

now almost totally absent from the well section under study, although our knowledge of the Brent Sand Formation suggests it was originally present, and also some of the kaolinite occupies 'grain-shaped' areas which may have once been feldspars (Pl. 1c). The kaolinite growth in the Brent Sand Formation may be associated with the late Jurassic-early Cretaceous Cimmerian earth-movements, when the crests of the structures in many Viking Graben oilfields were eroded (Bowen 1975, Ziegler 1975), and probably exposed to rain water.

Subsequent growth of authigenic illite, and conversion of kaolinite to illite, reflects the appearance of alkaline conditions at raised temperatures. These may be expected to develop with deeper burial, associated with the compaction and dewatering of shales (Müller 1967). Under these conditions, cations become concentrated in the pore fluids (Degens & Chilingar 1967).

In the well section under study, kaolinite formation took place freely throughout the Brent Sand. Subsequent illite diagenesis, however, was inhibited in the higher parts of the reservoir, and only proceeded to completion low in the Brent Sand.

Relation of oil migration to clay diagenesis

It is suggested that oil migration into the reservoir took place synchronously with illite diagenesis, as amplified below. The clay mineral relationships indicate that, following late diagenesis, the stable clay mineralogy consists of illite. It follows, therefore, that the kaolinite preserved unaltered in the upper part of the reservoir is a disequilibrium assemblage. Diagenetic processes take place in an aqueous medium, and consequently, as rocks become oil-saturated, diagenesis will be arrested. Inhibition of diagenesis by hydrocarbon accumulation has been described from various localities (e.g. Millot 1970, Webb 1974, Marie 1975).

In the middle part of the reservoir, illite began to form before diagenesis was arrested. This demonstrates that progressive filling of the reservoir took place downwards from the top. As the hydrocarbon column extended progressively further downwards, water was excluded and diagenesis halted. The 'frozen' clay assemblages demonstrate that the alkaline waters forming illite must have been present, but they were expelled by the hydrocarbon accumulation before equilibrium could be attained. Oil migration was thus synchronous with the illite diagenesis; this has also been suggested by Sommer (1975). Only near the base of the sandstones did aqueous diagenetic reactions continue long enough for the development of abundant, well crystallized illite.

Time of clay diagenesis

It seems most likely that the growth of kaolinite is

closely linked with the late Cimmerian earth-movements near the Jurassic-Cretaceous boundary. However, the time of the alkaline (illite) diagenesis is much less certain.

The evidence of the well section studied suggests contemporaneity of illite diagenesis and filling of the reservoir with hydrocarbons, but does not in itself determine the date of either process. The best evidence possibly comes from consideration of generation of the hydrocarbons. These only begin to be released in significant quantities from the organic matter of sediments after the temperature exceeds 140–150°F (Tissot *et al.* 1971), and there is evidence that pronounced oil production takes place at around 220–240°F (Philippi 1965, Burst 1969). Study of palaeotemperature gradients suggests that these temperatures were probably not reached until the Tertiary, perhaps the Miocene (Cooper *et al.* 1975). This, therefore, may represent the time of illite formation in the Brent Sand Formation.

The clay diagenesis-hydrocarbon migration relationships described here are not unique to this well, and they may prove to have relatively wide applications. Dewatering of montmorillonite has been shown to be of great importance in hydrocarbon exploration (Burst 1969). More recently, a relationship between clay diagenesis and hydrocarbon migration has been demonstrated in the Mackenzie Delta (Barefoot & Van Elsberg 1975) which may have considerable exploration potential. The clay/hydrocarbon field needs further investigation.

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PLATE 1 (facing)

Photomicrographs (A, C, E) and scanning electron micrographs (B, D, F) of authigenic clay mineral textures in the Middle Jurassic Brent Sand Formation.

FIGS. A, B. Abundant interlocked 'books' of authigenic kaolinite fill the pore space near the top of the Brent Sand. Note the pseudo-hexagonal platy crystals. A, photomicrograph, $\times 200$. B, scanning electron micrograph, $\times 1500$.

FIGS. C, D. An 'island' of authigenic kaolinite is surrounded by later-formed illite, and some penetration of illite into the kaolinite occurs. The shape of this kaolinite aggregate suggests that it may represent a replaced feldspar grain. C, photomicrograph, $\times 175$. D, scanning electron micrograph, $\times 730$.

