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NATURAL GAMMA RAY SPECTRAL LOGGING DATA AS ENVIRONMENT INDICATORS

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ABSTRACT

Natural gamma rays originate from the radioactive isotope of potassium and the radioactive elements of the uranium and thorium series. Each of these three groups of elements contributes its distinctive spectrum to that of the formation in proportion to its abundance.

Thus, by analysis of the formation spectrum, the presence of each can be detected and its amount estimated.Scince, the distribution of these radioactive elements reflects sedimentary processing and products, natural gamma ray spectral data can be used as environment indicators.

In this work, two examples from the middle portion of the Gulf of Suez area were taken to study environment during Mesozoic Era using well logging data.

INTRODUCTION

The gamma ray log is a record of a formation's radioactivity. The radiation emenates from naturally occurring potassium, uranium and thorium. The simple gamma ray log gives the radioactivity of the three elements combined while the spectral gamma ray log shows the amount of each individual element contributing to this radioactivity.

The basic measurement principles of the spectral gamma ray tool (NGT) have been presented in some litratures such as [3,8 and 11].

In essence, the tool measures the emitted natural gamma ray spectrum over the energy range of about 0.5 to 3.0 Mev in five appropriately chosen windows. The counting rates in the five measurement windows are then used to estimate the individual contributions of potassium, uranium and thorium to the total gamma ray single.

In any systematic attempt to interpret a gamma ray log, the values recorded on the log must be corrected for changes in the position of the detector in the borehole, the diameter of the borehole and the density of the fluid within, the thickness of casing and cement and the axial thickness of the formation using any published charts like those of Dresser Atlas [2] and Sclumberger [12].

Various authors have suggested that radioactive characteristics of sedimentary beds have geologic significance. Adams and Weaver [1] asserted the thorium to uranium ratios indicated sedimentary processes. Similary, Whitfield et al. [14] examined the relationship between petrology and thorium-uranium contents of some granitic rocks.Also, Quirein et al. [9] used thorium and potassium contents to identify different types of clay minerals, heavy minerals and evaporites.

GEOCHEMICAL BEHAVIOUR OF POTASSIUM, URANIUM AND THORIUM

The constituents of a sedimentary formation whether radioactive or not are derived from the alteration of igneous rocks. The radioactive elements are librated and dispersed and may be locally concentrated during sedimentary cycles and diagenesis. Therefore, geochemical studies of these elements are necessary for recognition of depositional environments.

Potassium

There are three natural isotopes of potassium ^{39}k, ^{40}k and ^{41}k.Their respective proportions on the Earth are 93.1%, 0.0199% and 6.88%. ^{40}k is the only radioactive isotope. Potassium emits gamma rays at a single energy of 1.46 MeV. The ratio ^{40}k/ total k is very stable and constant on the Earth and provides a direct indication of the total amount of potassium in a formation.

The original source of potassium are chiefly the silicic igneous rocks (granite, granodiorite, syenite, rhyolite), in which it is present through potash feldspars (orthoclase, microcline), mica (muscovite, biotite) and a number of other minerals of secondary importance.

During the alteration process, feldspars and micas are largely destored, depending upon the degree of weathering to give clay minerals : illite, interstratified illite, montmorillonite, chlorite, and kaolinite. A small part of total potassium concentration enters into the formation of some of those minerals, but the major part is dissolved by water. In arid regions this large part tends to remain with the product of alteration (residuum). In other regions it is transported by rivers to the sea.

As the depth of burial of shales increases temprature, pressure and ion concentration of the formation water also increase. Montmorillonite disappears progressively by illitization and chloritization and kaolinite is progressively destroyed, during those transformations. The amount of potassium in the clay increases as montmorillonite is transformed into illite through the interstratified illite-montmorillonite stage.

Uranium

There are three natural isotopes of uranium and all are radioactive: ^{234}U, ^{235}U and ^{238}U. Their respective proportions on the Earth are 0.0057%, 0.72% and 99.27%. In sea water the relative concentration of ^{234}U is higher because ^{238}U ions are selectively fixed on $CaCO_3$. The half-lives of uranium isotopes are $2.5x10^5$ years for ^{234}U, $7.1x10^8$ years for ^{235}U and $4.4x10^9$ years for ^{238}U.

The original sourses of uranium are also the silicic igneous rocks in which uranium exists as a number of accessory minerals.

The uranium mineral forms soluble salts, especially the uranyl ion (UO_2^{2+}) and in this form is present in river and sea water. The salts are unstable and pass easily out of solution. From sea or river water, uranium can be fixed and pass into sediments in three geologically important ways (from Rider, 10); chemical precipitation in acid (pH 2.5-4) or reducing (pH 0-0.4) environments, adsorption by organic matter (plants,plankton,shells or animal skeletons) in certain environments and absorption of uranium by phosphates.

The extremely acid, reducing conditions required for direct chemical precipitation of uranium indicated above are found in few natural environments. An environment of stagnant water and a relatively slow rate of deposition is required to produce black shales and this is geologically important.

In general, uranium behaves as an independant constituent; it is not chemically combined in the principal molecules of rocks like potassium, but is loosely associated with secondary components.

Thorium

There is only one long-lived thorium isotope: ^{232}Th, other isotopes (^{234}Th, ^{230}Th) are found in nature as daughters of ^{238}U, but they are relatively short-lived and therefore very rare.

Like uranium , thorium has its origins mainly in the silicic igneous rocks. However, it is exteremely stable and unlike uranium, will not generally pass into solution. For this reason, it is found in bauxites (residual soils). Thorium and its minerals find their way into sediments principally as detrital grains. They are typically heavy minerals such as zircon, thorite, epidote and sphene. They are all very stable.

