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THE DAWN OF THE CRETACEOUS PERIOD IN BRITAIN

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(*Preprint of presidential address to the Geological Section*)

SOME REGIMES were born in violence and others flowed in on a silent tide. So it is in geology. Not every page of Earth's history is numbered by crustal upheavals, volcanic outbursts and similar revolutions: all too often it is hard to tell where one chapter ends and the other begins. For this reason the placing of regional or global events in the local stratal record is frequently a temporary affair and liable to change as the progress of research brings boundaries into line over wider and wider areas. From time to time some new find or new idea suddenly illuminates one of these obscure episodes and a geologically significant line may be traced across the face of a continent. This I believe has happened with the Jurassic-Cretaceous boundary. Scattered over Northern Europe are signs, which, if I have read them aright, speak of concerted movements of the sea and of a natural starting-point for the Cretaceous Period, an event of about 130 million years ago. I want to show how this hypothesis affects ideas on the geography of Britain in those distant times and on the grouping of the strata at this level.

First consider the problem. At the end of the Jurassic and the beginning of the Cretaceous the seas withdrew from many parts of the northern hemisphere, leaving dry land or lakes and swamps in their place. This has made it difficult for the geologist to link local events into a connected story, for few of the strands of evidence can be followed through the changing sedimentary and faunal provinces. Even the ammonites, those extinct molluscs that form the common currency of dating in Secondary rocks, fail us. In consequence the very boundary between the two Systems is recognized as arbitrary and not necessarily on the same level everywhere. The problem is felt most sharply in Europe, where, as if the shifting pattern of lake, swampland and brackish sea were not enough, the oceans themselves were divided into life-provinces, each province now requiring a vocabulary of its own. In northern regions like that of Moscow, for example, the topmost Jurassic (Volgian) and the basal Cretaceous (Ryazanian) are characterized by ammonites quite different from those found in the Alpine-Mediterranean province, where the topmost Jurassic is called Tithonian and the basal Cretaceous is called Berriasian. Somehow we have to integrate these successions with the Portlandian-Purbeckian-Wealden sequence of Southern England. It is as though a language once common to a nation had broken into a diversity of dialects.

The English basins and the Spilsby time-scale

In Britain this fragmentation is seen in the three separate basins that received deposits spanning the Jurassic-Cretaceous boundary. On a floor of Jurassic Kimmeridge Clay we find:

1. Southern basin. Kent-Dorset-Bucks. Portland Beds, comprising Portland Sand (marine) below and Portland Stone (mariny with brackish traces) above (together up to 220 ft.), followed be Purbeck Beds (up to 400 ft.) and Wealden Beds, comprising Hastings Beds below and Weald Clay above (together up to 2500 ft.) (fresh-water and brackish with marine or near-marine episodes).

Bounded on north by London-Midlands landmass (now buried) but with intermittent seaway through Bedfordshire, giving access to:

2. Spilsby basin. Lincolnshire and Norfolk (with relics in Cambridgeshire and Bedfordshire). Spilsby Sandstone (up to 80 ft.) in Lincolnshire. Sandringham Sands (up to 100 ft.) in Norfolk (both marine, shallow water).

Separated by Market Weighton swell from:

3. Speeton basin. Yorkshire coast. Speeton Clay (up to 695 ft.) (marine).

For many years the lower limit of the Cretaceous has been drawn in these basins at the base of (1) the Wealden Beds, (2) the Spilsby Sandstone and Sandringham Sands, and (3) the Speeton Clay. Until recently it was thought that the marine record in the Spilsby and Speeton basins was cut off abruptly in the Kimmeridge Clay and that strata of Portland age were found in Britain only in Southern England. It was also supposed that the incoming of the Purbeck regime caused the ammonites to disappear all over north-west Europe and that such ammonites as *Craspedites*, which flourished in Russia at the end of the Jurassic (Volgian), were barred immigration to this province. Not until the Cretaceous, when the Wealden deltas were spreading over Southern England, was the sea believed to have returned to the Eastern Counties, bringing ammonites (*Subcraspedites* and *Paracraspedites*) supposedly descended from *Craspedites*.

Renewed study of the ammonites of the Spilsby Sandstone (Casey, 1962*a*) has shown that there is no such missing interval in the Jurassic marine record in Britain. Genera which occur in the Portland Beds of Southern England and in the Volgian of Russia are found also in the lower part of the Spilsby Sandstone. Furthermore, *Subcraspedites* and *Paracraspedites* are Jurassic ammonites and appear in Lincolnshire *before Craspedites*. These discoveries have given us a new perspective on the Jurassic-Cretaceous transition

period in Britain. The next step is to see if the new Spilsby time-scale can be co-ordinated with movements outside the basin.

