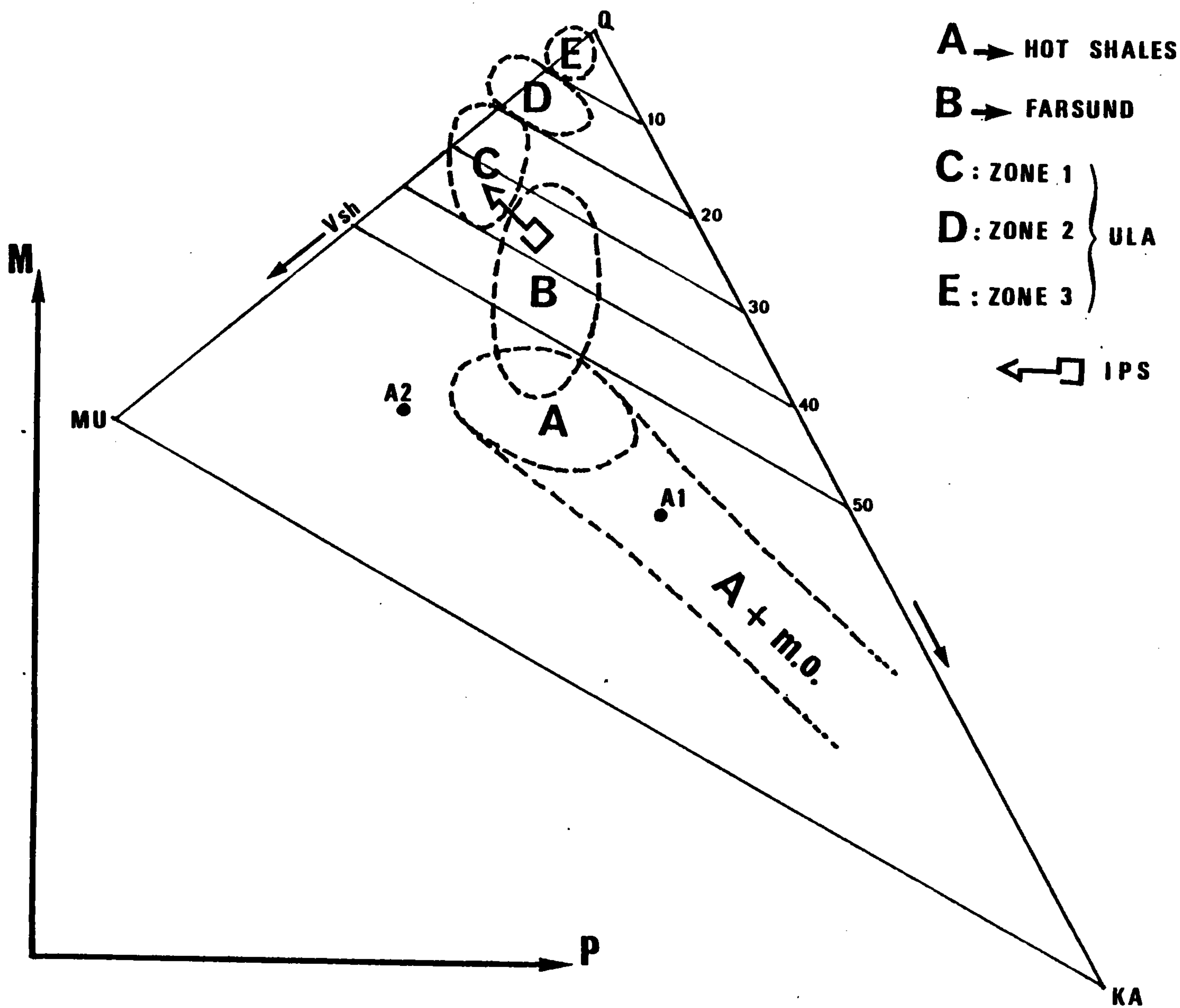

Q
E
D
C
B
A
10
20
30
40
50
Vsh
M
MU
A2
A1
A + m.o.
P
KA
A → HOT SHALES
B → FARSUND
C : ZONE 1
D : ZONE 2
E : ZONE 3
ULA
IPS

fig. 3

The heterogeneity (SPI) is still present (cf. interation, charts an. 17 and 18), and here is no indication of accessory mineralization influence or clay component change. Nevertheless, the present extreme decrease of the clayey rate does not match with a simultaneous increase of the Øu. On the contrary the latter drops drastically and systematically :

$$4 < Øu < 10\ \% \quad \text{(cf. an. 19)}$$

with a significant mean value of about 5 %.

These apparently contradictory phenomena may be explain only if we admit the existence of a strong cementation of the detritic matrix, which origin is probably diagenetic, mainly due to silicifications. The lower member of the Ula fm has practically become a quartzite.

2.6 - Conclusion

In the studied interval, the detailed analysis of the various upper Jurassic detritic blocks confirms and precises the general preliminary observations given by the facies profile alone.

In the frame of a negative megasequence, the evolution of the log-facies is fundamentally depending on the decisive influence of the clayey character and of the heterogeneity Index. Only the latter keeps approximately constant. Except for the lower member of Ula fm, bearing a secondary cementation, the variations of the clay rate and effective polarity are in agreement. The schematic fig. 3 here resumes this evolution of the log-facies.

Finally, it is worthy of note that the comparisons with core samples analysis have shown for every block a good agreement or convergence of the results.

When the values are not the sames, the recorded differences, very slight after all, are normal and justifiable.

All the data are now available which make possible the calibration of the three variables of the facies log-polarity, relative spacing, absolute recorded values -. With the help of the Mvs P charts, we can draw up an algorithm. The latter may be programmed and may originate automatic plotting of lithologically informed facies profiles.

This process may become useful when several wells are concerned for given sedimentary series.

III - SEQUENTIAL ANALYSIS

Only the knowledge of log-facies in every point gives the possibility to examine, along a vertical section, its evolutive or constant character in - and this is fundamental - a continuous way. Once this preliminary step completed, we can begin the sequential analysis. It will be focused, in a classic way for detritic deposits and logging interpretation techniques, on the detection of granulometric sequences which are mainly connected to the evolution of the sand/clay ratio, and which sedimentological origin will be searched for.

3.1 - Characterization of log gradient and deposition mechanisms (Fig. 1).

In the studied interval, log gradients are scarce, and very few are those which may be connected to a granulometric evolution. Not one somewhat important takes place in the cored zones where we did not observe any sequence.

While the Haldager Fm is not included in this study, it is worthly to note that we find, at its roof, between 4350 and 4303 m., a regular gradient which matches a negative mesosequence - increasing grain - size - with concordant unit elements. It shows a composite mechanism or progradation cyclothem. The sequential analysis may be conducted now following the normal course of the sedimentation.

3.1.1 Lower Ula (Zone III) : The profile of this member is an almost perfect "cylinder". The fair grouping of the plots on the corresponding chart (an. 16) shows the lack of any notable evolution; thus, we have here a typical non-sequential zone. It is enclosed by two short - that is to say quick - evolutionary gradients of porosity : decreasing near the floor, increasing near the roof.

While these quartzite-sandstones are very likely concerned by notable post-sedimentary and diagenetic phenomena, we may think that the original sandy deposit was likely to show some graded-bedding homogeneity, consequently connected to a permanent energy of the sedimentation environment with a constant intensity. It would thus enter the permanent reworking mechanisms category.

3.1.2 Middle Ula (Zone III) : we may observe a succession of little gradients, almost all oriented in the same direction. Now, according to the chart (an. 12), they are not connected with significant granulometric evolutions, but rather with porosity changes and/or with fairly slight variations in the relative proportions of the clayey mixture components or in every other mineralization without any relation with the sand/clay ratio. These phenomena, which have perhaps still a diagenetic or neogenic origin, cannot be explained in terms of sedimentology by the means of logging techniques. The resolving power limits of the latter are trespassed and we enter here the scope of mineral geochemistry.

Consequently, such log gradients informed by the initials : Ø M (M = mineralogical evolution without important log significance) will conventionally enter the so-called assimilated non-sequential zones.

Usually, they always betray the existence of permanent reworking mechanisms. We shall only notice that the clayey rate, still relatively moderate, has yet globally and systematically increased of about 10 % in a rather sudden way. The mere superposition of Ula - Zone III and Ula - Zone II members show the beginning of an induced decreasing grain-size sequential evolution which will continue and develop.

Finally, concerning the characterization of the gradients in this zone, we have to notice an important exception. We find at about 4219 m. a very short positive gradient with a granulometric origin, which leads to define the transition from Zone IIb level to zone IIa level. Here, the Vsh increases of about 10 % along 3 m. Because of its situation, this isolated evolution is interesting from a double point of view :

- it marks hydrodynamics which, notwithstanding their very slight character, underline a general grain-size decreasing evolution which appears, besides this, mainly in an induced way.

- this gradient is concordant with a comparable one which is observed on the Resistivity record; oriented to the ascending R. order and situated exactly on the transition between an aquifer and an hydrocarbon-bearing supposed zone (cf. chap. IV).

N.B. : This gradient of evolution, situated at the junction zone between K 3 and 4, has not been observed on the cores.

3.1.3 - Upper Ula (Zone I) : Sandstones become really clayey, and no significant gradient does appear from the basis (4211 m.) up to about 4189 m., that is in the cored interval. At the utmost should we notice several short evolutions of different orientations which could have a granulometric origin, but they are at the limit of the resolving power. This zone may be therefore also described as a non-sequential one.

Given now the succession :

- Middle Ula (Zone II)
- Roof of middle Ula (Level a)
- Floor of upper Ula (Level b)
- Upper Ula till 4189 m.

We notice that its represents a piling of more and more clayey layers which log-contracts are more marked than estimated on the cores themselves. It confirms this good example of positive induced sequential evolution.

Moreover, this tendency will be concretized at the top of upper Ula (non cored zone) where we find the single well-marked gradual-sequence in the studied interval (along 1C m.). It is not homogeneous but made of two clear positive-grain-size decreasing - pulses. Their concave shape reveals the preponderance of clay development (contrary to what happens in channel positive sequences) and the existence of a transgression process.

This positive sequence has a transitional position and is the best marker of the boundary with the very clayey underlying Farsund formation.

3.1.4 - Farsund : very clayey silty seams are found in a very silty clayey background. A succession of strata appears, which profiles, having a "cylindrical" character, do not show any gradient of evolution. This group may be therefore described as a "crenellated" non sequential system; every layer having a specific clayey rate with alternating more or less high value. Their development shows both ephemeral and impromptu characters, which is worthy of note at this step of the analysis.

3.1.5 - Hot Shales : They are of course marked by the strong development gradient of organic matter we spoke about previously. A careful observation, especially the Neutron one, shows that the progressive character of this gradient is more apparent than real : IH increases by successive steps and the first one marks the lower limit of the formation. The development of the organic component thus shows similarities with the one of the clayey rate : it progresses by successive pulses of increasing intensity.

However, this is a mineralization gradient which does not have a granulometric character - in the logging sense of the word -. As far as we are concerned, the positive mega-sequential evolution we followed step by step until now, already reaches its end with the first clayey silty levels - not yet contaminated by organic matter - founds from the floor of this formation.

3.2 - Patterns of deposition and oil implications.

Straight above 1/3-3, Ula fm sandstones follow without transition a well developped coarse detritic progradation mechanism which characterizes the top of the Haldager Fm ... This suggests the selting up of a coastal deposition pattern, with hydrodynamic stabilization in a very littoral zone with constant reworks.

These reworks explain the non sequential accumulations - notwithstanding the paleostructural evolutions and the local subsidence which may influence the thickness.

Nevertheless, lower Ula already looks like a transition block at the end of a sea recession, because an opposite and transgressive evolution begins already in middle. Ula and, by successive pulses, shows its non-reversible character in the overlying blocks. We find therefore the vertical profile of a positive megasequence.

This coastal pattern may be considered to persist till the upper Ula - included -, but shows slight variations due to reworking hydrodynamics which lose strength by sudden steps (slight increasing step by step of the clayey rate). The Farsund already shows the existence of a so-called bassin pattern, probably still shallow, by which setting up could have been quickened as would indicate the most significant gradual transgressive mechanism notices as a matter of fact as the basis of the formation. Within this basin sedimentation which remains somewhat terrigenous, we find a recurrence of very silty levels mainly concentrated in the middle part of the formation. Their impromptu and ephemeral character, under lined by clear limits and by the random distribution of their clayey rate, leads to the determination of particular reworking mechanisms : the so-called turbiditic - sensu stricto - effusions; these ones - which may take place even in shallow water - are compatible with their little thickness.

Finally, in the limits of our study, the Hot Shales deposits would represent a new step in the expansion of the basin and of the transgressive phenomena.

To summarize, the single sequential profile of 1/3-3 suggests, during the upper Jurassic, the existence of two general patterns of sedimentation, successively of coastal and basin types, which superposition is connected to the dynamic of a transgression system. The predominant induced character of the positive sequential evolution, at all the observation scales, suggests himself a connection of the transgressive phenomenon with sea-level enstatic changes, intensified by sudden steps. Of course, these conclusions would have to be supported and verified by the study of other bores in this area.

Consequences for oil research

The observations which we have just made may have logical implications concerning the reservoir nature and the hydrocarbon setting. The most unfavorable factors connected to the proving of coastal deposits obliterated by a transgressive phenomenon would be as follows :

- as the transgression phenomenon progresses by gradual or induced sequential pulses, the reservoir blocks may be systematically damaged near their top simply because of the grain-size decreasing tendency and simultaneous increasing clayey character as shown by the logs. This is valid for all the observations scales : thin seam or thick and massive detritic member. In other words, hydrocarbon trapping tends to take place in the higher part of the reservoir block showing the worst characteristics compared to its basis.

- in any case, as the coastal deposits may cover a large area - and following our previous idea - only one of the best structural backgrounds or an important hydrocarbon potential could vouch that the accumulation also takes place in the lower - and not yet damaged - strata.