Thorium minerals may be found as silt-size particales in placer concentrations, but occur more generally distributed throughout most shales where thorium seems to become fixed by adsorption. Moreover, because of its detrital nature and consequent transport by current, thorium shows an affinity for terrestrial minerals and amongst the clay minerals for example is abundant in kaolinites (of terrestrial origin) than in glauconite (of marine origin) [6].

APPLICATIONS OF GAMMA RAY SPECTRAL LOGGING

A sedimentary facies is the sum of all the primary characteristics of a sedimentary unit. It is a result of deposition in a given environment and thus possesses characteristics of that specific environment. Hydrodynamic conditions such as current and wave intensity and velocity, water depth, the presence of oxygen and organism etc are among the most important factors which may characterize environments. In ancient rocks, information regarding certain minerals which may have originally deposited with the mass of the sediments, could provide important clues as to the source material and to the chemical conditions of erosion and deposition.

The radioactive elements are useful tool in geological interpretation.The relative amount of Th, U and K as well as Th/U ratio can be employed to differentiate certain sedimentary facies. Hassan et al. gave the following simple principles about the uses of these elements in facies studies :

a) In clean carbonate rocks, uranium is the only element present and their passage to marl is signaled by thorium and potassium. Concentration of uranium greater than 3 to 4 ppm may indicate horizon enriched in phosphates and/or organic material, and in certain cases could be related to an abundant stylolite development.

b) In shale series thorium concentration range from 8 to 20 ppm, depending on their content in clay minerals. Potassium normally indicates the presence of micaceous clay minerals, illite and mixed layer clays of the type illite-montmorillonite. High uranium concentrations indicate organic shale facies in which concentration over 100 ppm could be attained.

c) In sand and sandstone formations, thorium is directly related to the clay content. High potassium concentrations are usually due to an abundant presence of mica and potassium feldspars. In rare cases heavy minerals in sufficient quantities are manifested by an excessive thorium content.

d) In evaporite, thorium and uranium are normally absent but certain minerals such as sylvite and carnallite are indicated by high potassium concentrations.

Also, certain minerals are characteristic of specific environments and their recognition by the gamma ray differentiated log could significantly contribute to environmental reconstruction.

Glauconite is strictly a marine mineral which forms mainly in continental shelf environments. It is generally taken as a bathymetric indicator.

Phosphate deposition takes place in a similar environment to that of glauconite, but reducing and warm water conditions.

Mica and feldspars may be used as indicator to the degree of evolution of sand deposits.

Bauxite are restricted to well drained, hot humid continental environments.

Clay minerals have been extensively used in environmental studies in many litratures such as Grim [5] and Keller [7].

Also, Th/U ratio may be used as environmental indicators through identification of geochemical facies in sedimentary rocks. Anyhow, depending on Th/U ratio, geochemical facies can be classified into three types [1]; the low (below 2) Th/U facies, the high (over 7) Th/U facies and the intermediate (2 to 7) Th/U facies.

The low Th/U facies develops in conditions where extraction from sea or frsh water is the major mechanism for the fixation of uranium in sediments. Many marine black shales and phosphate rocks belong to this facies and their uranium content is commonly more than 10 ppm. Carbonate rocks with little admixed detrital silicates also belong to this facies, their uranium content seldom exceeds 3 ppm.

The high Th/U facies may develop in by two ways; the concentration of high Th/U resistants such as monazites in beach sands and placers or the removal of uranium by thorough weathering and leaching, leaving the relatively insoluble thorium behind in high concentration.

The intermediate Th/U ratio facies is thought to reflect poor weathering and rapid deposition of igneous rock detritus or it may arise from mixtures of materials from both low-ratio and high ratio situation. Many gray and green shales and graywackes are thought belong to this inter mediate-ratio facies.

FIELD EXAMPLES

Two wells were taken as examples to explain how natural gamma ray spectral logging data can be used as environmental indicators. These wells were drilled by CONOCO Oil Company in the middle portion of the Gulf of Suez and namely C4SA-1 and C4NA-1.

The study section includes Mesozoic Era which are comprised of the following formations from the bottom to top ; Nubian, Abu Qada-Raha, Wata, Matulla, Brown limestone and Sudr.

Nubian Formation consists of sand, sandstone and shale. Generally Nubian Formation in the Gulf of Suez area is subdivided into Nubian "A", "B", "C" and "D". Nubian "A" is Early Cretaceous while the others may be Carboniferous. Nubian "D" is absent in the study wells.

Abu Qada-Raha Formations are combined in one rock unit in the study section. They are Cenomanian and are composed of sandstone, shale and limstone.

Wata Formation is Turonian and made of limestone interbedded with sandstone and shale.

Matulla Formation is Lower Senonian and composed of sand, sandstone, shale and streaks of limestone.

Brown Limestone and Sudr Formations are Upper Senonian and are made mainly of chalky limestone. Sudr Formation is overlained by Esna Formation of Paleocene.

To study depositional environment in the study area, it should follow the distribution of thorium and uranium as well as Th/U ratio in different formations, because the geochemical behaviours of the two elements vary with the tectonic and basin conditions.

For this purpose, two groups of Th-U crossplots were constructed to show relationship between two elements in the two study wells. (figs 1 and 2).

According to geochemical classification discussed by Adams and Weaver [1] based on Th/U ratio as environment indicators, it is found that Nubian "C" and "B" are high and intermediate Th/U ratio which represents continental to shallow marin environment (figs. 1, f and 2,a). In Nubian "A", the data points indicate intermediate Th/U ratio facies which indicate shallow marine environment (figs. 1,c and 2,b).