Experience has shown that beds full of phosphatic nodules, worn fossils, and the green mineral glauconite give important clues to geological events. Beds of this sort show that the flow of sediment to the sea-floor had been halted or slowed down, perhaps because the land was submerged and the rivers drowned or because the sea-bed had been lifted up within reach of sweeping currents. In Kent the best examples of nodule-beds linked with submergence of the land and marine *transgression* are at the base of the Gault and the base of the Chalk; that at the bottom of the Sandgate Beds in the eastern part of the county marks the reverse process of uplift and marine *regression*. Three such beds are associated with the Spilsby Sandstone and its equivalents in the Sandringham Sands, respectively at the base, in the middle, and at the top. It is suggested that these represent alternating phases of regression, transgression and regression, and that they are reflected in the Southern basin in (1) the Upper Lydite Bed of the Portland and the diminished area of Portland Stone, (2) the "Cinder Bed" marine incursion in the Middle Purbeck, and (3) the beginning of the Hastings Beds. During periods of regression the seaway joining the Spilsby and Southern basins is believed to have closed.

The Portland-Purbeck regression

The Upper Lydite bed is a thin seam crowded with black chert ("lydite") pebbles, phosphatic nodules and worn fossils, mostly ammonites washed from the underlying Kimmeridgian clays. Proceeding northwards from Dorset we see it first in the Vale of Wardour, South Wiltshire, as a condensed version of part of the Portland Sand of the coast. It becomes much more conspicuous in North Wiltshire and Buckinghamshire, where it forms a basal conglomerate to the Portland, overlain by a decreased amount of Portland Sand and an attenuated Portland Stone.

The basal Spilsby-Sandringham nodule-bed may be traced from the vicinity of Southery, near the Cambridgeshire-Norfolk border, northwards to Caistor, Lincs. Its physical characters are those of the Upper Lydite bed, but around Spilsby ammonites like those found above the Lydite bed in Buckinghamshire (*Crendonites* and *Kerberites*) are mixed with the Kimmeridgian debris. At the northern end of the outcrop near Caistor, where there was an axis of uplift subsidiary to that of Market Weighton, ammonites of yet higher horizon (early *Subcraspedites*) are added to the nodule-bed. Carried northwards this plane of inhibited deposition is lost in the much larger gap denoted by the "Coprolite Bed" at the base of the Speeton Clay.

It is thus possible to see the Upper Lydite bed as the tail-end of an important marker-bed in the British Upper Jurassic, aligned across England from the Yorkshire coast southwards to the Vale of

Wardour. Along this line deposition ceased at the close of the Kimmeridge Clay period. The front of active sedimentation then moved slowly north from Dorset across the shrunken Southern basin; similar conditions did not reach Lincolnshire until much later and, so far as we know, never got as far north as Speeton in the Jurassic. The absence of Upper Portland ammonites among the derived material in the Lower Greensand of Bedfordshire supports the idea that during this regressive phase the seaway linking the Southern and Spilsby basins became silted up, probably at the time of the Portland Stone, when the sea seems to have receded from much of the Weald (Taitt and Kent, 1958). Purbeck conditions followed with the prolonged southwesterly ebb of the sea. Already they are foreshadowed in the Portland Stone from Aylesbury to the Vale of Wardour by beds rich in the bivalve *Eomiodon*, an indicator of decreased salinity (Casey, 1956). The final rehearsals for the Purbeck regime are recorded in the lower part of the "Swindon Series" of North Wiltshire and Buckinghamshire. How much, if any, of the Portland Stone is represented in the dried-up-sea deposits of the Lower Purbeck of the Weald has yet to be determined.

The incoming Cretaceous tide

The mid-Spilsby nodule-bed marks the base of the Cretaceous and consists of a seam of pebbles and phosphatic nodules with Ryazanian ammonites of the group of *Tollia* (*Surites*) *spasskensis*. My colleague Dr. R. Thurrell has traced it over a wide area in the Spilsby region and it has been identified at a depth of 209 feet in a well at Fordington, near Alford, Lincs. Old collections from the King's Lynn district and recent finds near West Dereham show its continuation in Norfolk. Long after this bed was formed the rim of the Spilsby basin was uplifted and ground away. Millions of years later, in Lower Greensand times, fossils from the Spilsby Sandstone or the Sandringham Sands lay about the beaches as far south as Upware in Cambridgeshire and Potton in Bedfordshire. Long subsequently Ryazanian ammonites (*Tollia*) in a Sandringham Sands type of rock were carried southwards by ice along with Jurassic debris from the Midlands and dumped at Highgate Hill, north London. All clues to the movement of the sea relative to the Spilsby shore-line at that time have thus been destroyed. This is where the testimony of Speeton becomes important.