- given a grain-size decrease, if the transition zone is too large between the required cover for oil trapping and the reservoir itself, it may contain several more or less tight permeability barriers which can favour secondary migration or hydrocarbon segregation phenomena.

Of course, these are extreme situations, particularly if they are cumulated. Beyond the way of development of the clayey character and beyond the principles, the permeability and porosity criteria mainly lead to appraise the reservoir properties. In conclusion, we shall simply say that if a coastal deposit is obliterated by a transgressive phase, several unfavourable factors may appear, connected to this kind of sedimentogenesis, which explain some of the productivity problems.

IV - HYDROCARBON DETECTION

Before discussing any problem of hydrocarbon detection, we have always better to get a knowledge, as detailed as possible, of the log - and facies - sequential characters of the studied layers, especially in the case of complex matrix. This previous step may be considered as completed.

We have prepared a new file, taking into account the previous log-samples between 4175 and 4247 m. (74 samples), which widely encloses the interesting zone between the proved covering and aquiferus levels.

4.1 - Available data

- due to the previous analysis, corroborated by those carried out on the cores, we have a good knowledge of the facies-sequential parameters : especially for the Vsh and Øu, depending on the matrix.

VOULEZ VOUS UN AUTRE DESSIN ?
Y - OUI : N = NON
J

NUMERO DE COURBE A TRACER
A = TOUTES LES COURBES
1 A 4 - COURBES DE 1 A 4
1.2.6 - COURBES NUMERO 1.2 ET 6
3

DEFINIR LA FENETRE DU TRACE
<XC> <YC>,<ECH>,<Y/X>,<ROT>
10,10

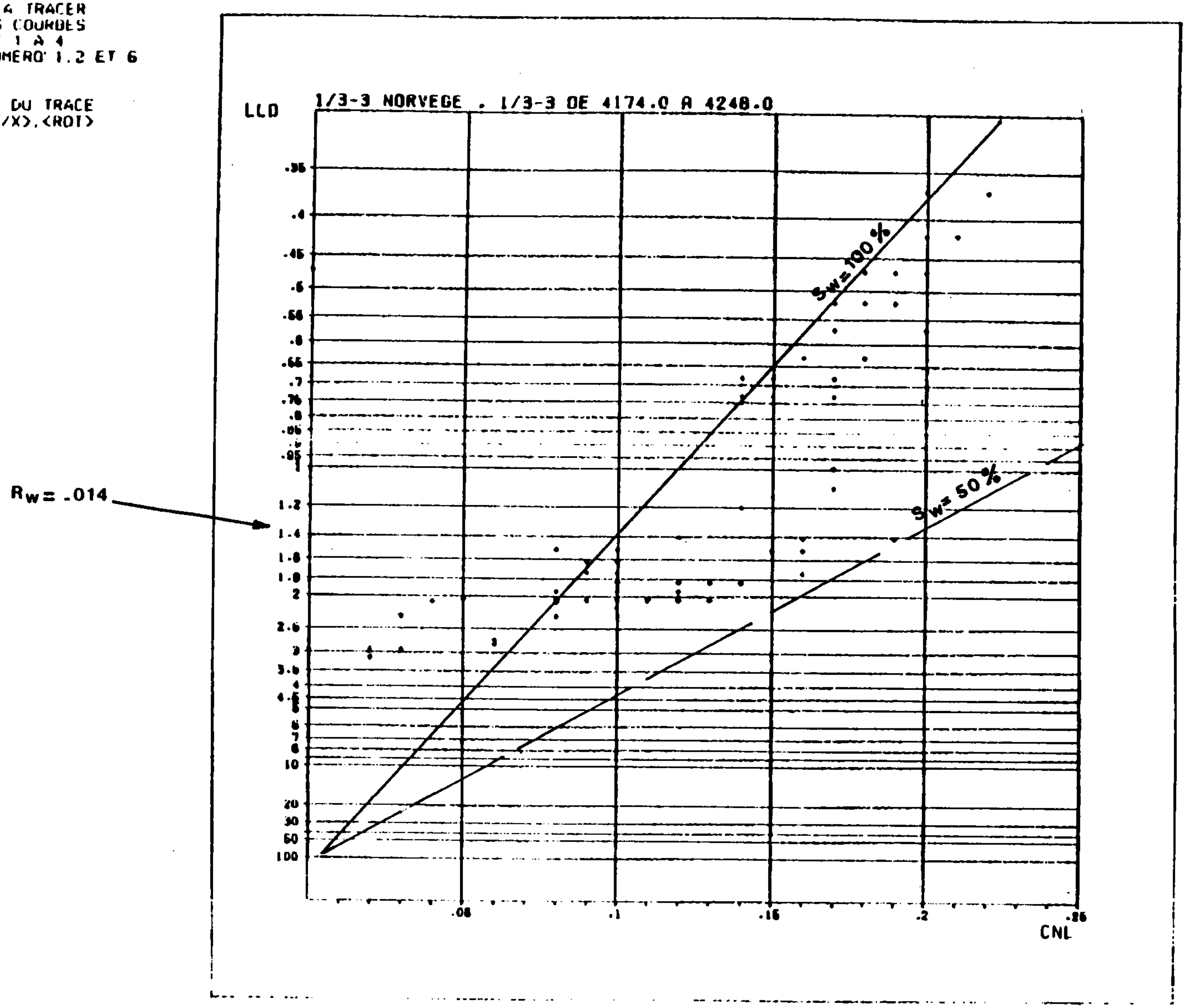


fig.4

- we have a good knowledge of the water problem in the field, for the DST n° 2 (4240 to 4233 m.) has yielded saturated saline water at 310 g/ℓ (mud salinity = 30 g/ℓ). This datum is in agreement with the estimate calculated for the aquifer with the formula :

$$R_w = \frac{R_{mf} \cdot R_{o(IL)}}{R_{xo}} = 0.01 \text{ Ohm}$$

- concretization of hydrocarbon presence, by means of DST n° 3B (4202 - 4208/4211 - 4214 m.) which has yielded 198 m3/day of anhydrous oil (d = 0,829), actually produced.
- very complete pack of Resistivity records (DLL-MSFL, ISF).

4.2 - General views concerning resistivity tools

1) First, the caliper logging reveals a notable and very constant cake thickness (1/2") along all the reservoirs, which proves a certain permeability. Keeping in mind the just average porosity values (10 to 19 %), we might fear an important invading affecting the maeroapparatus - But a qualitative estimate mainly using the Rt plots (IL or LLd) Vs Øu, shows that this is not the case. The water straight lines which may be traced are well concordant with Rw values of about 0.010 - 0.014 Ohm (Fig. 4). Thus, the macroapparatus well read Rt.

2) All the tools are in agreement to point out to very high conductivity values, even along the supposed hydrocarbon-bearing zone : maximum 2 Ohm ! In this case, Induction compared to laterolog could give somewhat lower resistivity values, provided the imperfect isotropy of the environment (SPI occurence) and the salinity contrast between the mud and the water of the well.

3) As one could expect, there are indications of a systematic and constant segregation between macro - and micro - apparatus in all the reservoirs, which confirms a generalized, important (see previous remarks) but not excessive (cf. calculation) inviding by the filtrate.

4) The stepwise ranging of absolute values measured towards increasing resistivities is oriented from macro - to micro - apparatus; given the salinity of the concerned fluids, it might point out to an aquifer polarity.

5) A second Resistivity run (ISF - MSFL) has been carried out more than one month later on, covering again the studied interval. Notwithstanding a calibrating problem, the obtained values enter the same range.

6) All the records fluctuate stepwise between the extreme values of the very saline aquifer on one hand (0.2 Ohm minimum) and the covering clays on the other hand (3 Ohm maximum) ! These steps are perfectly fitting with those of sedimentary levels or members described and delimited by the means of facies-sequential analysis. The scarce gradual sequential gradients defined previously are also concerned. Then we have :

- Ula - Zone IIb : 0.2 RIL 0.4 Ohm = aquifer certitude
- Ula - Zone IIa : 1 RLLD 2 Ohm = transition and oil probability ?
- Ula - Zone Ib : RLLD 2 Ohm = oil probability ?
- Ula - Zone Ia : 1 RLLD 2 Ohm = cover probability ?
- Farsund : 2 RLLD 3 Ohm = cover certitude

N.B. : The two resistivity gradients which respectively link Ula - Zones IIb and Ula - Zone Ia/Farsund, match the lithological gradients (cf. p. 10 - 11).

Consequently, a possible hydrocarbon effect would superimpose over a lithological effect.

4.3 - Results

The results have been got using "PICARDIA INTERACTIF" by processing the previously prepared files, on the basis of the resistivities of the Dual Laterolog - which is relatively the most favourable to hydrocarbon occurence - and entering several parameters and formulas which vary inside definite ranges. This last process especially concerns :

- taking into account the clay effect (Simandoux, Poupon ...)
- the cementation coefficient (m.) of Archie's formula,
- the matrix density.

The results obtained following the different hypothesis are convergent and almost the sames - they lead to conclude to the occurence of an aquiferus zone with residual oil. Indeed, the most favourable result included on Fig. 5 table shows that water saturation is still important, at least about 50 %. The only levels having a Sw < 60 % would be situated near 4207 m. and between 4211 and 4216 m., that is about 6 m. of e.p., including a main layer 5 m. thick.

Relations between fluid content and effective porosity :
Aquifer (Ula - Zone IIb) : Øu ≠ 18 % mean value (22 % maximum)
Zone with residual oil (Ula - Zone IIa) : 14 < Øu < 19 %
The overlying levels of Ula - Zones Ia and Ib, while still showing locally a reasonable porosity (but always < 13 %) could be

identified with permeability barriers and would behave as a more or less tight cover.

To summarize, crude results seem to be consistent; in such a case the interesting zone would have yielded during the test and oil/water mixture, if we consider a classic production way connected to the matrix (here of intergranular type). Now, only anhydrous oil has been obtained. We face here a contradiction that we have to try to explain.

Provided that :

- macrolithological data are consistent and verified;
- there is no doubt concerning the quality of log records;
- the choice of variable parameters privileges the hydrocarbon occurence; it is possible to propound at least two hypothesis :

1) the anhydrous oil production would not have a classic matrix - connected origin, but would be due to particular draining (such as fissures, vesicular channels, of different permeability...).

   - no anomaly of this kind has been observed, which could be assigned to these phenomena, neither on the logs - macro - or micro - apparatus -, nor on the cores.
   - the evolution of macro lithological characters is continuous and regular; would it be induced (the most common way) or gradual.

   Nevertheless, it is still possible that a very detailed laboratory analysis of the porous network - Purcell type - could show the presence of two matrix types more or less intermixed : a network which is a little or not at all permeable, with residual water, associated with an "active" network only favourable to oil migration. The whole is in agreement with the global log result : Sw of about 50 %

2) About four months elapsed between the recording, the installation of a 7" well-casing and the tests. During the handling and during this gap of time, a depletion could thus have happened by accident, favoured by the high pressure of layers, and a first test (DST 3A) having shown a filtred outpouring. This could have led to a new arrangement of the exiting fluids, especially the oil. But this hypothesis is not so much conceivable because of the somewhat difficult reliability with the important - about 200 m^3 - oil production.