In Abu Qada-Raha Formations, the data points are still in intermediate Th/U ratio, but in the same time there is a lot of data points lies in low Th/U ratio facies indicating a gradual advance of the sea (fig. 1,d).

In Wata and Matulla Formations, data points almostly do not change their locations on the Th-U crossplots between intermediate to low Th/U facies as shown in fig.1,e representing Wata Formation and figs. 1,f and 2,c representing Matulla Formation. This indicates a slow change in depositional environment of shallow marin nature.

A great change in the depositional environment is observed on Th/U crossplots representing Brown Limestone Formation (figs. 1,g and 2,d) where most of data points lie in extreme position of low Th/U ratio facies. It is noticeable that uranium concentration has great values which may be due to the presence of uranium-organic compounds as explained by Swanson [13]. This formation is recognizable by this observation which indicates deep marine environment.

In Sudr Formation, data points remain in the low Th/U ratio facies, but uranium concentration shows greatly reduction (figs. 1,h and 2,e) which may refer to sea regression.

The data points representing Esna Formation are in low Th/U ratio facies in spite of increasing of thorium concentration values as result of increasing shale.

The different types of clay minerals which are also environment indicators, can be identified using thorium and potassium data of potassium and photoelectric cross section (Pe) data measured by lithodensity tool [4]. Figs. 3 and 4 represent Th-K and Pe-K crossplots respecively which show the theoretical positions of different types of clay minerals [12]. The comparison between the two crossplots is necessary to differentiate between two clay minerals, their positions are close to each others on any one of these crossplots.

On analysis of the Th-K crossplots of different formations, it was found that Nubiah Formation is charachterized by high thorium concentrations and relative low potassium concentrations, also, the predominant clay mineral is kaolinite. The high thorium concentrations indicate the presence of some heavy thorium-bearing minerals. The presence of low potassium concentration may attribute to libration of potassium ions during alteration of feldspars to kaolinite and transported in solution. Figs. 5,a and 6,a show Th-K crossplots in Nubian "B", while figs. 5,b and 6,b are those of Nubian "A". It is clear that thorium concentration is generally high in Nubian Formation, but it is lesser in Nubian "A".

In Abu Qada-Raha, Wata, and Matula Formations, thorium concentrations decrease until reach a maximum value of about 8 ppm and potassium concentrations remain at a maximum value of 2%. Figs. 5,c and 6,c are Th-K crossplots of Matulla Formation which is an example to clarify this observation. The Brown Limestone and Sudr Formations show considerable reductions in both thorium and potassium concentrations as seen in figs. 5,d and 6,d which represent Th-K crossplots of Brown Limestone Formation as an example.

With the available lithodensity log of the well C4NA-1, some Pe-K crossplots were constructed to identify different types of clay minerals existed in the study section.

From fig. 7,a&b representing Nubian "B" and "A", it is clear that the prodominant clay mineral is kaolinite. Abu Qada-Raha and Wata Formations are absent in this well. Fig. 7,c shows a mixture of montmorillonite, kaolinite and chlorite in Matulla Formation. On the analysis of Pe-K crossplots of Brown Limestone, Suder and Esna Formations, it was found that the chlorite mineral is predominant. Fig. 7,d represents Pe-K crossplot of Brown Limestone

Formation which is taken as an example.

CONCLUSIONS

Natural gamma ray spectral logging data which give the individual concentraion of potassium, uranium and thorium occuring naturally in geologic formations, have been proved to be good environment indicators in the middle portion of the Gulf of Suez.

On the basis of the distribution of the three radioactive elements, the environment in the different formations of Mesozoic Era was recognized in the study area.

Nubian sandstone has high to intermediate Th/U ratio facies which indicates continental to shallow marine environments. Also, this observation is supported by the presence of kaolinite as indicated by both Th-K and Pe-K crossplots. Potassium concentration in this formation is relatively low which may attribute to alteration of feldspars to kaolinite. High Th/K ratio is also observed due to the presence of heavy thorium-bearing minerals.

Abu Qada-Raha, Wata and Matulla Formations lie in the intermediate to low Th/U ratio facies which points to a gradual advance of sea level but in slow rates. The predominant clay mineral is kaolinite in the first two formations, while a mixture of montmorillonite, kaolinite and chlorite is shown in Matulla Formation.

A great change in depositional environment started in Brown Limestone Formation which has great uranium concentrations. This formation lies in low Th/U ratio facies and indicate to deeper marine environment than the anjerlying formations. The high uranium and low potassium concentrations are also indicator of reducing environment. The predominant clay mineral is chlorite. The high uranium concentration characterized this formation makes it a good marker bed.

A considerable reduction in uranium concentration is observed in Sudr Formation, although it still remains in the low Th/U ratio facies which may reflect sea regression. Chlorite is common clay mineral in this formation.

Kaolinite and chlorite are the common clay minerals in the study section as discussed before and without natural gamma ray spectral logging data, it was difficult to recognize on them because they are considered to be noneffective shale due to their very low cation exchange capacity which make the study formation seems to be clean. This leads to missunderstanding interpretation.

So, natural gamma ray spectral logging data plays an important role in well logging interpretation.