Almost the whole of the Lower Cretaceous is represented in the Speeton Clay of Yorkshire and ammonites are now known to range down to within two or three feet of the basal " Coprolite Bed " (Neale, 1962). Though many of these early Speeton ammonites have been described under such generic names as *Subcraspedites*, *Paracraspedites* and *Laugeites?* which apply properly to Jurassic forms, they all belong to the Ryazanian group which includes *Tollia* and *Surites*. They have their closest match in Lincolnshire in the ammonites found at the top of the Spilsby Sandstone and at the

base of the overlying Claxby Beds; this leaves room for the earlier *spasskensis* fauna of the Spilsby Sandstone in the bottom few feet of the Speeton Clay. Though relatives of the ammonites (belemnites) are fairly common at this level in the Speeton succession, they do not include any Volgian species such as occur in the Lower Spilsby Sandstone. Far from suggesting that the base of the Speeton Clay is older than the base of the Spilsby Sandstone, the new evidence from Speeton shows that the sea had regained a footing in Yorkshire more or less simultaneously with formation of the basal Cretaceous mid-Spilsby nodule-bed. In other words this nodule-bed marks a transgressive phase in the geological history of Eastern England.

The search for some expression of this movement in Southern England takes us to the thick series of lagoon and delta deposits of the Purbeck-Wealden Beds. Most of the pioneer workers of the beginning of the last century such as Webster and Fitton united this series under the single name Wealden and put it at the base of the Cretaceous. Subsequently Forbes (1851; *in* Lyell, 1855) showed that the Purbeck Beds could be divided into three on the basis of differences in the fossils, chiefly in the water-fleas (ostracods), and that interleaved among the freshwater beds, especially in the Middle division, were strata with brackish or marine types of life. In the most conspicuous marine bed of all, the Cinder Bed, in the middle of the Middle Purbeck, he found Portland-type fossils, notably the sea-urchin *Hemicidaris purbeckensis*. This convinced Forbes that the Purbeck Beds belonged to the Oolitic (=Jurassic) System rather than to the Cretaceous, and with few exceptions (e.g., Topley and Jukes-Browne, 1885) this conviction has been tacitly reaffirmed by British geologists ever since.

The Cinder Bed makes a firm datum-line across the basin, traceable in borings and at outcrop along a front of 150 miles from Dorset to Kent, and it marks a salt-water invasion comparable in importance with some of the major " marine-bands " of the Coal Measures. Besides *Hemicidaris*, the fauna includes the bivalve *Laevitrigonia gibbosa*, which also occurs in normal marine deposits, but diluted sea-water seems to be indicated by the absence of cephalopods, corals and brachiopods and by the dominance of molluscs whose modern analogues thrive near river-mouths (e.g., *Liostrea*, the *Corbicula*-like *Myrene*, and thin-shelled *Protocardia*). At Swanage and other parts of the Dorset coast the bed is little more than a bank of oyster-shells and indicates a period of slow accumulation such as produced phosphatic nodule-beds in ordinary marine deposits.

Hitherto the Cinder Bed has not been recognized in the western part of the basin farther north than the Vale of Wardour, where it is sandy and has a richer molluscan fauna than is found on the Dorset coast. About 15 miles north from The Vale of Wardour ferruginous sands emerge from beneath the Chalk cover of Salisbury Plain and form a string of outliers running for some 75 miles north-east to

Stewkley, Bucks. These sands, previously mapped as Lower Greensand, Wealden Beds, and Portland Sand, override Lower Purbeck Beds and Portland Stone; they carry a marine fauna of Middle Purbeck type, richer in mollusca than that seen farther south, and are interpreted as the transgressive margin of the Cinder Bed (Casey and Bristow, 1963).