NIVEAU	TOIT	ARG.	POR. Øu	SXO	SW	D.HY.	D.MAT.	NEU	DEN	SON	SEC	Di		VSH
5	4179.0	40.6	2.0K	100.0	100.0	****	2.700	14.6	2.0	14.9	****	9999	A	40.[illegible]
6	4179.5	33.1	6.0K	97.8	79.9	.75	2.700	14.6	4.6	15.6	****	9999	A	33.[illegible]
7	4180.0	31.1	8.0K	94.3	73.6	.75	2.700	16.[illegible]	7.2	17.0	****	30		30.[illegible]
8	4181.5	23.9	4.0K	100.0	100.0	****	2.700	15.7	8.7	17.0	****	180		22.[illegible]
9	4182.5	34.9	6.0K	98.6ER	93.0	.75	2.700	15.1	4.6	15.6	****	175		34.[illegible]
10	4184.5	31.8	8.0K	99.2ER	95.9	.75	2.700	16.3	6.9	16.3	****	230		31.[illegible]
11	4185.5	27.8	10.0K	96.2ER	82.6	.75	2.700	16.3	9.3	17.0	****	232		27.5
12	4186.0	27.1	10.0K	98.1ER	90.9	.75	2.700	19.7	11.2	19.1	****	242		26.4
13	4186.5	25.3	9.0K	85.7	77.9	.75	2.700	17.5	10.4	18.4	****	9999	NC	25.[illegible]
14	4187.5	23.8	14.0K	91.0	86.2	.75	2.700	20.4	14.4	21.3	****	519		22.7
15	4188.5	29.1	9.0K	84.0	74.0	.75	2.700	17.5	9.2	13.4	****	9999	NC	28.7
16	4189.5	25.4	10.0K	100.0	86.1	****	2.700	18.1	10.9	19.1	****	231		25.4
17	4190.5	34.5	8.0K	91.6	84.5	.75	2.700	19.7	8.6	18.4	****	9999	NC	34.1
18	4191.5	27.3	10.0K	100.0	8[illegible].3	****	2.700	18.7	10.9	18.4	****	231		27.[illegible]
19	4192.0	29.4	9.0K	92.1	91.8	.75	2.700	19.1	9.3	17.7	****	254		29.[illegible]
20	4193.0	29.0	12.0K	93.8	75.8	.75	2.700	21.0	13.2	19.1	****	333		23.[illegible]
21	4194.0	28.0	10.0K	94.8	82.1	.75	2.700	18.7	10.9	17.0	****	326		27.[illegible]
22	4194.5	31.6	8.0K	98.8ER	94.1	.75	2.700	17.5	8.3	17.7	****	218		31.2
23	4195.5	29.4	9.0K	97.0	89.8	.75	2.700	18.1	9.5	17.7	****	283		29.[illegible]
24	4196.5	36.0	5.0K	100.0ER	100.0	.75	2.700	15.7	4.9	15.6	****	9999	NC	35.[illegible]
25	4197.5	21.4	10.0K	97.1	77.8	.75	2.700	16.3	10.6	17.7	****	235		20.7
26	4199.0	25.3	10.0K	90.2	77.3	.75	2.700	18.1	11.2	19.4	****	224		24.[illegible]
27	4201.0	31.6	8.0K	98.5ER	92.9	.75	2.700	17.5	8.3	16.3	****	246		31.[illegible]
28	4201.5	25.1	10.0K	93.6	75.7	.75	2.700	17.5	10.6	18.4	****	303		24.[illegible]
29	4202.2	29.1	9.0K	96.9ER	85.6	.75	2.700	17.5	9.2	17.7	****	248		28.7
30	4202.8	27.0	12.0K	81.6	64.0	.75	2.700	20.4	13.2	19.9	****	243		26.[illegible]
31	4204.0	26.3	11.0K	78.9	70.9	.75	2.700	19.3	12.1	19.1	****	295		25.[illegible]
32	4204.5	22.6	13.0K	77.8	61.5	.75	2.700	19.8	14.1	19.9	****	426		21.7
33	4205.5	23.4	10.0K	81.0	80.1	.75	2.700	17.5	11.2	18.4	****	266		22.[illegible]
34	4206.5	17.3	16.0K	75.0	52.4	.75	2.700	21.0	17.2	22.7	****	210		16.1
35	4207.5	23.8	12.0K	75.4	66.5	.75	2.700	18.7	12.4	19.1	****	295		23.1
36	4208.0	21.8	13.0K	78.2	61.1	.75	2.700	19.8	14.4	19.9	****	235		20.9
37	4209.0	27.4	11.0K	85.2	69.8	.75	2.700	19.3	11.6	18.4	****	425		26.7
38	4209.3	25.1	12.0K	81.2	58.4	.75	2.700	19.9	13.2	19.1	****	397		24.[illegible]
39	4210.5	27.1	10.0K	82.9	77.0	.75	2.700	18.7	11.2	18.4	****	233		26.[illegible]
40	4212.0	21.3	16.0K	85.0	53.[illegible]	.75	2.700	22.2	17.2	22.7	****	399		19.[illegible]
41	4213.0	14.8	14.0K	77.6	56.5	.75	2.700	13.7	19.5	20.6	****	130		13.[illegible]
42	4214.0	13.1	19.0K	79.2	44.6	.75	2.700	22.2	20.1	23.4	****	425		11.[illegible]
43	4214.5	15.0	15.0K	72.9	61.5	.75	2.700	19.3	18.1	21.3	****	134		14.[illegible]
44	4215.5	17.6	16.0K	84.8	55.6	.75	2.700	21.0	17.2	22.7	****	228		16.[illegible]
45	4216.5	17.4	17.0K	83.0	77.4	.75	2.700	22.2	18.7	24.1	****	450		15.7
46	4217.5	15.3	14.0K	97.0	36.2	.75	2.700	16.7	15.5	21.3	****	340		13.[illegible]
47	4219.0	7.3	17.0K	100.0	98.5	****	2.700	17.0	19.0	23.4	****	414		7.[illegible]
48	4220.5	9.2	20.0K	100.0	74.3	****	2.700	22.8	21.2	25.5	****	9999	NC	8.[illegible]
49	4221.0	13.7	[illegible]	100.0	77.4	****	2.700	24.0	21.3	2[illegible].2	****	9999	NC	13.7
50	4221.5	3.2	20.0K	100.0	100.0	****	2.700	22.[illegible]	21.8	27.0	****	261		6.[illegible]
51	4222.5	14.0	17.0K	96.5	93.7	.75	2.700	21.0	18.7	24.1	****	279		[illegible]
52	4223.5	3.8	20.0K	100.0	86.4	****	2.700	21.5	22.1	27.7	****	9999	NC	3.[illegible]
53	4225.3	12.0	17.0K	100.0	93.2	****	2.700	21.0	18.7	22.4	****	334		12.[illegible]
54	4226.0	13.7	[illegible]	94.1ER	95.6	.75	2.700	22.2	19.0	24.8	****	269		[illegible]
55	4227.2	8.3	22.0K	100.0	76.2	****	2.700	24.5	23.6	23.4	****	9999	NC	8.[illegible]
56	4228.0	6.5	21.0K	100.0	75.3	****	2.700	22.8	22.4	27.0	****	9999	NC	6.[illegible]
57	4228.5	9.6	19.0K	100.0	100.0	****	2.700	21.5	20.1	24.5	****	281		9.[illegible]
58	4229.5	9.6	19.0K	100.0	94.2	****	2.700	21.6	20.1	24.1	****	297		9.[illegible]
59	4230.0	9.1	17.0K	100.0	52.5	****	2.700	19.9	18.4	24.1	****	9999	NC	9.[illegible]
60	4230.5	11.[illegible]	19.0K	100.0	81.5	****	2.700	21.5	19.5	24.1	****	9999	NC	11.[illegible]
61	4232.5	12.3	15.0K	100.0	100.0	****	2.700	19.0	16.7	22.0	****	273		12.[illegible]
62	4233.5	13.5	13.0K	87.5	77.2	.75	2.700	13.7	16.1	21.3	****	9999	NC	12.[illegible]
63	4234.5	12.5	15.0K	100.0	73.5	****	2.700	19.[illegible]	17.2	22.0	****	9999	NC	12.[illegible]
64	4235.0	13.9	14.0K	100.0	85.3	****	2.700	13.7	15.5	21.3	****	9999	NC	13.[illegible]
65	4236.0	11.5	19.0K	100.0	77.3	****	2.700	22.2	20.[illegible]	24.1	****	9999	NC	11.[illegible]
66	4237.0	13.7	15.0K	94.8	79.9	.75	2.700	15.7	16.1	[illegible]	****	9999	NC	12.[illegible]
67	4238.5	7.[illegible]	18.0K	100.0	74.3	****	2.700	21.0	20.1	23.4	****	9999	NC	7.[illegible]
68	4240.0	9.1	17.0K	100.0	79.7	****	2.700	19.9	18.4	22.7	****	9999	NC	9.[illegible]
69	4241.5	13.0	14.0K	100.0	82.8	****	2.700	18.7	[illegible]	22.0	****	9999	NC	13.[illegible]
70	4242.5	10.5	16.0K	97.2	73.9	.75	2.700	15.7	17.2	22.7	****	9999	NC	[illegible]
71	4243.5	8.1	17.0K	100.0	78.0	****	2.700	22.2	21.3	27.7	****	9999	NC	[illegible]
72	4245.5	6.4	20.0K	100.0	74.0	****	2.700	22.2	21.2	26.5	****	9999	NC	[illegible]
73	4246.5	12.9	17.0K	100.0	81.3	****	2.700	21.0	18.4	24.1	****	9999	NC	12.[illegible]
74	4247.0	9.7	19.0K	100.0	95.5	****	2.700	21.6	20.1	24.8	****	263		9.7

Handwritten annotations: FARSUND (above level 5); ULA - Zone Ia (levels 5–29); ULA - Zone Ib (levels 30–39); ULA - Zone IIa (levels 40–46); DST 3a; DST 3b.

NORVEGE - 1/3-3 - Poupon simplifiée

fig. 5

In conclusion, from the well logging point of view, the mechanism of 1/3-3 oil productivity is still hypothetical. Nevertheless, for the moment, the first suggested hypothesis is the most fascinating; more especially as it is in agreement with several general characters which are directly or indirectly shown by the logs.

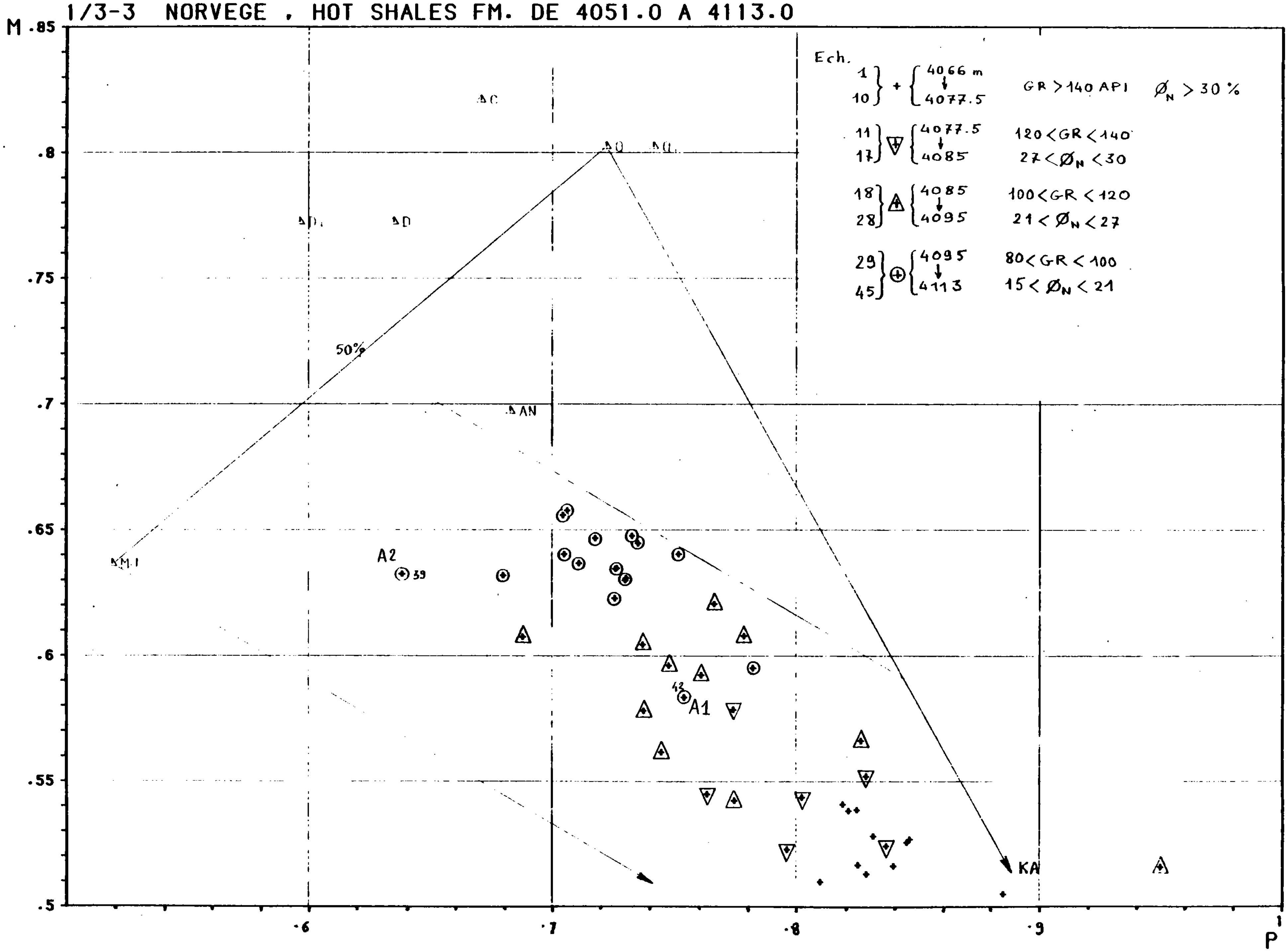
- constant occurence of an heterogeneity index (SPI)
- complex aspect of hydrocarbon setting in reservoirs which are damaged near their top by transgression effects.

But the possible verification of the occurence of a double permeability network does not enter any more the scope of well logging study. It would need further complementary laboratory analysis.