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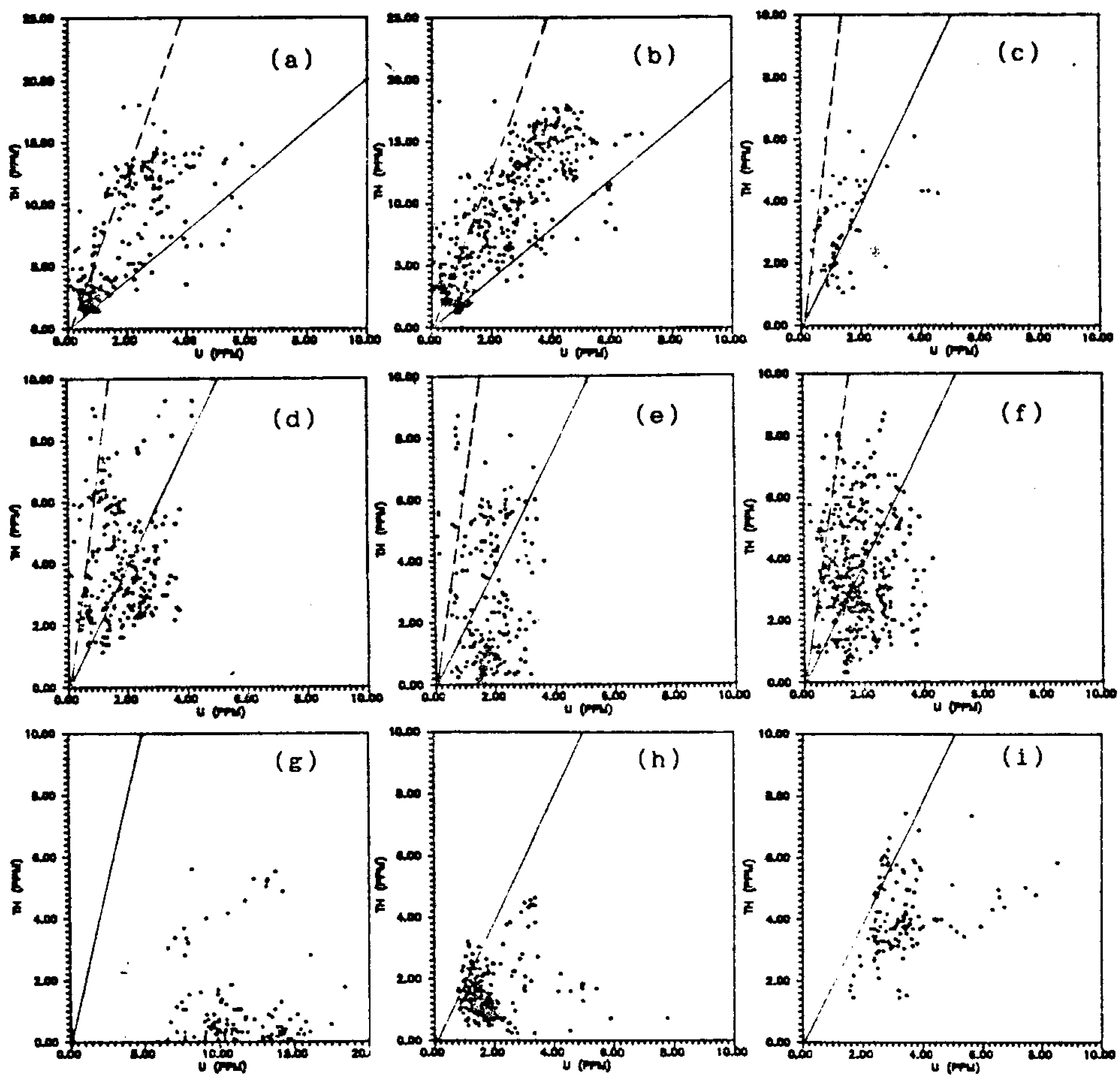

Fig.1 Th-U crossplots of some formations in the well C4SA-1. (--- Th/U=7, —— Th/U=2).