Stewkley, the most northerly known occurrence of these Middle Purbeck sands, lies at the northern tip of the Southern basin and is barely 25 miles south-west of Potton, where derived fossils in the Lower Greensand testify to the former southerly extension of the Spilsby sea. It is hard to believe that movements in the one basin

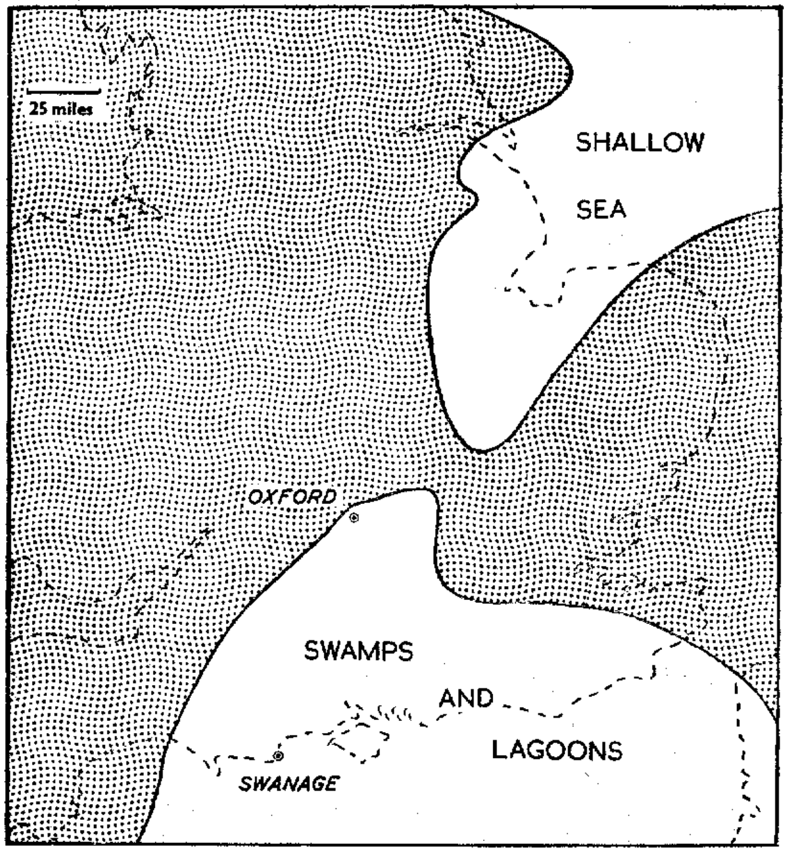

FIG. 1

Cartographic impression of England at the end of the Jurassic Period, illustrating the separation into a mainly freshwater Southern basin and a shallow northern (Spilsby) sea

were not felt in the other; and it is difficult to see what corresponds with the Cinder Bed transgression in the Spilsby basin and with the basal Cretaceous transgression in the Southern basin if these movements are not one and the same. The richness of the molluscan fauna of these Middle Purbeck sands points to increased salinity northwards and supports the idea of a northern source for the Cinder Bed invasion (Casey, 1962*a*). It seems possible, therefore, that the advancing Cretaceous sea re-opened the connexion between the Spilsby and Southern basins in Middle Purbeck times, flooding the Purbeck swamps and laying the Cinder Bed as the bedrock of the Cretaceous System in Southern England. In both basins the trans-