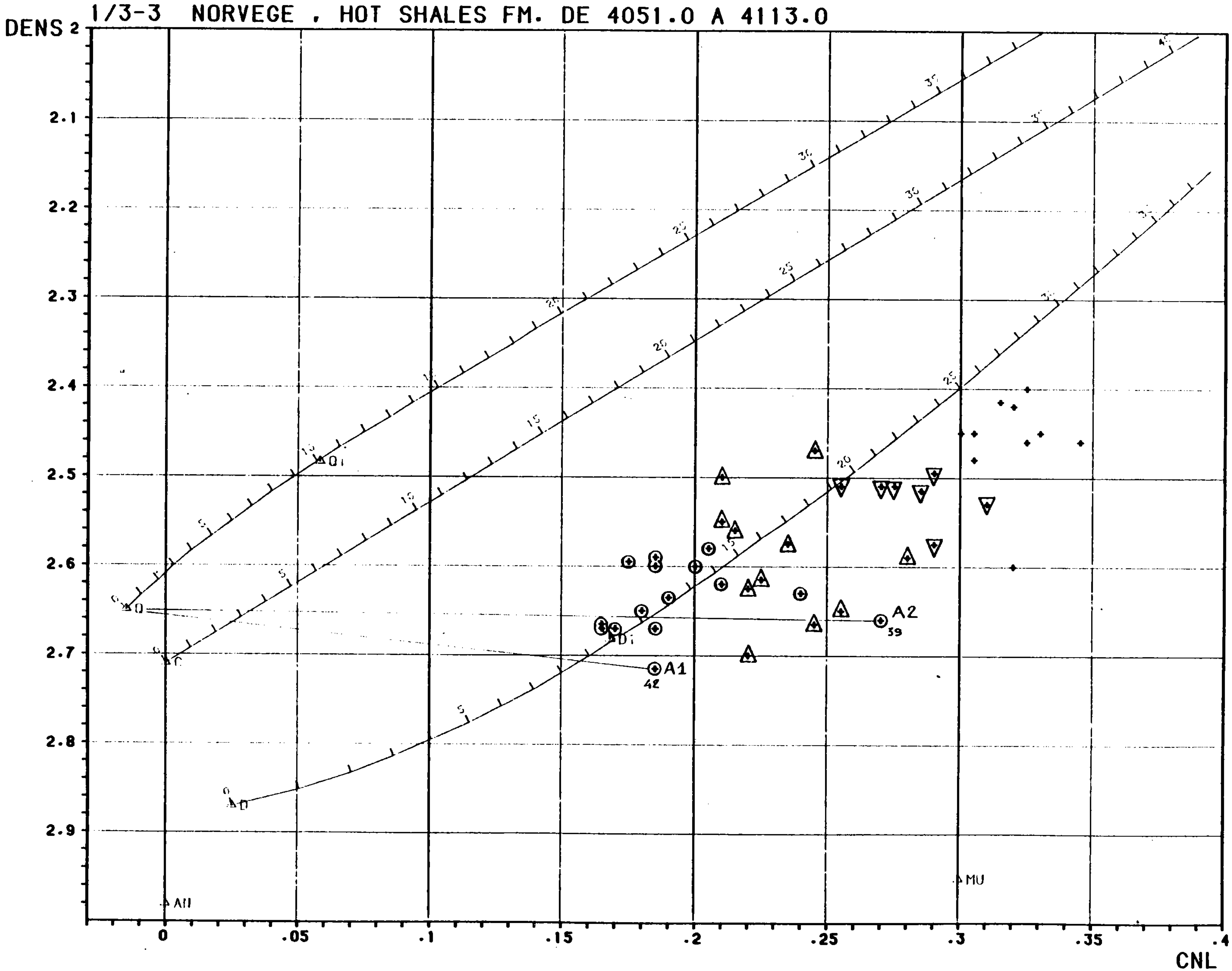
5 Figures

19 Annexes

ANNEXES 1 à 19

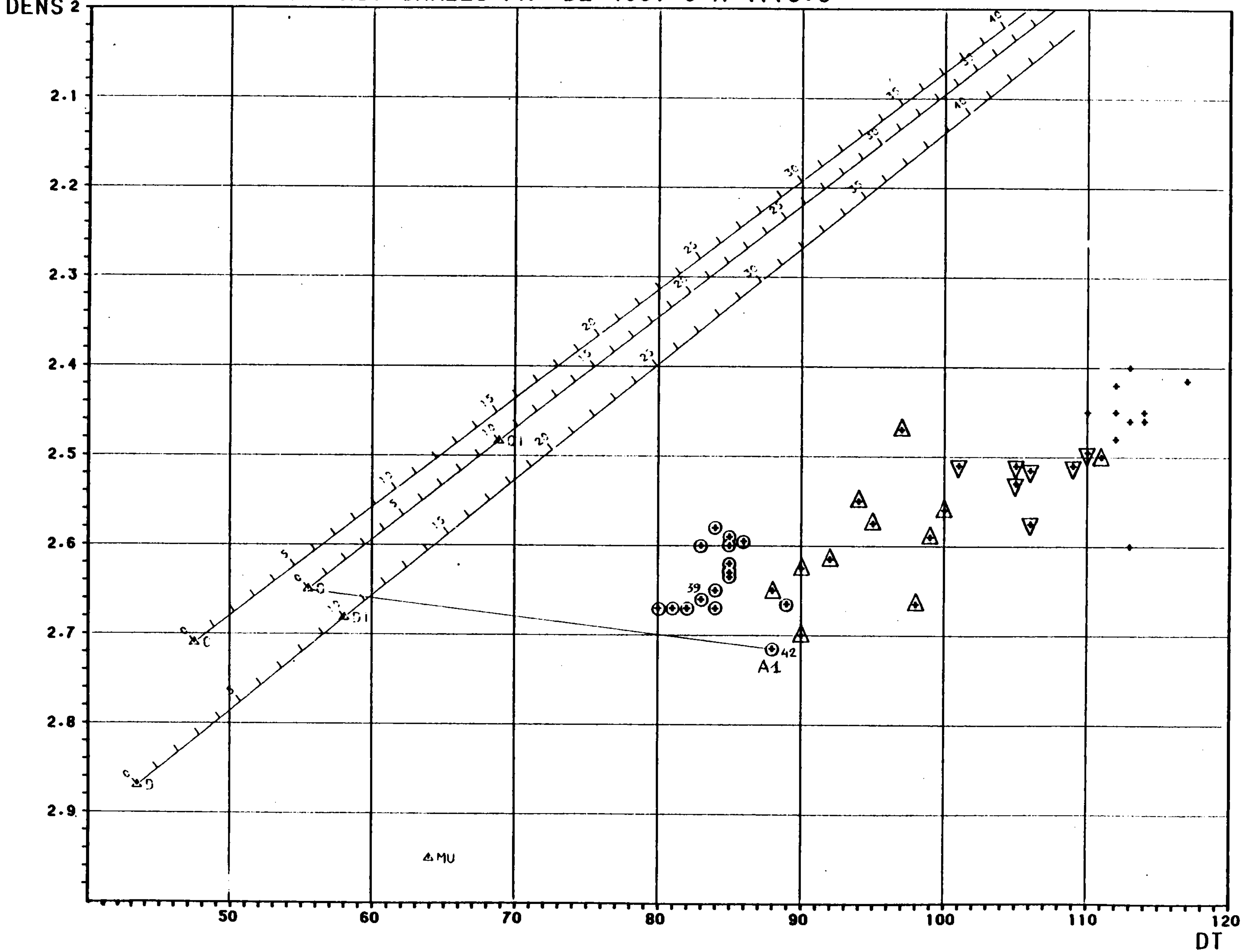

1/3-3 NORVEGE , HOT SHALES FM. DE 4051.0 A 4113.0
M
P
Ech.
1 10 + 4066 m → 4077.5 GR > 140 API Ø_N > 30 %
11 17 4077.5 → 4085 120 < GR < 140 27 < Ø_N < 30
18 28 4085 → 4095 100 < GR < 120 21 < Ø_N < 27
29 45 4095 → 4113 80 < GR < 100 15 < Ø_N < 21
50%
A2
A1
KA
AN
.85
.8
.75
.7
.65
.6
.55
.5
.6
.7
.8
.9
1

