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INFLUENCE OF CRYSTALLOGRAPHIC HABIT AND AGGREGATE STRUCTURE OF AUTHIGENIC CLAY MINERALS ON SANDSTONE PERMEABILITY

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SUMMARY

Our studies have shown that shifts in the trend of the permeability/porosity relationship for sandstones may be explained in terms of the crystallographic habit and aggregate structure of authigenic clay minerals. It is also suggested that the specific surface (surface/volume ratio) of the clay minerals (either authigenic or detrital in sandstones) could account quantitatively for the different permeability/porosity relationships and might represent a parameter that could be introduced into conventional permeability/porosity plots.

It is assumed that a high specific surface of the interstitial clay minerals will induce tortuosity and therefore turbulence at higher flow rates and will also cause pore-space reduction by favouring water adsorption on the large available clay-mineral surface.

The thread-like habit often observed for authigenic illite will also cause a division of pore space into a large number of tiny holes, through which fluid flow is much more difficult.

INTRODUCTION

Until now, it has been accepted that intergranular permeability of sandstones depends, for a given fluid viscosity, on the rock's pore and poreconnection properties. The latter in turn are determined by:

(i) primary texture, i.e. median grain size and sorting, and
(ii) diagenetic features, such as degree of cementation and compaction.

These factors, excluding median grain size, also directly determine the porosity of the relevant sandstone. For a given median grain size, therefore, there should be a constant relationship between permeability and porosity.

However, major shifts in the permeability/porosity trend are currently observed which cannot be explained in terms of median-grain-size differences, all other factors being constant (sorting, cementation and compaction). It will be shown that these shifts can be attributed to the crystallographic habit and aggregate structure of authigenic and detrital clay minerals occurring in the pore spaces, by means of an example drawn from the Permian Rotliegend sandstones of NW Europe.

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HABIT AND AGGREGATE STRUCTURE OF AUTHIGENIC CLAY MINERALS

The eolian Rotliegend sandstones of NW Europe are a major gas-producing formation (Glennie, 1972). Depending upon their location, these dune sandstones contain different assemblages of authigenic clay minerals with either kaolinite or illite largely predominating; their total volume varies around 5%.

An authigenic character for these clay minerals is inferred from:

(i) the radiate structure of illite as seen in thin section, a well-known structure (e.g. Carrigy & Mellon, 1964),
(ii) the very narrow range of illite crystallinities (Kübler, 1968) in a given section, and
(iii) the euhedral shape of the kaolinite "booklets" as seen in thin section.

Numerous Scanning Electron Microscope (SEM) analyses have revealed that these clay minerals occur with a very constant crystallographic habit and aggregate structure:

(i) *Kaolinite* has a strong tendency to form compact aggregates ("booklets") of pseudo-hexagonal flakes (fig. 1); the specific surface (surface/volume ratio) is then rather small.
(ii) *Illite* occurs as tiny thread-like crystals of rectangular section and builds intricate networks crossing the pore spaces (figs. 2a & b); the specific surface is then very large. Incidentally, the well defined lath shape of the illite crystallites suggests a crystallographic individuality; the latter in turn may deserve a definition in the future.
(iii) *Chlorite* occasionally occurs in the assemblage and shows a marked tendency to build very individual pseudo-hexagonal plates, more or less perpendicular to the surface of the detrial grains [very much the "Ib type" reported by Hayes, 1970].

INFLUENCE OF CLAY MINERALS ON PERMEABILITY

If one compares the permeability/porosity plot of a section cemented predominantly by kaolinite with that of a section cemented predominantly by illite, the first appears to be shifted towards higher permeability values than the second (fig. 3). As there is no difference in median grain size between the sandstones of these two sections, it must be assumed that the *crystallographic habit* and *aggregate structure* of the two cementing clay-mineral species are responsible for the difference in porosity/permeability relationship.

Fig. 1
SEM photograph of compact kaolinite aggregate in pore space of Rotliegend sandstone.

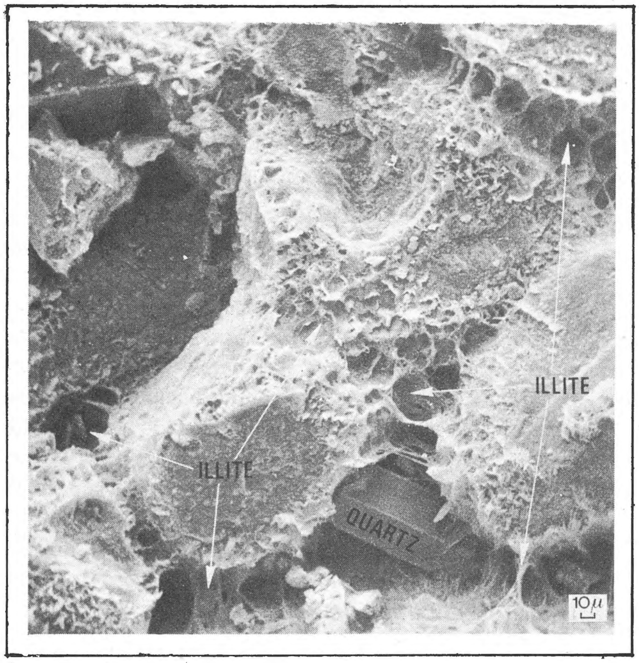

Fig. 2a
SEM photograph of intricate network formed by fibrous illite in pore space of Rotliegend sandstone.