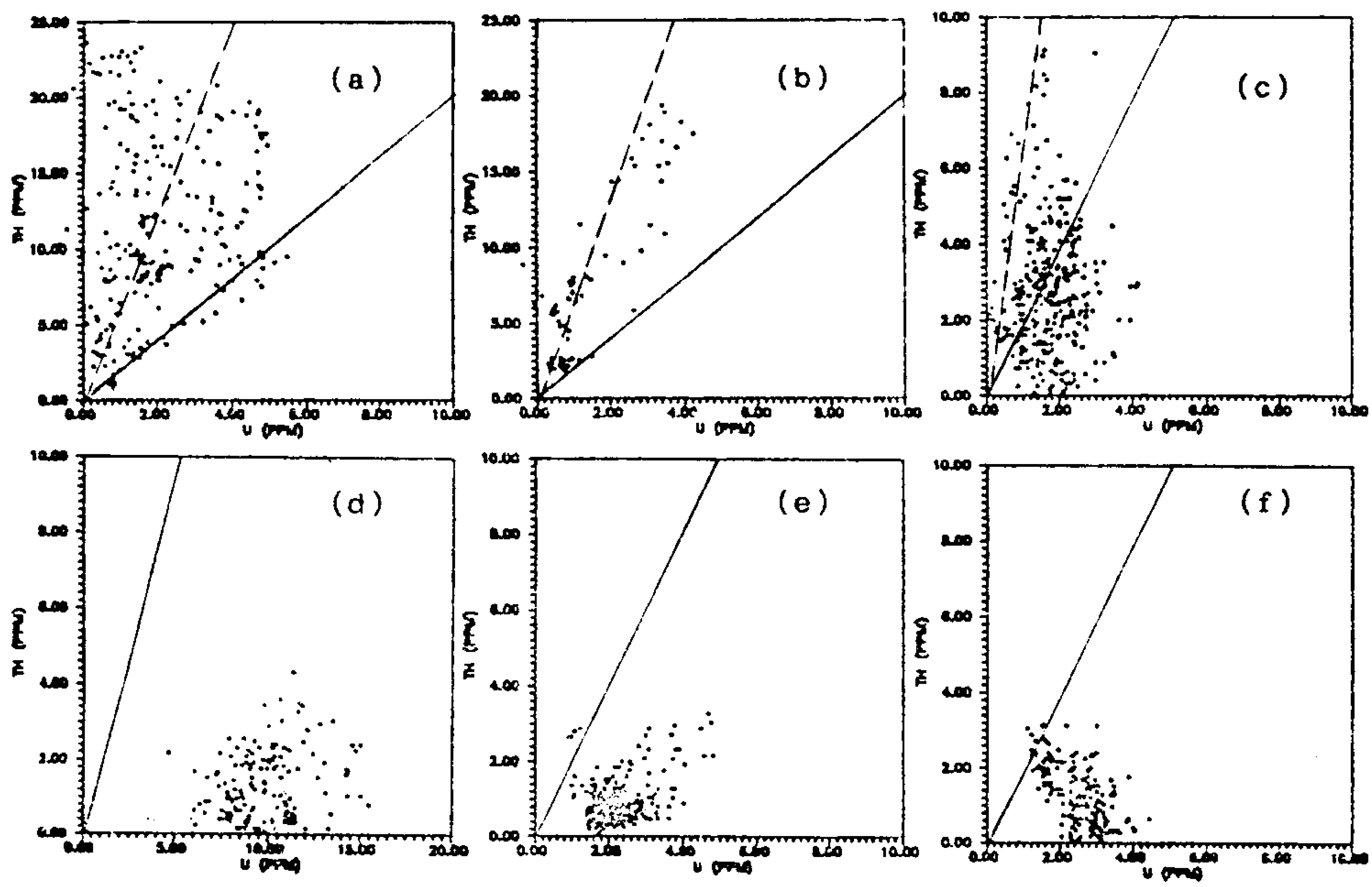

Fig.2 Th-U crossplots of some formations in the well C4NA-1. (--- Th/U=7, —— TH/U=2).

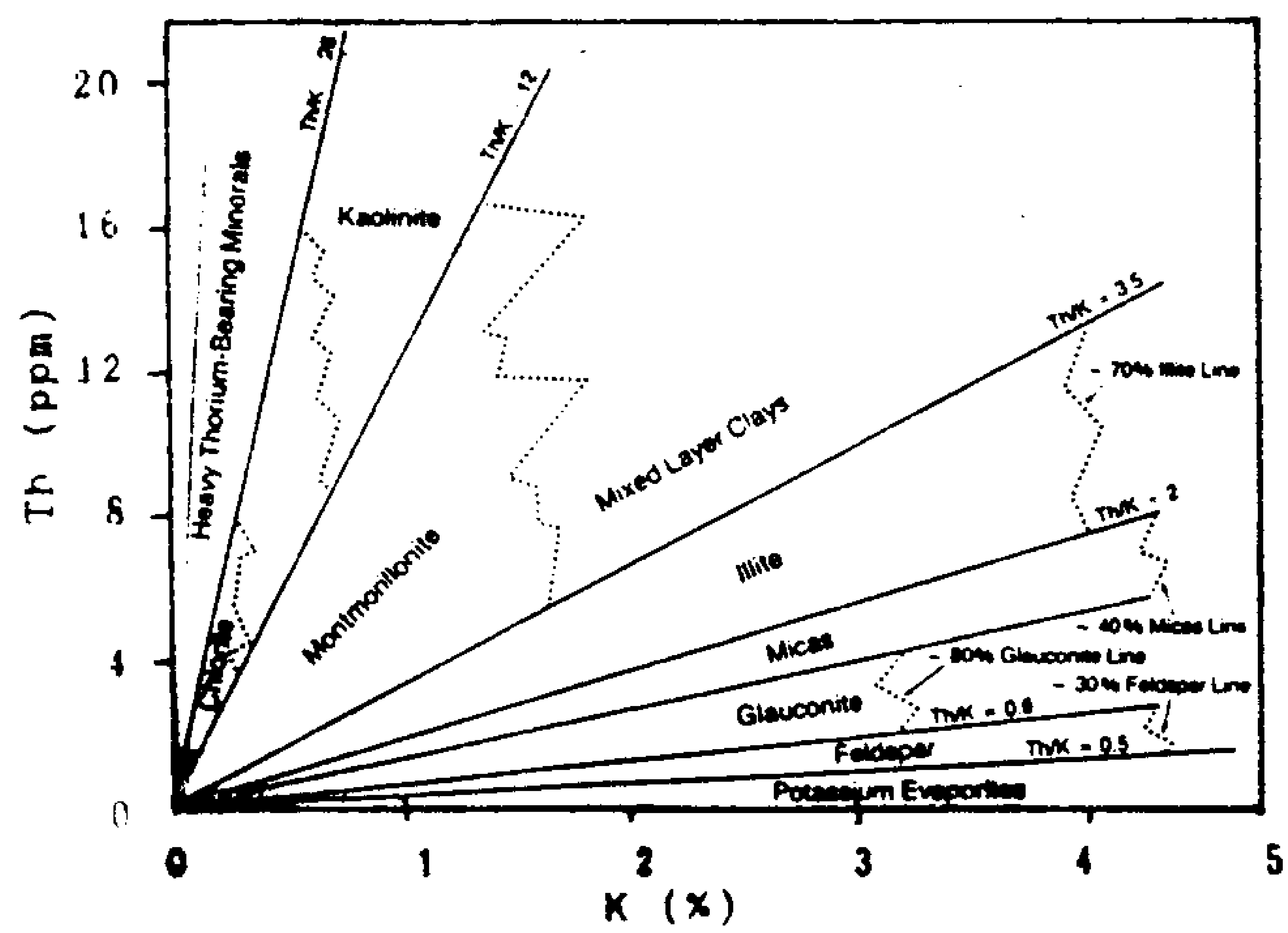

Fig.3 Th-K crossplot for radiactive mineral identification.(from Schlumberger,1986).