An. 1


1/3-3 NORVEGE . HOT SHALES FM. DE 4051.0 A 4113.0
DENS
CNL
A1
42
A2
39
MU

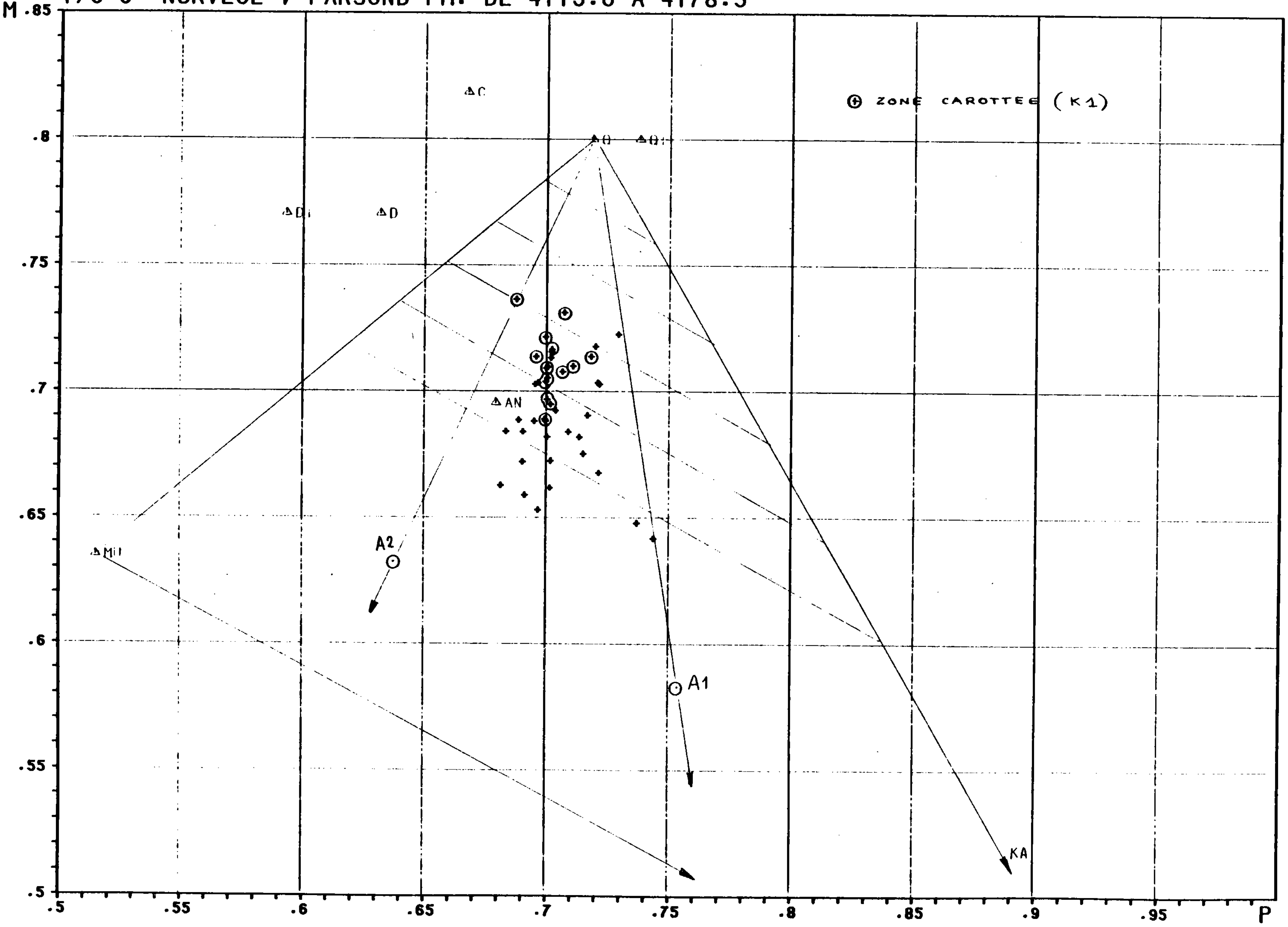
An.2

1/3-3 NORVEGE . HOT SHALES FM. DE 4051.0 A 4113.0



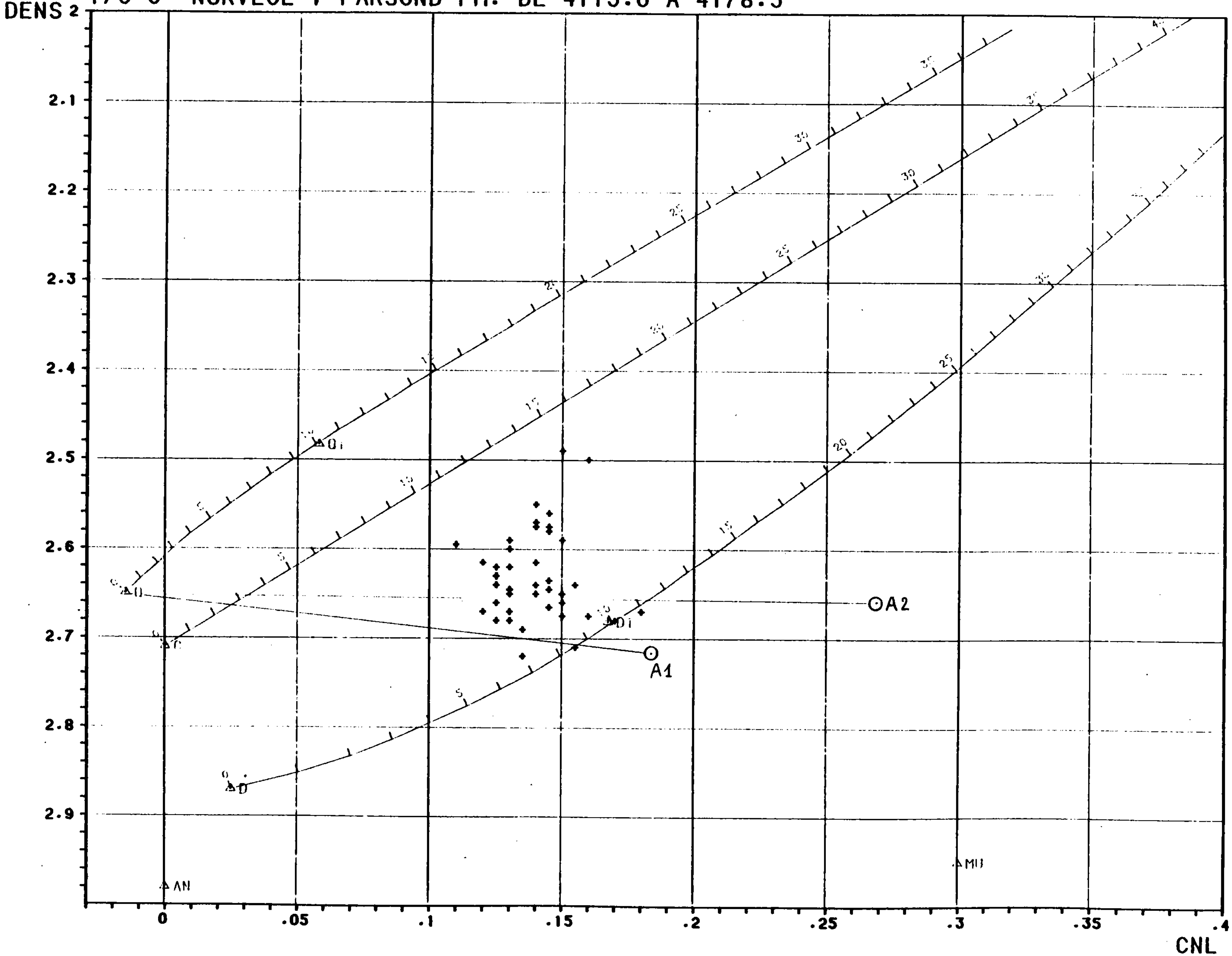
An. 3

1/3-3 NORVEGE , FARSUND FM. DE 4113.0 A 4178.5



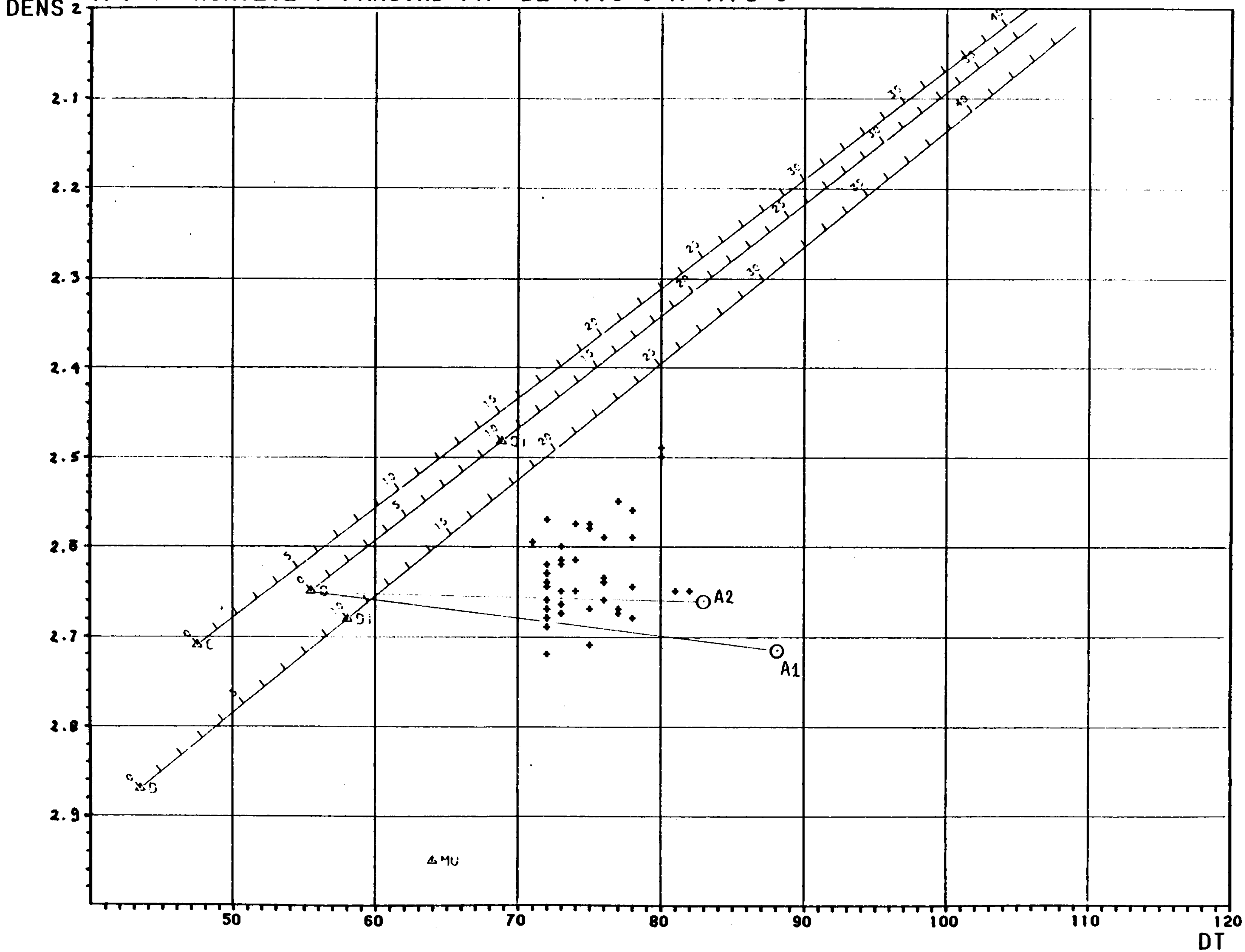
An. 4

1/3-3 NORVEGE , FARSUND FM. DE 4113.0 A 4178.5



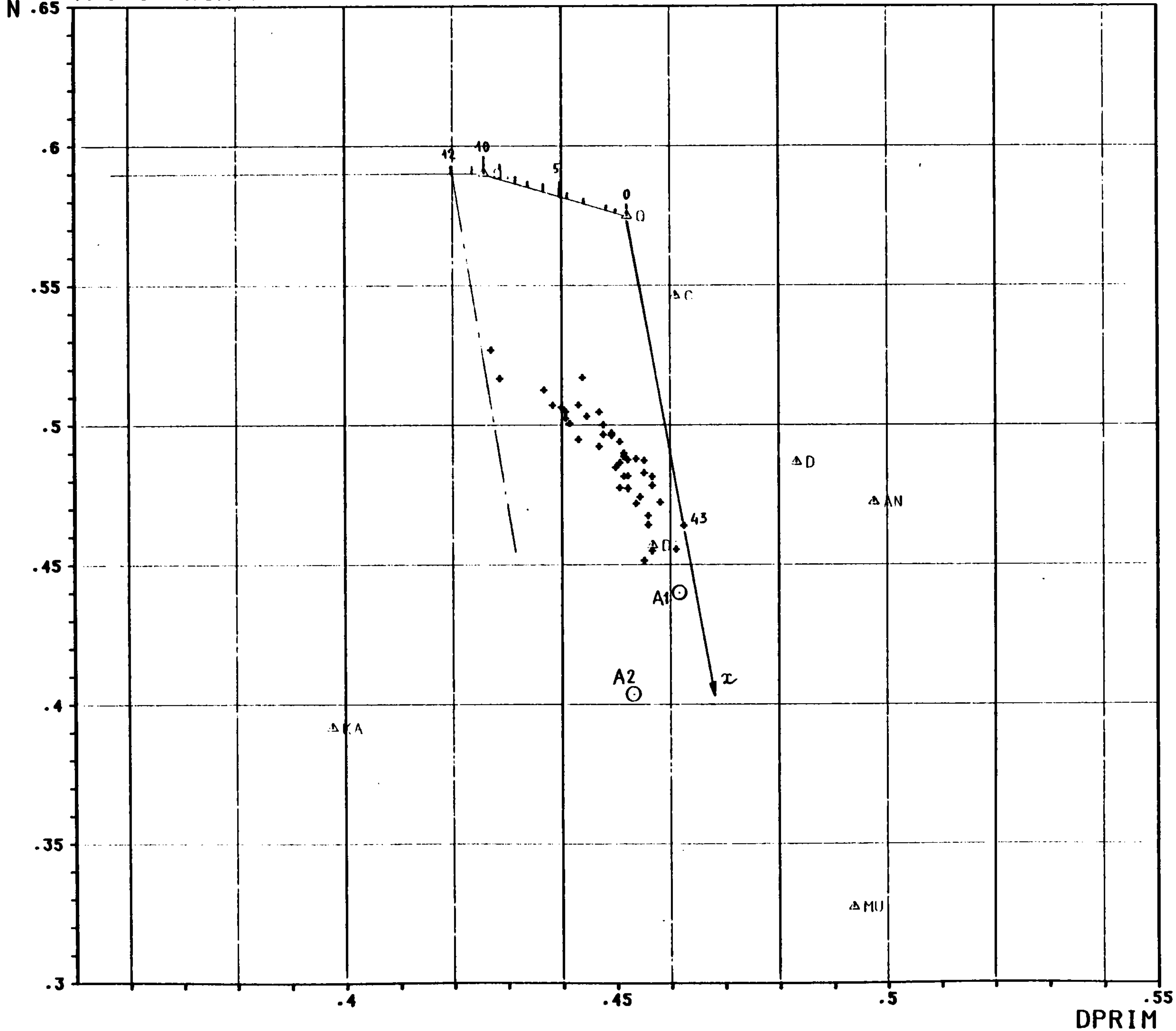
An. 5

1/3-3 NORVEGE , FARSUND FM. DE 4113.0 A 4178.5



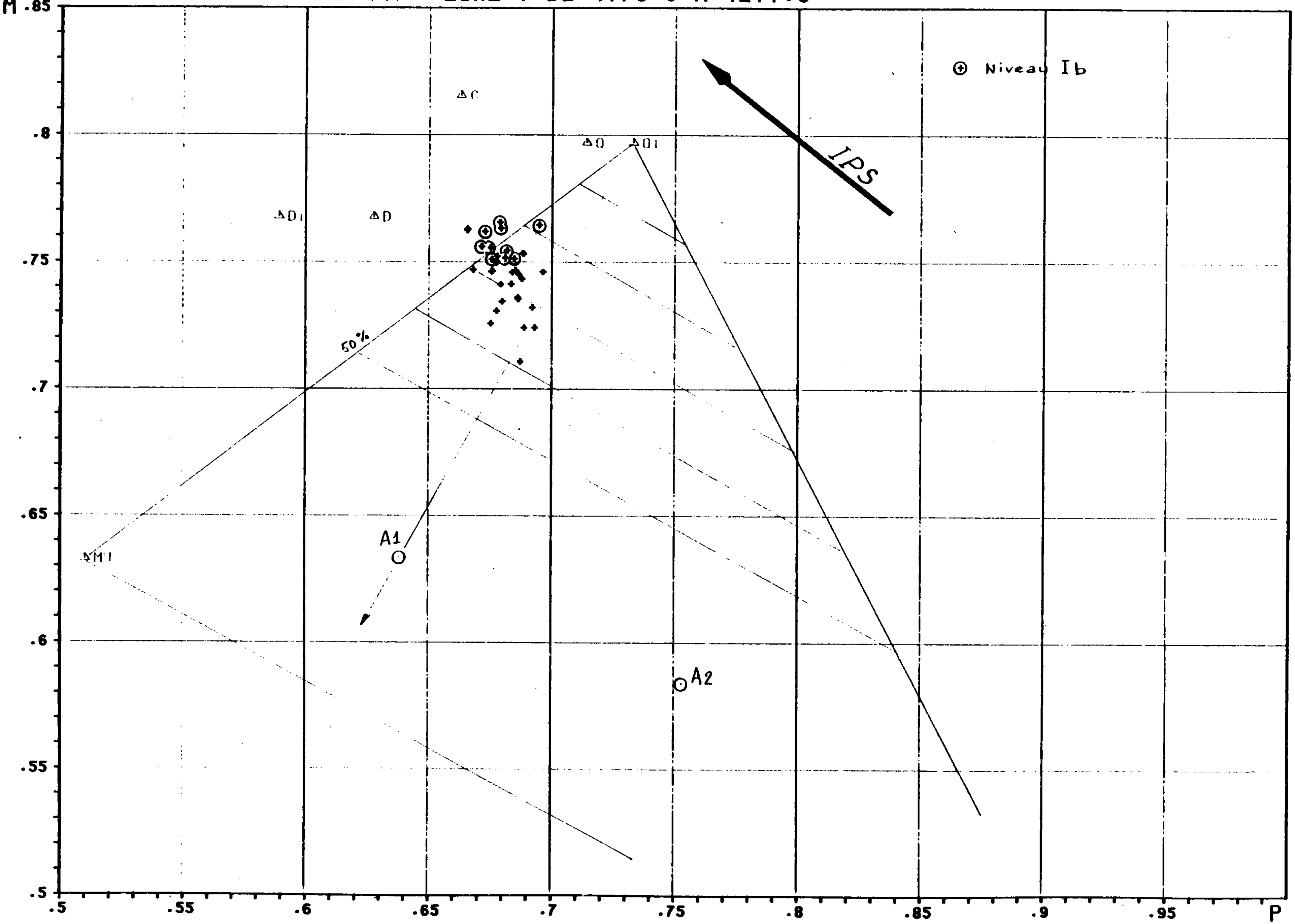
An. 6