FIGS. E, F. Authigenic illite pseudomorphing pre-existing kaolinite. The 'book' texture characteristic of kaolinite is clearly displayed (cf. A, B), but it is now composed of illite. Birefringence colours in thin section are those of illite. Note at high power the ragged nature of individual (illite) crystal plates (F) as compared to B, E, photomicrograph, $\times 400$. F, scanning electron micrograph, $\times 1500$.

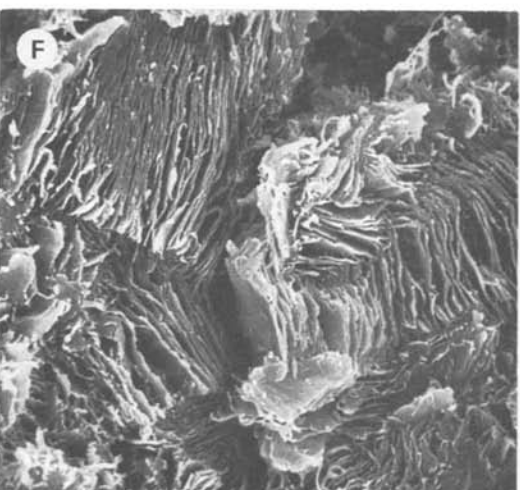
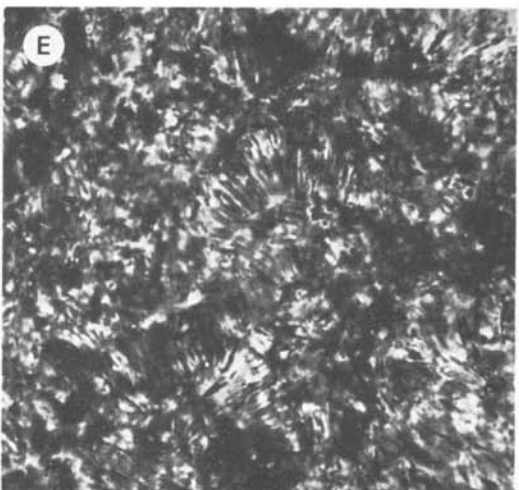
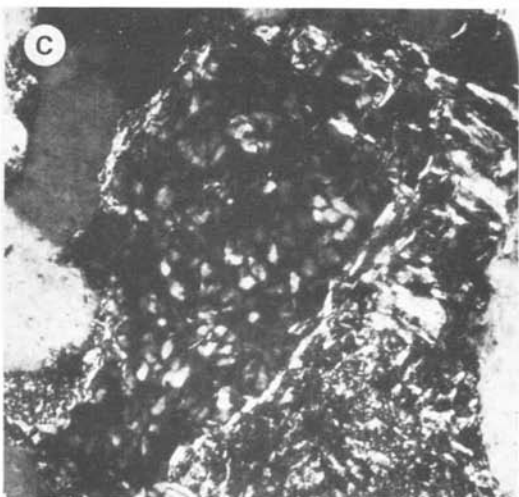
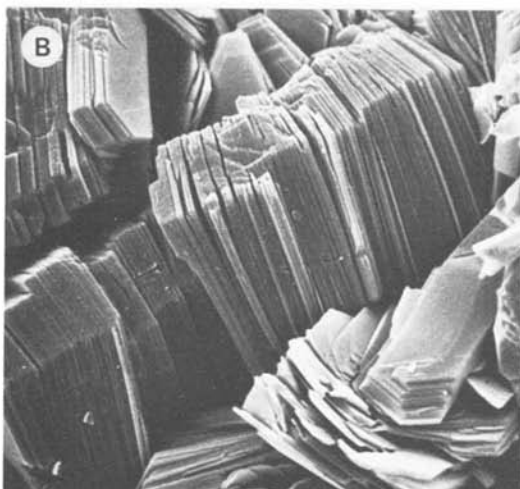
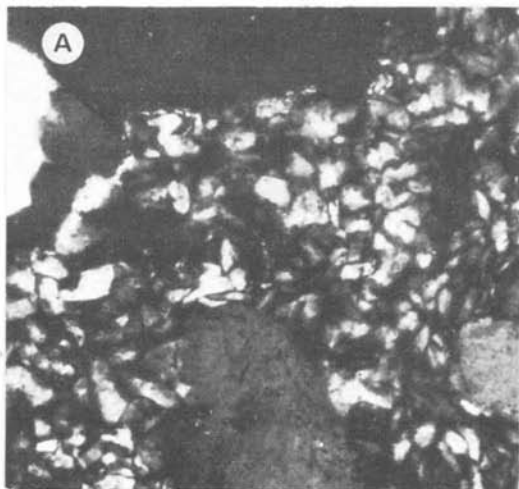