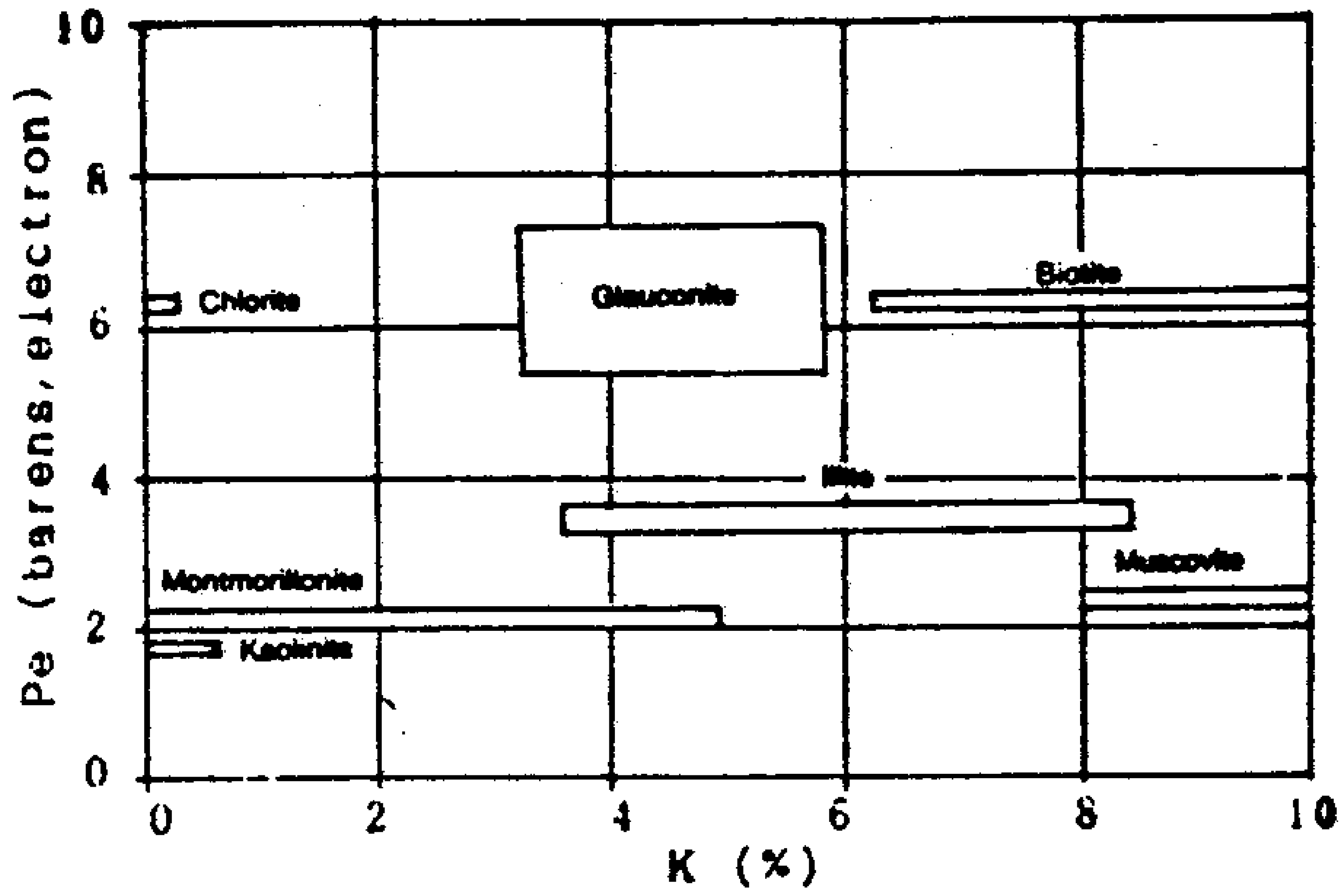

Fig.4 Pe-K crossplot for radioactive mineral identification (from Schlumberger,1986).