1/3-3 NORVEGE , FARSUND FM. DE 4113.0 A 4178.5

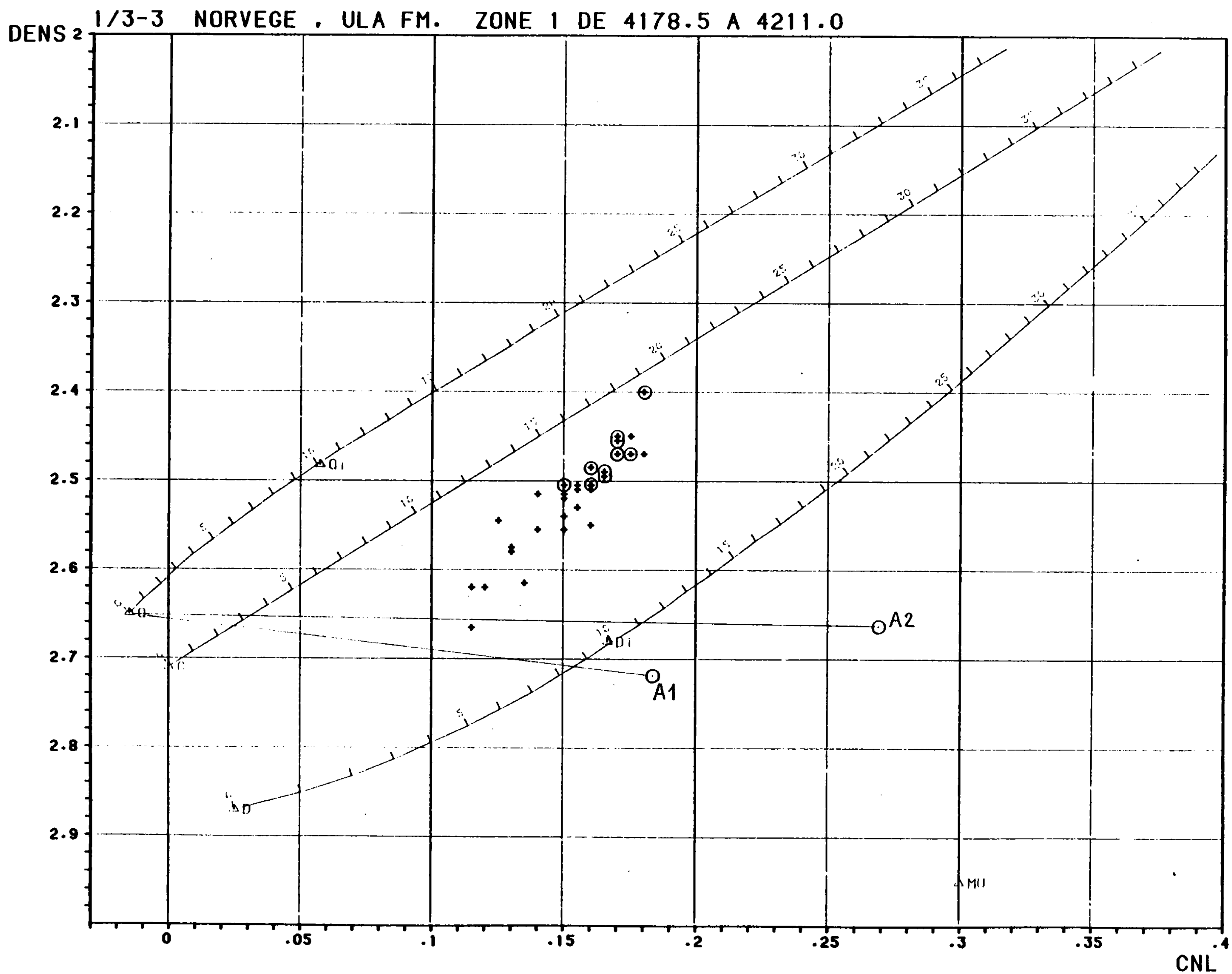


An.7

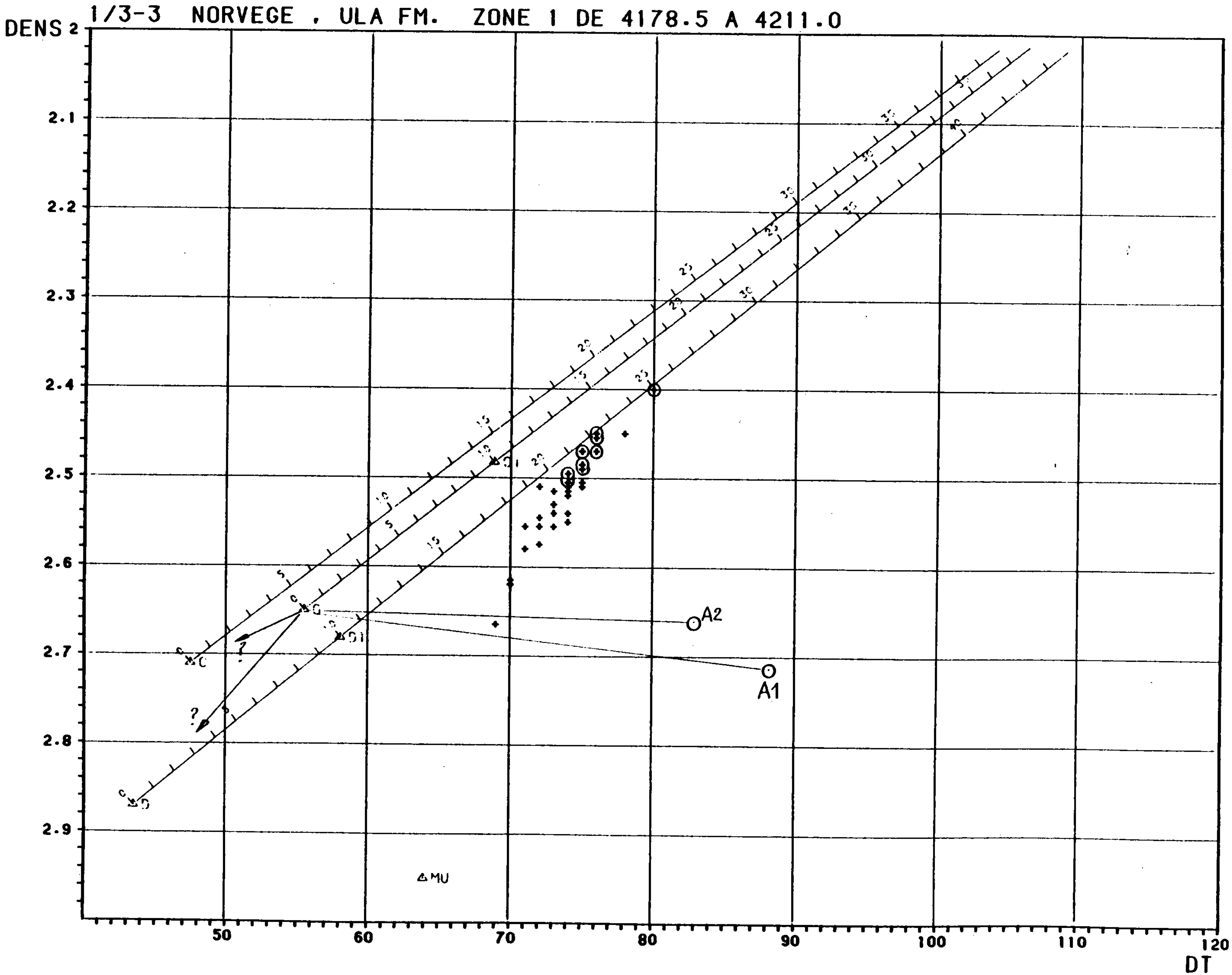
1/3-3 NORVEGE , ULA FM. ZONE 1 DE 4178.5 A 4211.0



An. 8

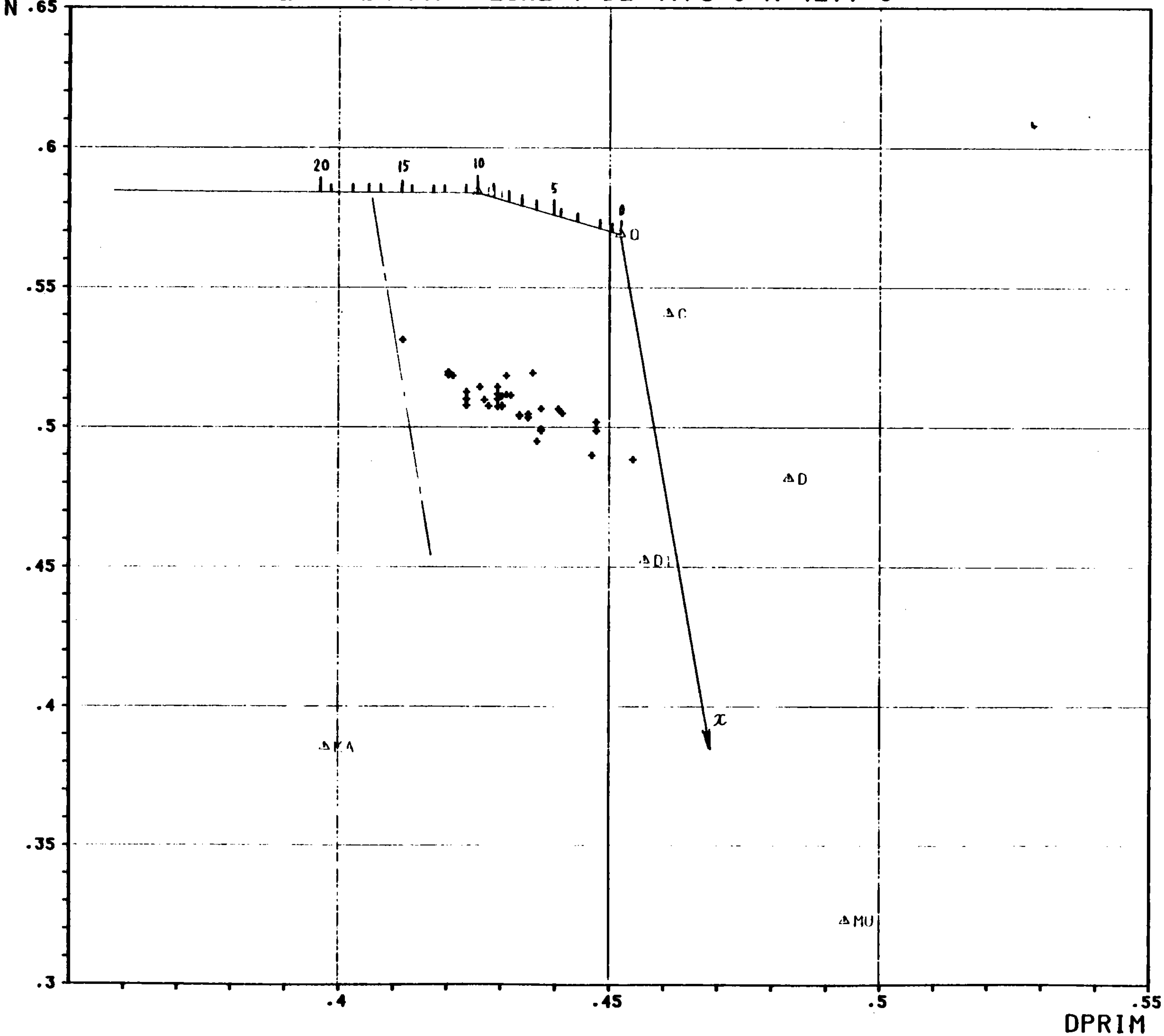

1/3-3 NORVEGE , ULA FM. ZONE 1 DE 4178.5 A 4211.0
DENS 2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
0
.05
.1
.15
.2
.25
.3
.35
.4
CNL
A1
A2
MO

An. 9


1/3-3 NORVEGE , ULA FM. ZONE 1 DE 4178.5 A 4211.0
DENS 2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
50
60
70
80
90
100
110
120
DT
A2
A1
MU