PLATE 1

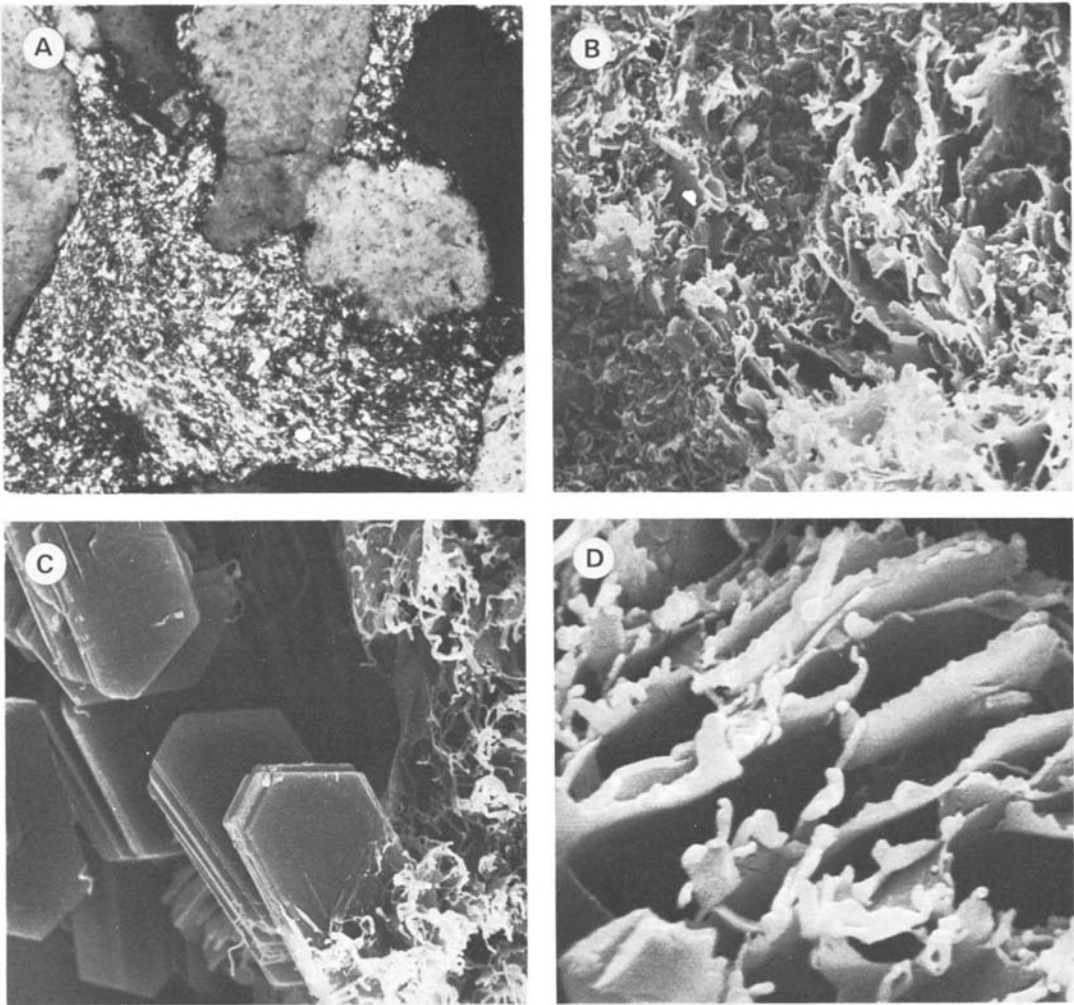


PLATE 2

Photomicrograph (A) and scanning electron micrographs (B-D) showing replacement textures of authigenic clay minerals in the Middle Jurassic Brent Sand Formation.