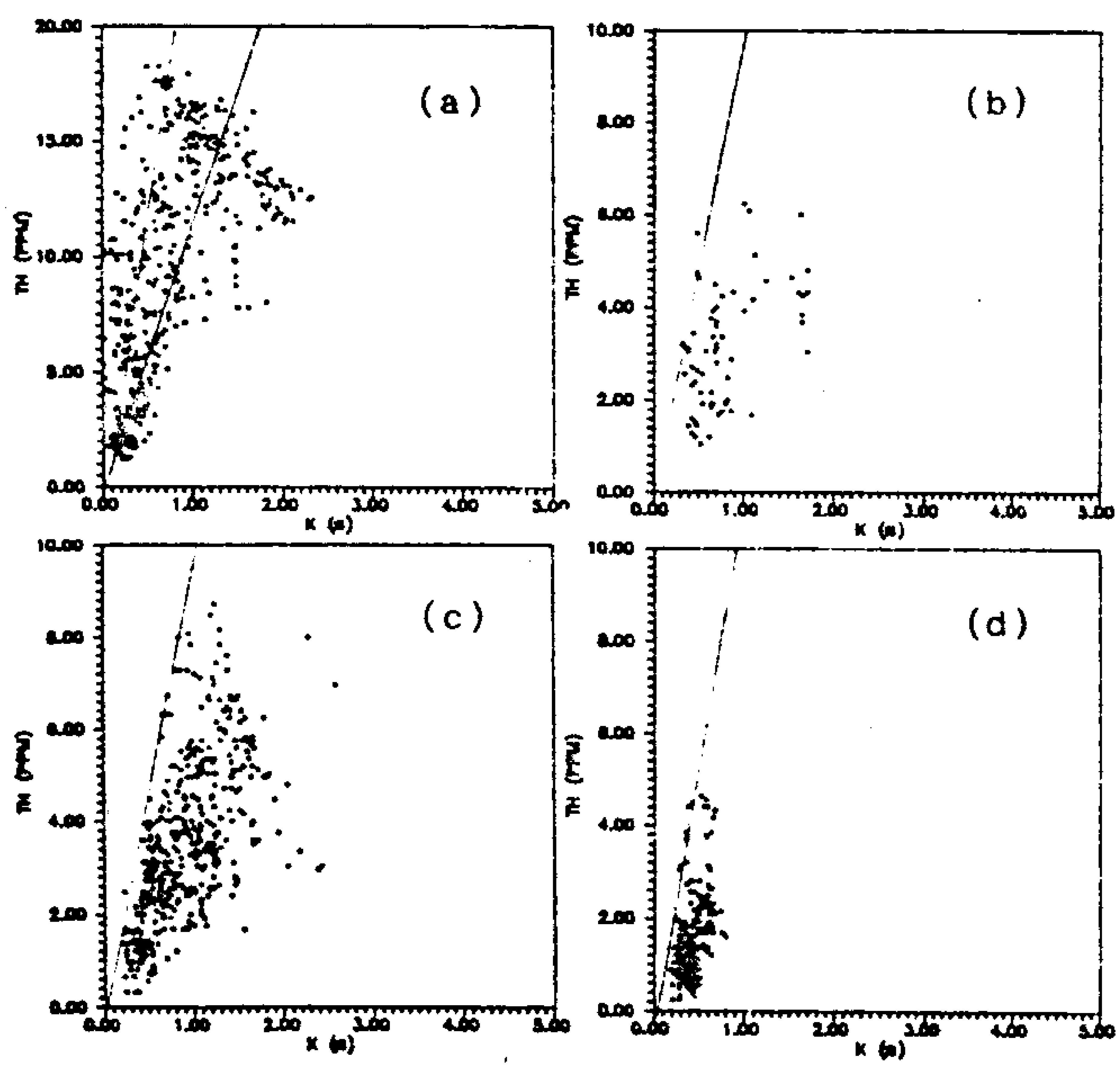

Fig.5 Th-K crossplots of some formations in the well C4SA-1. (--- Th/K=28, —— Th/K=12).

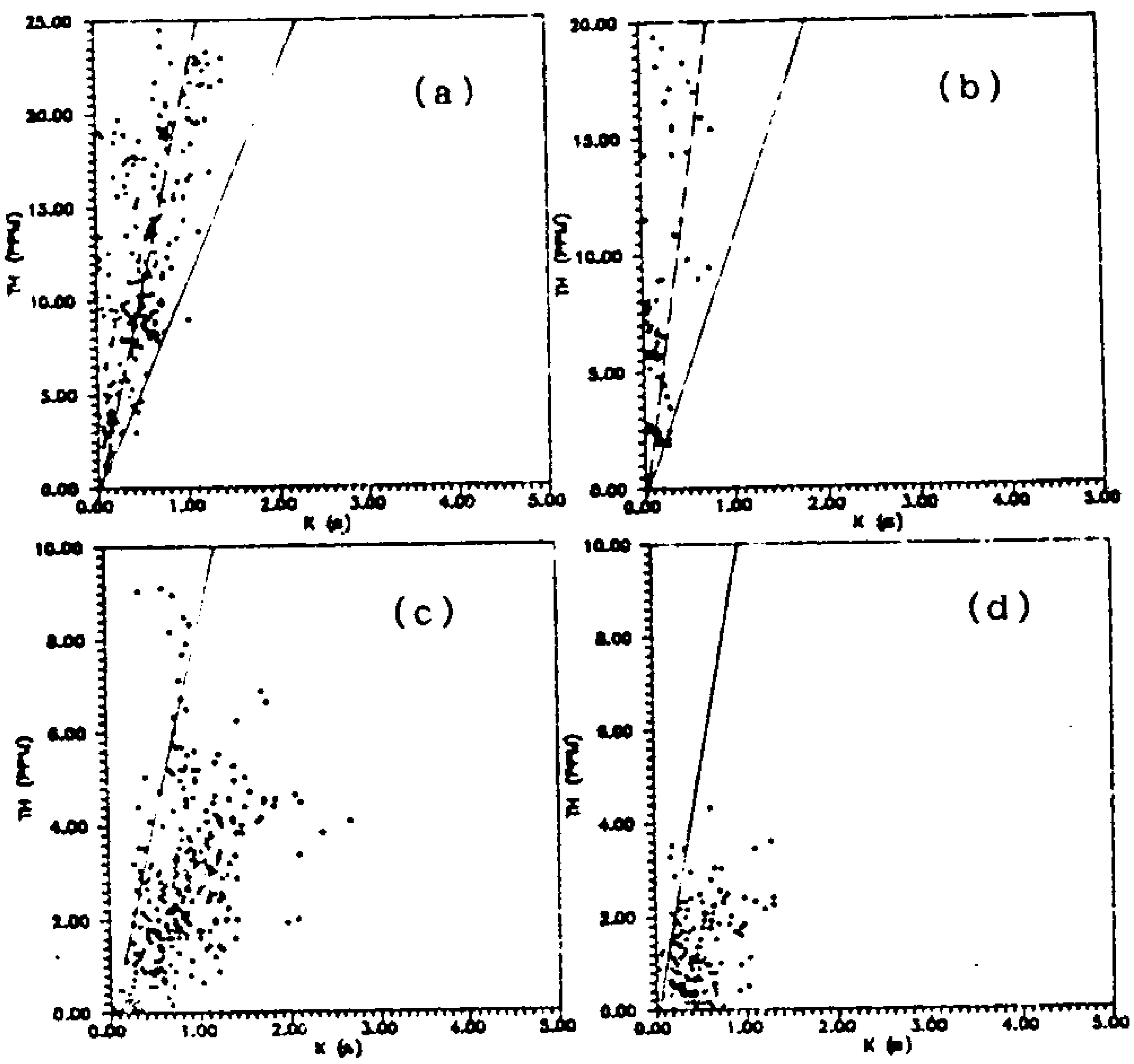

Fig.6 Th-K crossplots of some formations in the well C4NA-1. (--- Th/K=28, —— Th/K=12).