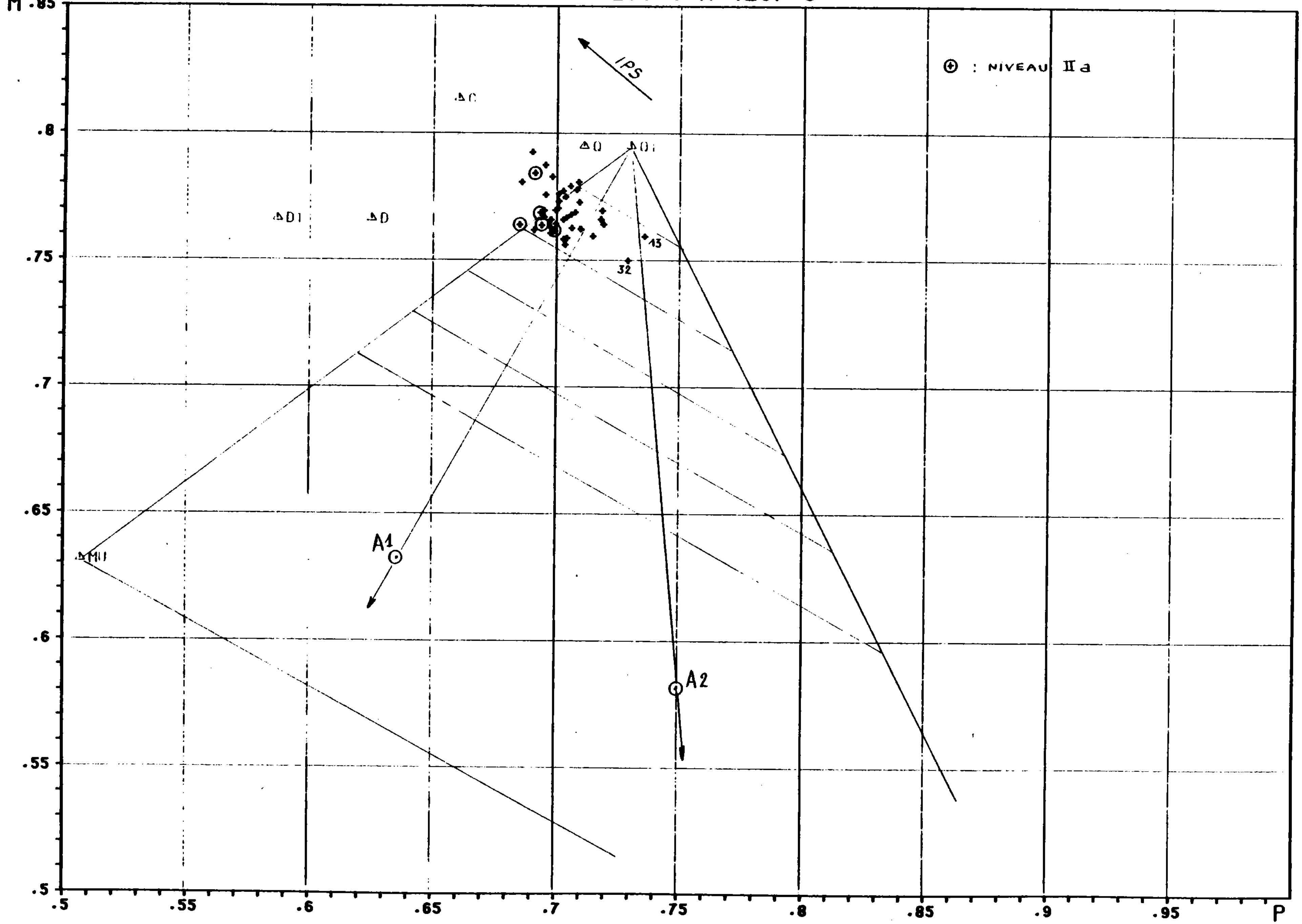
An.10

1/3-3 NORVEGE , ULA FM. ZONE 1 DE 4178.5 A 4211.0

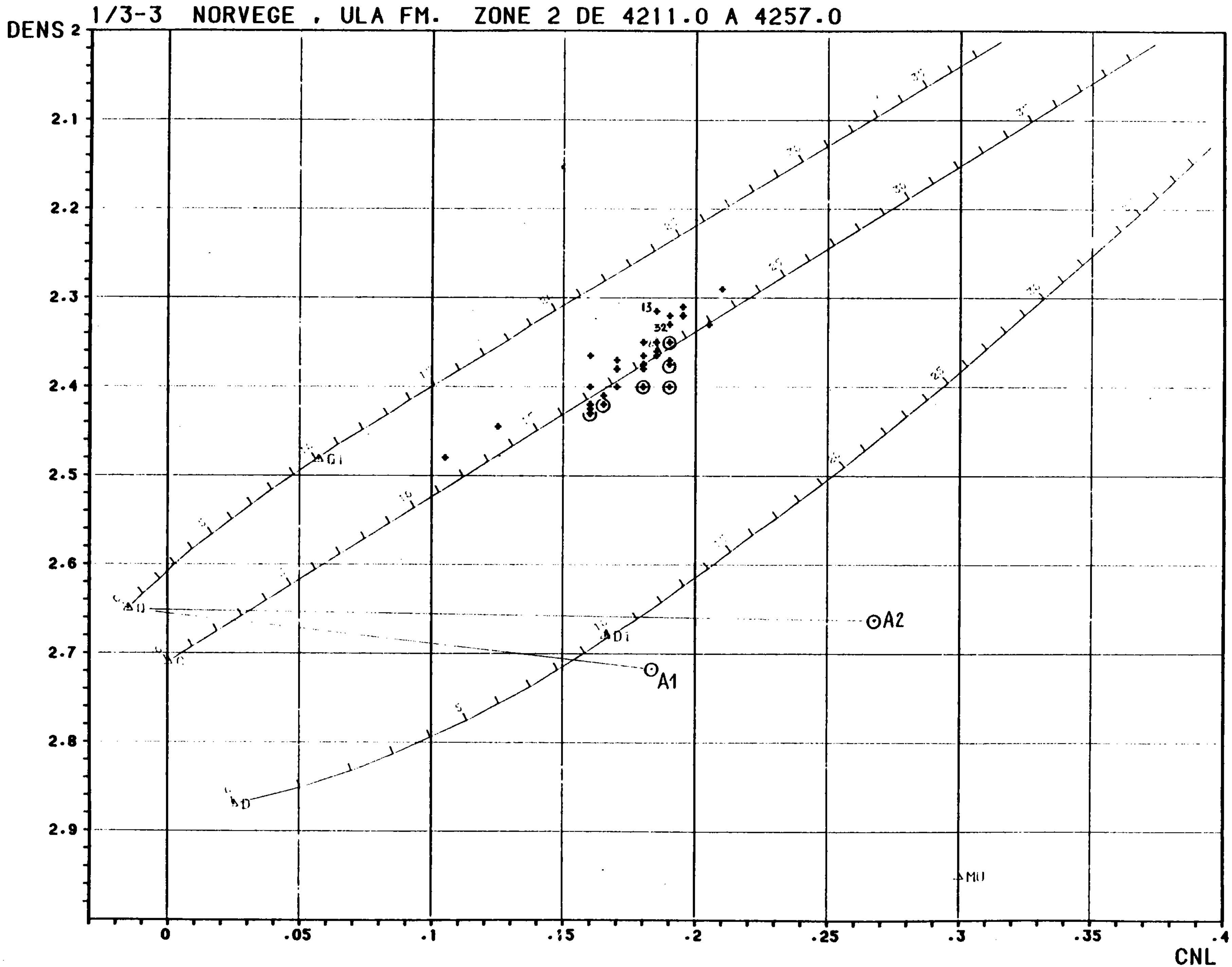


An.11

1/3-3 NORVEGE . ULA FM. ZONE 2 DE 4211.0 A 4257.0

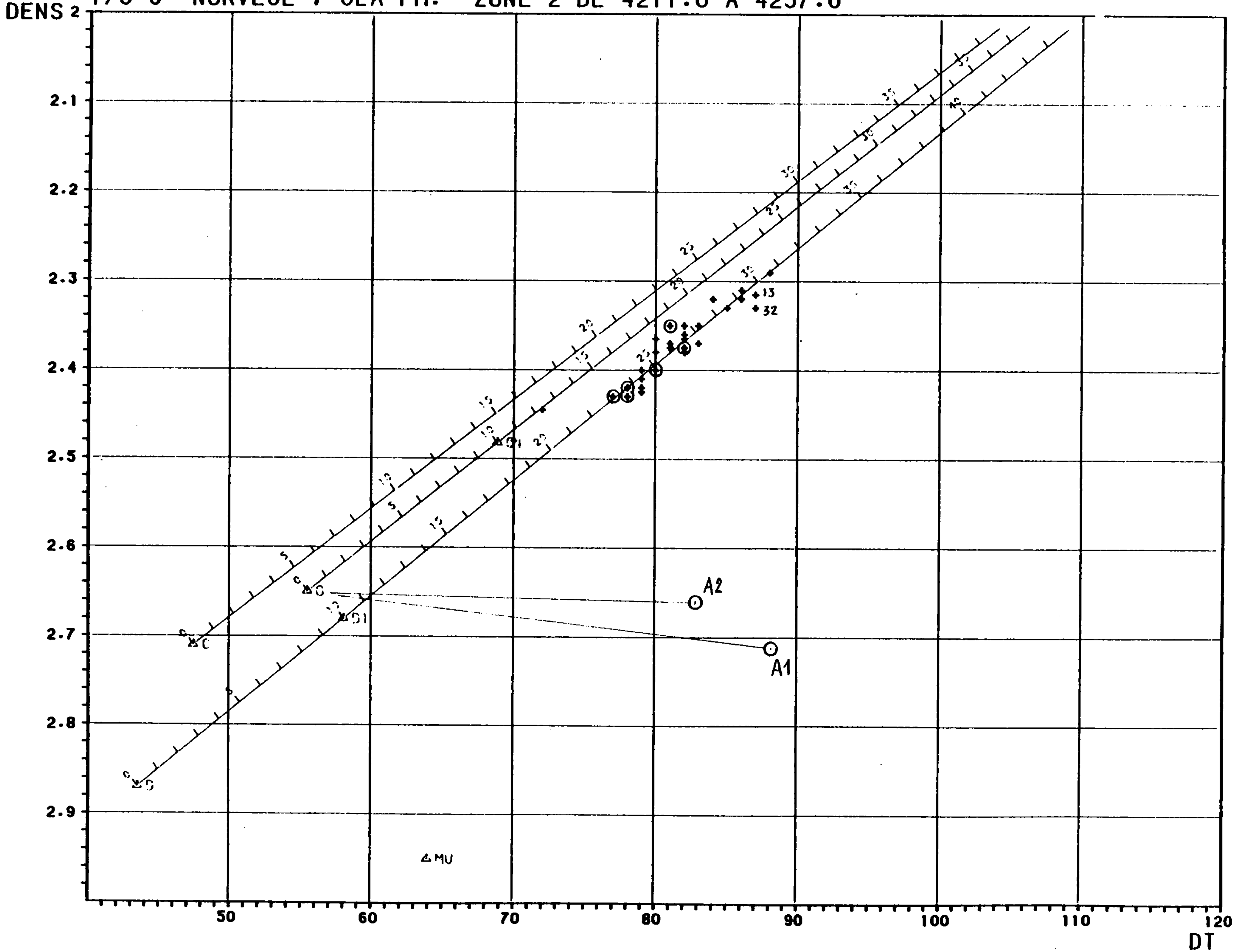


An. 12


1/3-3 NORVEGE , ULA FM. ZONE 2 DE 4211.0 A 4257.0
DENS 2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
0
.05
.1
.15
.2
.25
.3
.35
.4
CNL
A1
A2
MU