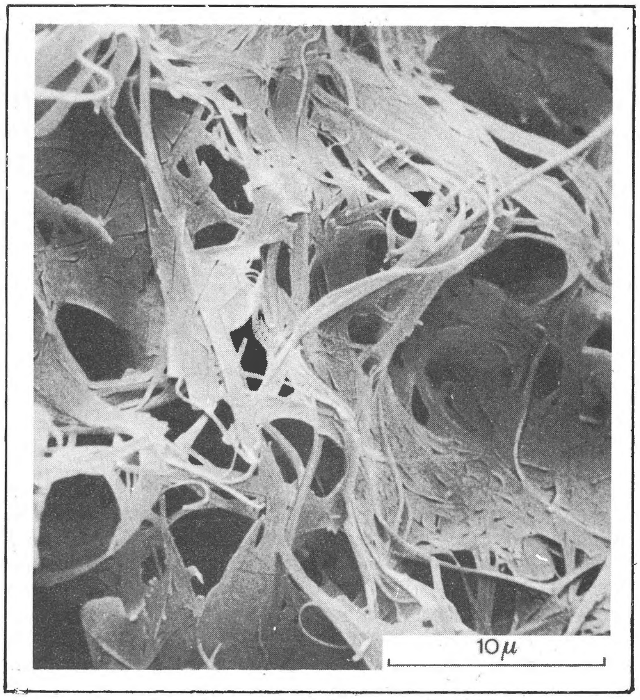

Fig. 2b
Detailed view of the crystal habit of illite grown in pore space of Rotliegend sandstone.

The *compact* aggregate structure of kaolinite probably influences porosity and permeability in the same way as quartz or carbonate cement, i.e. the amount alone determines porosity and permeability values. The *intricate network* built by the illite, on the other hand:

(i) divides the pore spaces into a large number of very thin channels causing increased *tortuosity*; the latter effect will become severe at high fluid-flow rates by inducing turbulence,

(ii) further reduces the pore spaces left because of adsorption of water by the large available crystal surface area (specific surface large, as shown by measurements).

CONCLUSIONS

From the above, it seems likely that differences in the permeability/porosity relationships of sandstones may be accounted for by the different crystallographic habit and aggregate structure assumed by kaolinite and illite in this particular case, provided there is no differnce in median grain size.

More generally, the determining factor is the *specific*

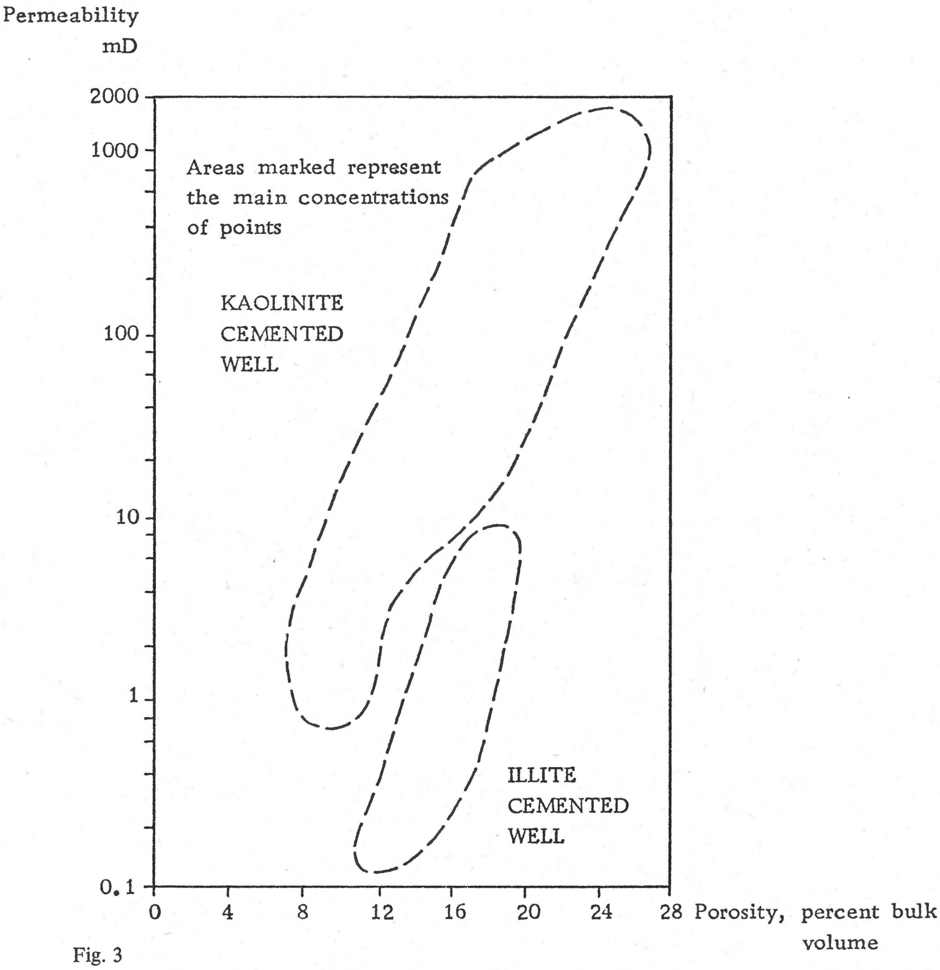

Fig. 3
Effect of the type of clay-mineral cement on permeability of *porous* Rotliegend sandstones of the North-Sea basin.

surface assumed by the different clay minerals, whether authigenic or detrial. It must be stressed in this respect that kaolinite, for instance, may occur as a network of very small plates that hides considerable ineffective porosity (e.g. this is usually the case with kaolinite pseudomorphoses).

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