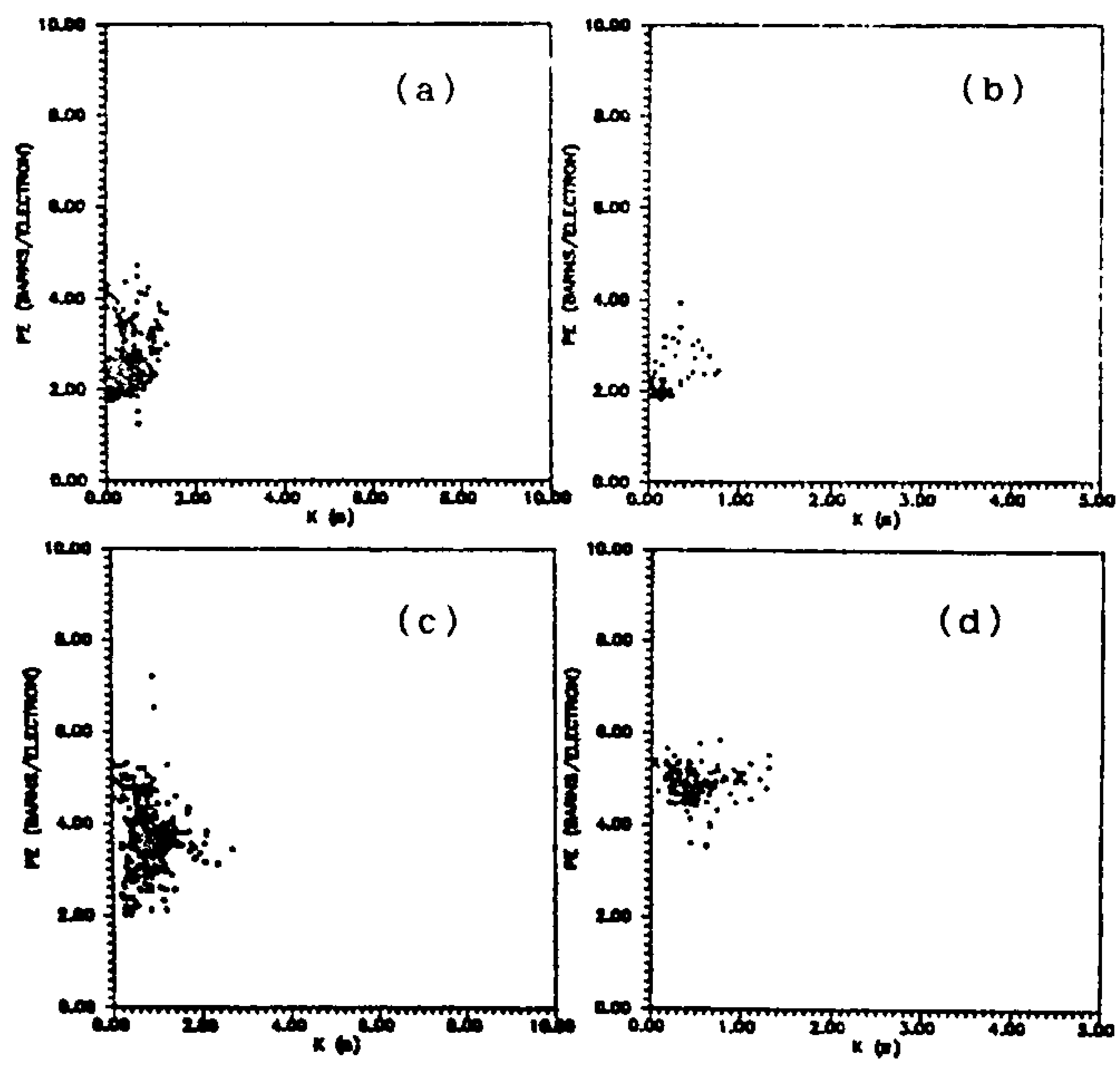

Fig.7 Pe-K crossplots of some formations in the well C4NA-1

معلومات تسجيلات الابار لطيف اشعة جاما الطبيعية للدلاله على البيئة

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اضافت الطرق الحديثه لقياس النشاط الاشعاعى فى الابار التى تحفر من اجل البحث عن البترول الى معرفه العناصر المشعه ونسب تركيزها فى التكاوين الجيولوجيه وذلك بقياس طيف اشعة جاما التى تنطلق بطريقة طبيعية من تلك الصخور ٠

وحيث ان البوتاسيوم واليورانيوم والثوريوم هم اكثر العناصر المشعة شيوعا فى الصخور وان كل منها تتكون تحت ظروف مختلفه فانه يمكن بمعرفه نسب تركيزات تلك العناصر الثلاثه الى معرفه بيئه ترسيب الصخور٠

وقد استخدمت هذه الطريقة بنجاح فى معرفة بيئات الترسيب لمجموعه التكاوين الجيولوجيه لعصر الميزوزويك فى الجزء الاوسط لخليج السويس ٠