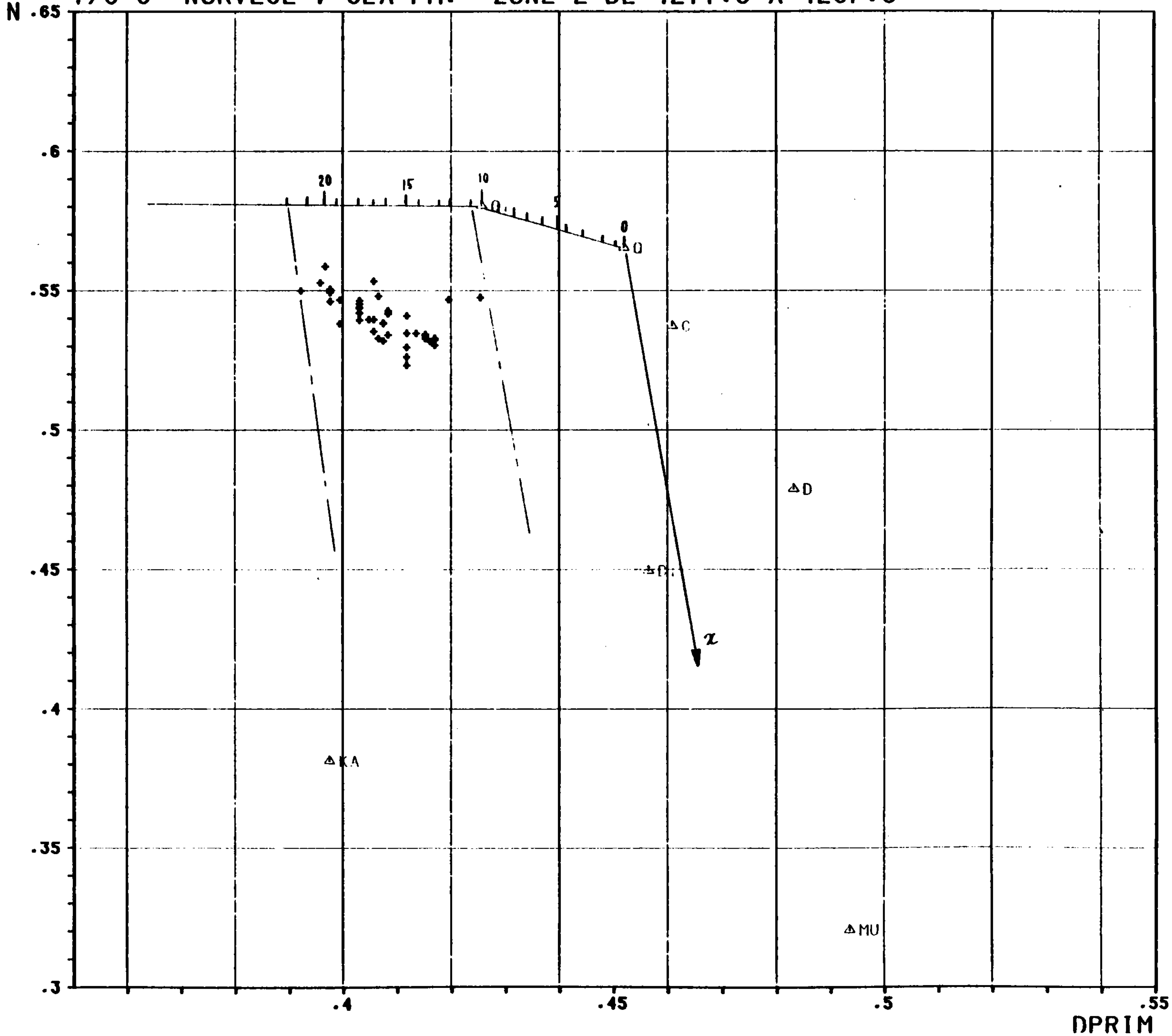
An.13

1/3-3 NORVEGE . ULA FM. ZONE 2 DE 4211.0 A 4257.0



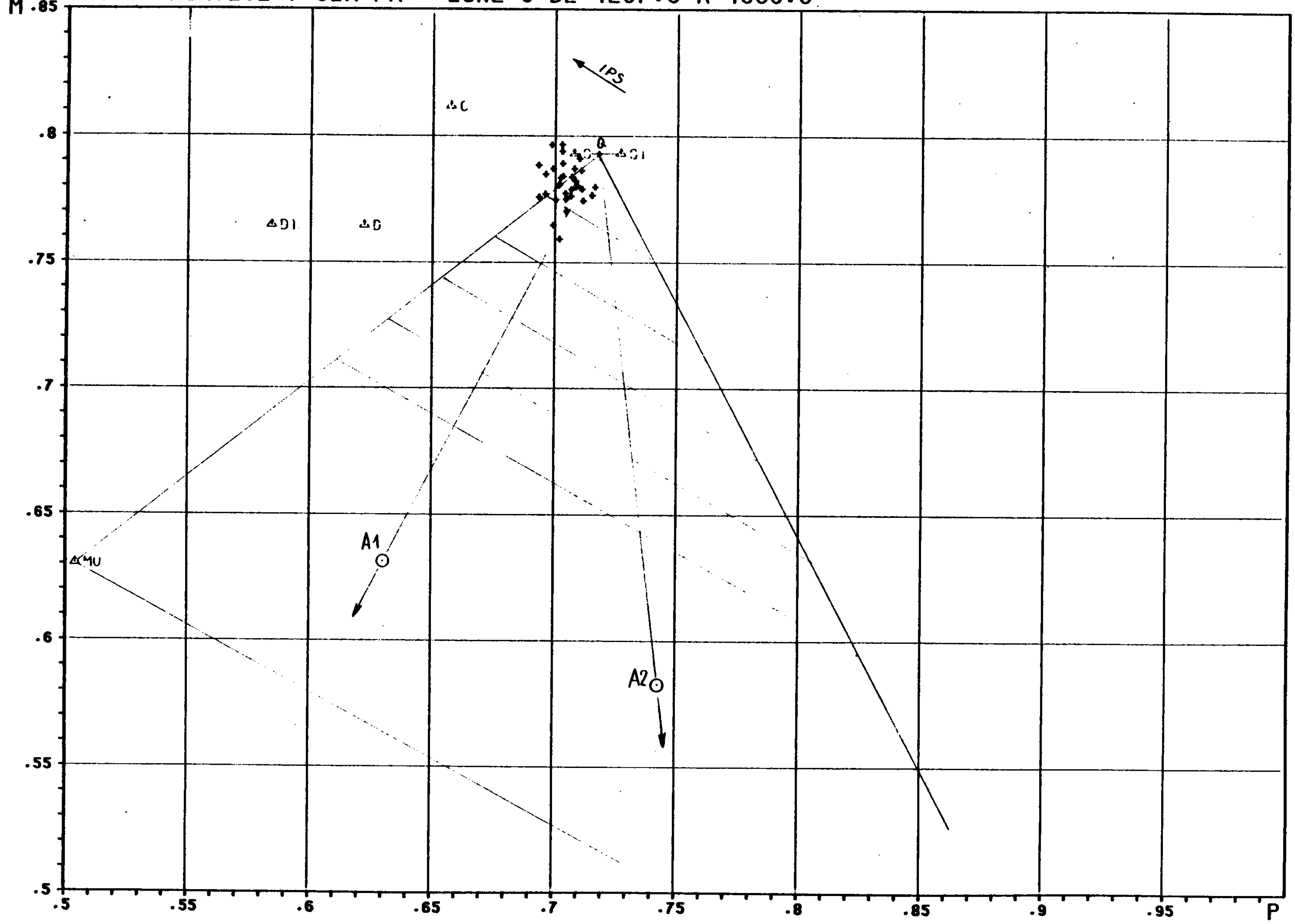
An.14

1/3-3 NORVEGE . ULA FM. ZONE 2 DE 4211.0 A 4257.0

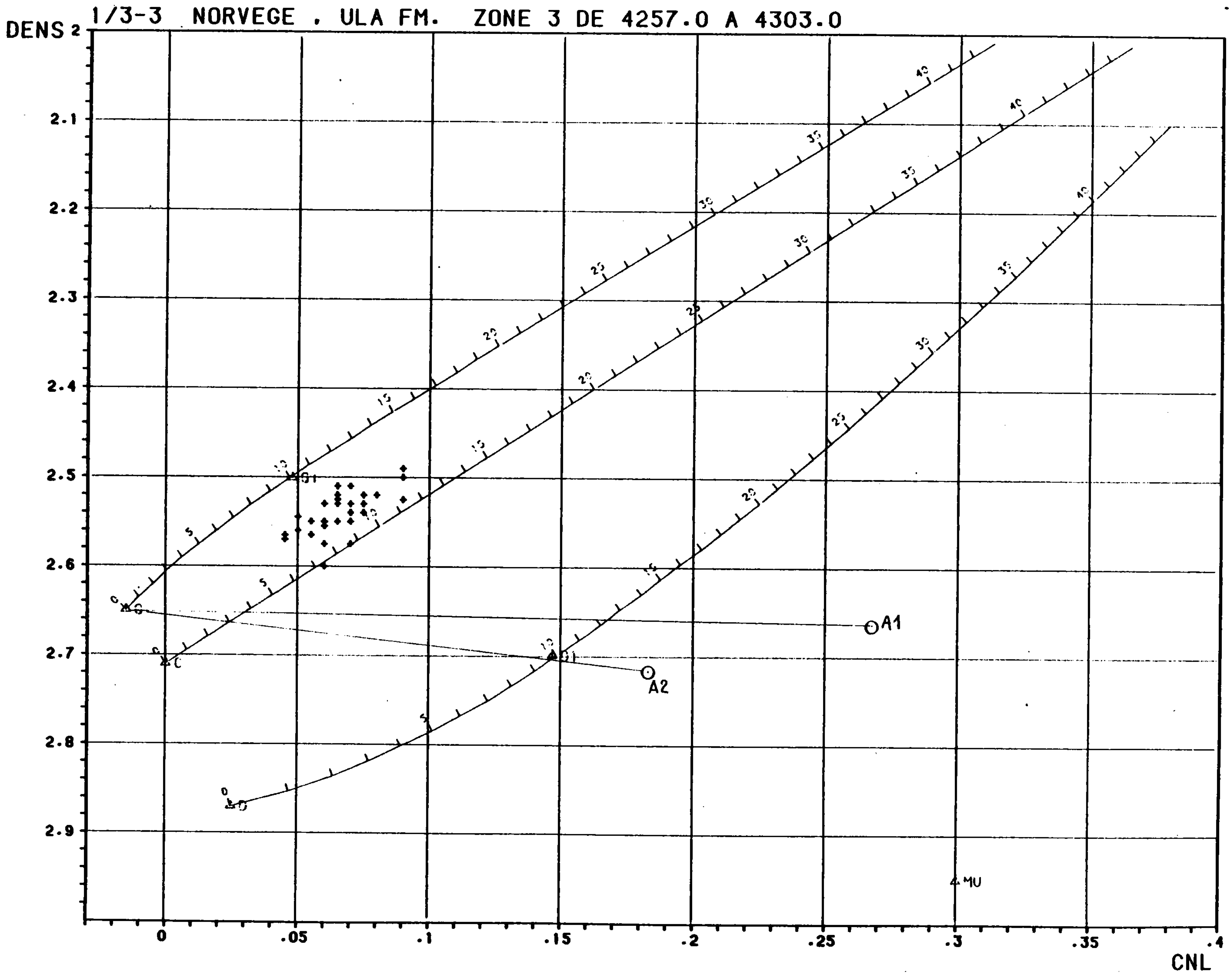


An.15

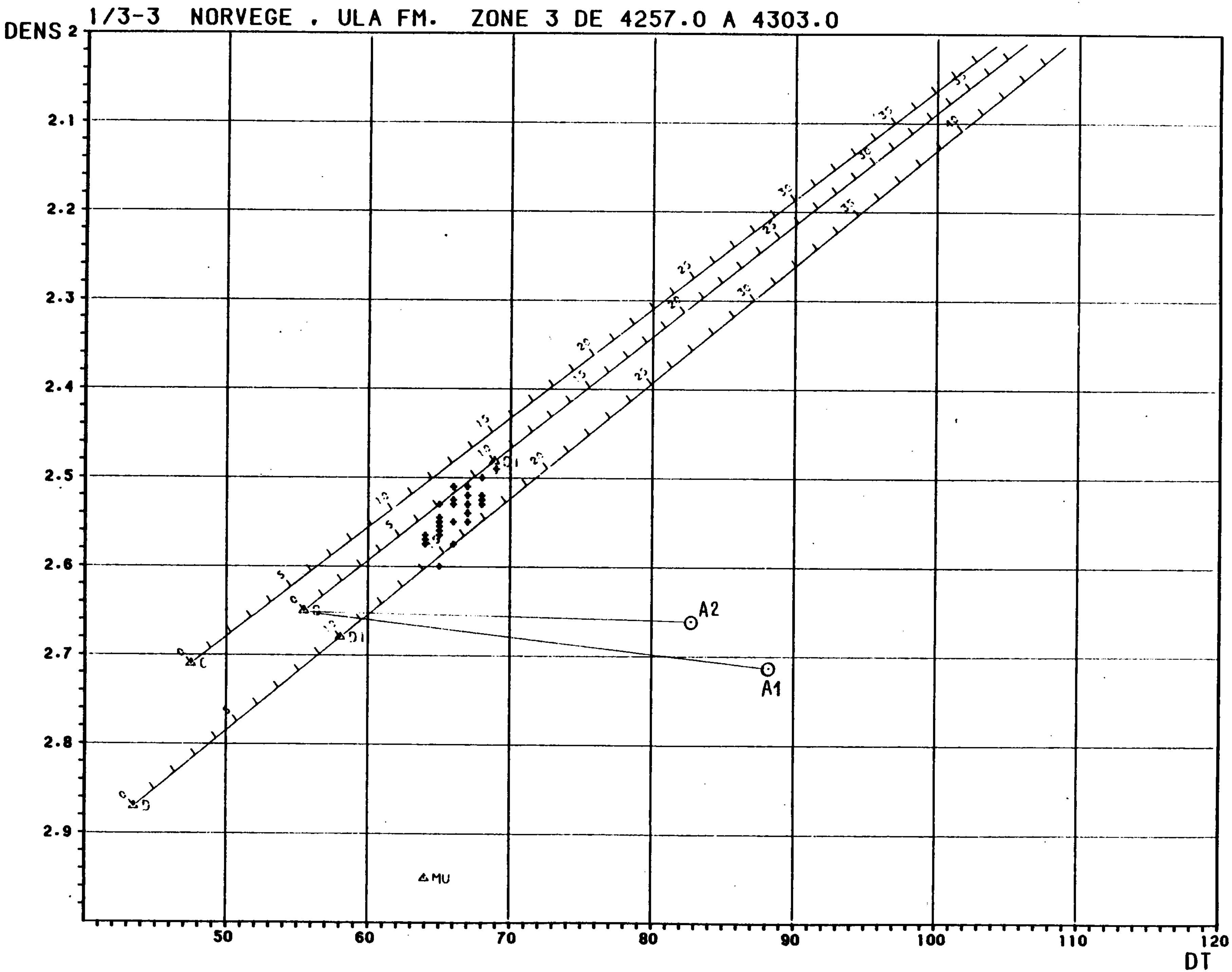
1/3-3 NORVEGE , ULA FM. ZONE 3 DE 4257.0 A 4303.0



An.16


1/3-3 NORVEGE . ULA FM. ZONE 3 DE 4257.0 A 4303.0
DENS
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
0
.05
.1
.15
.2
.25
.3
.35
.4
CNL
A1
A2
MU

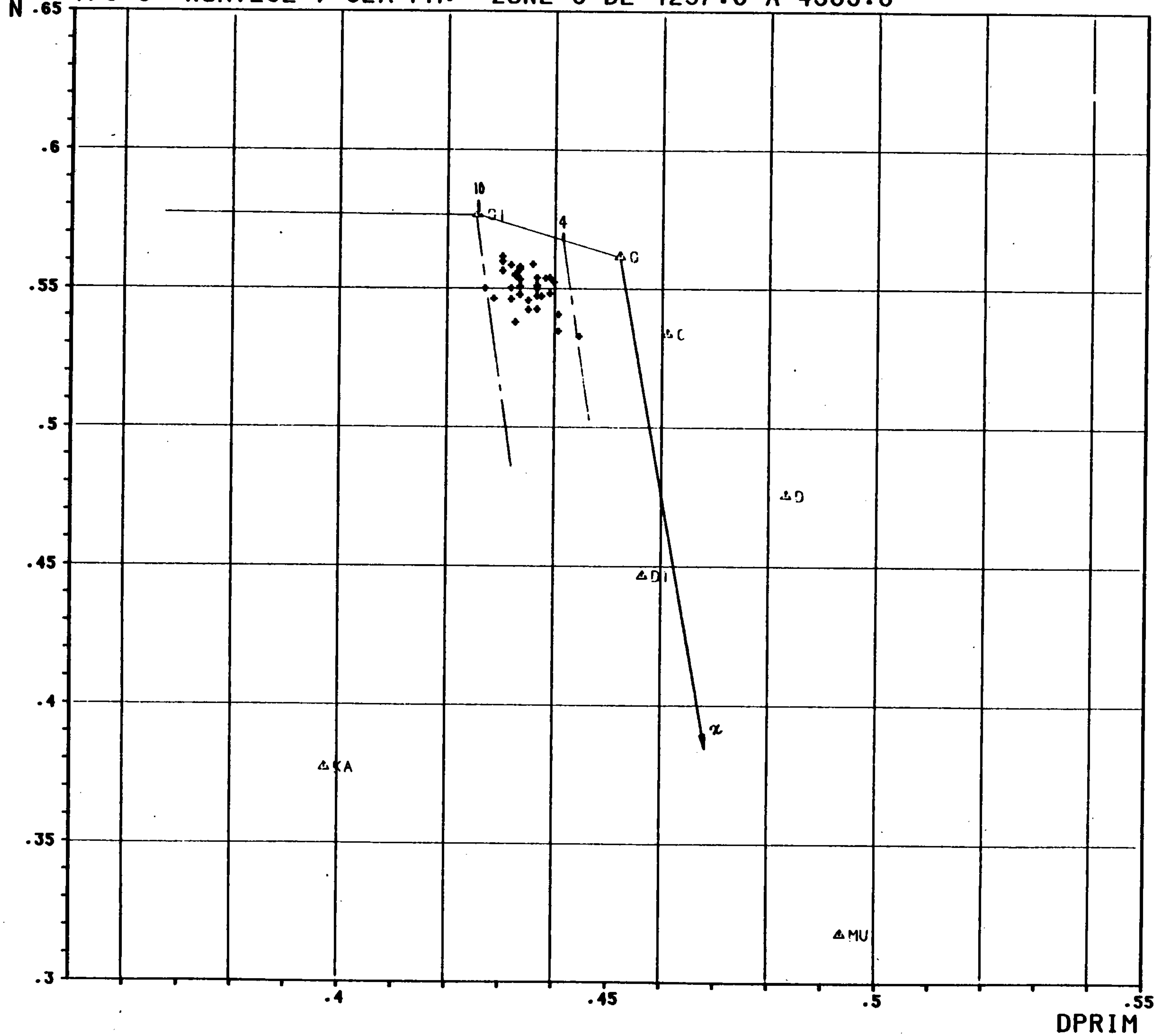
An.17



1/3-3 NORVEGE . ULA FM. ZONE 3 DE 4257.0 A 4303.0
DENS
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
50
60
70
80
90
100
110
120
DT
A2
A1
D1
MU

An.18

1/3-3 NORVEGE , ULA FM. ZONE 3 DE 4257.0 A 4303.0



An.19