- FIGS. A, B. Authigenic illite fully recrystallized from pre-existing kaolinite characterizes the lower part of the Brent Sand. Pseudomorph textures (cf. Pl. 1) have disappeared leaving a typical illite morphology. A, photomicrograph, $\times 160$. B, scanning electron micrograph, $\times 900$.
- FIG. C. Authigenic kaolinite crystals being attacked by filamentous illite (right). Scanning electron micrograph, $\times 1700$.
- FIG. D. Detail of the edge of a partly pseudomorphed kaolinite 'book', showing illite growths developing on the rims of larger kaolinite sheets. Scanning electron micrograph, $\times 5700$.

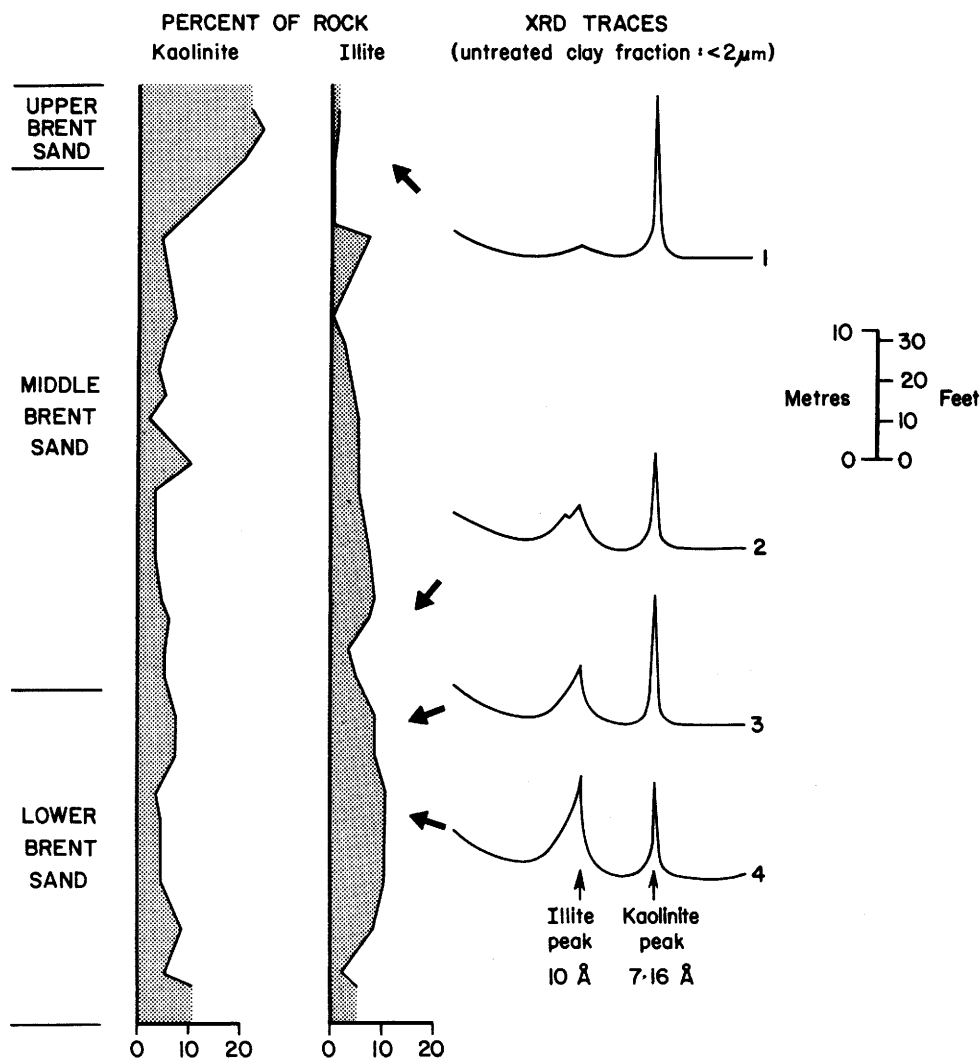


FIG. 1. Clay mineralogy of the Brent Sand in the well section studied. Petrographic data show that kaolinite is replaced downwards by increasingly abundant illite. Representative X-ray diffraction traces (right) show changing emphasis from kaolinite to illite downhole, together with downward improvement in illite crystallinity (sharper peak). Note some detrital mixed-layer illite/montmorillonite in sample 2 (secondary peak on flank of 10 Å peak).

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