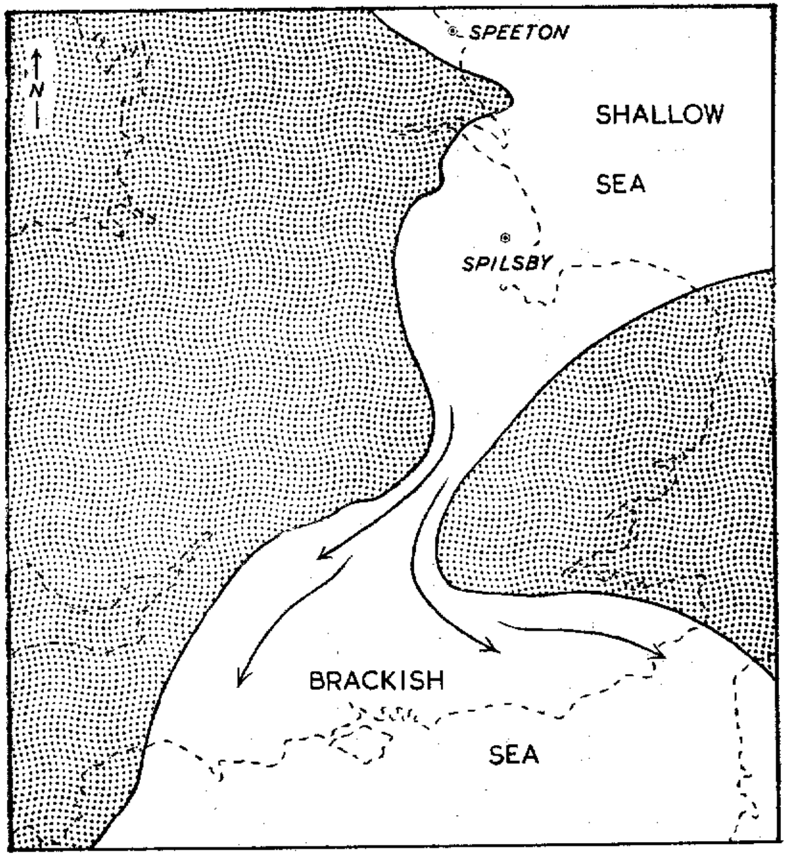

FIG. 2

Cartographic impression of England at the beginning of the Cretaceous Period, illustrating the hypothesis of invasion of the Southern basin by the Spilsby sea in 'Cinder Bed' times gression was temporary and failed to reverse a major sedimentary cycle; deposits just above the critical level are essentially the same as those below it. This is an unusual state of affairs and strengthens the belief that the Cinder Bed and the mid-Spilsby nodule-bed mark a single episode. There is another avenue of approach that leads to the same conclusion. For this we must go to Continental Europe.

Evidence from Continental Europe

While the sea was ebbing and flowing across Southern England during Portland and Purbeck times a similar sequence of events was unfolding in Germany. In Lower Saxony, chiefly around Hanover, we find flaggy limestones (Einbeckhausen Plattenkalk) and marls (Münder Mergel) followed upwards by a variable set of strata (Serpulite), which is in turn overlain by limestones, shales and sandstones ("Wealden"), the whole representing our Upper Kimmeridge Clay, Portland, Purbeck and basal Wealden Beds. The most remarkable part of the series is the Serpulite, which is generally acknowledged to correspond to the lower part of the Middle Purbeck of Dorset, though much thicker (see Arkell, 1956). It yields mostly marine fossils of the sort found in the Cinder Bed and was laid down in a freshwater or brackish basin that had been broken into by the sea. In some places it is crowded with fossil worm-tubes (*Serpulae*), in others it is an oyster-bank like the Dorset Cinder Bed and it passes laterally from limestones and marls to sandstones and conglomerates. It is succeeded by freshwater limestone, also of Middle Purbeck age; in the centre of the basin it grades down into Lower Purbeck (Münder Marls) by way of a lower portion ("Unter Serpulit") that is inferred to represent the strata just below the Cinder Bed. Towards the Dutch frontier it spills over the rim of the Lower Purbeck basin and spreads across older Jurassic rocks to rest on Trias. In fauna, transgressive behaviour and the way it fits into the sedimentary pattern, the upper part of the Serpulite thus mirrors the salient features of the Cinder Bed.

We now pass to Poland, where, thanks to the presence of workable iron-ore like our Claxby Ironstone, the basal Cretaceous and underlying Jurassic have been exposed on the surface and traced underground in a huge arc west of Warsaw. The strata change greatly in character and thickness when followed across country and in places marine beds with ammonites of Russian affinities interfinger with Portland-"Wealden" deposits of German type. In the region of Tomaszow, about 60 miles south-west of Warsaw, limestones and shales with the ammonite *Zaraiskites* provide a link with the Russian Volgian to the east and with the lower part of our Portland Sand to the west. Flaggy limestones and marls like the Einbeckhausen Plattenkalk and Münder Marls then follow and are succeeded by a serpulitic Purbeck limestone equivalent to the Serpulite of Hanover (Lewinski, 1923; Arkell, 1956). Signs of movement in the margins of the basin, such as preceded deposition

of the Serpulite in Germany, have been detected in borings around Radom, some 55 miles south of Warsaw. Here a *Serpula* fauna in clays, marls and limestones with a basal conglomerate overstep the equivalents of the Lower Purbeck and Upper Portland (Osika, 1958). Though evidence of age is lacking, these transgressive beds behave as the base of the marine Cretaceous and are described as such.

Unfortunately, in the Polish literature the Serpulite rock is still usually referred to as "Bononian", this being an old name for part of the Portlandian, which was once thought to embrace the Serpulite; and the term "Wealden" has been used in the German sense of comprising the upper half of the Purbeck as well as genuine Wealden. Sixty years ago the Russian geologist Michalski (1903) noticed that in a boring down near Nieszawa, about 100 miles north-west of Warsaw, the Serpulite (which he recognized as Purbeck) passed gradually upwards into "Wealden". In the more condensed sequence near Tomaszow, however, Lewinski (1931, 1932) found an equally gradational passage from Serpulite into marine clays with Lower Cretaceous fossils, the ammonite *Platylenticeras*, which marks the beginning of the Valanginian, the stage next above the Ryazanian, occurring less than three feet above the Serpulite. Between these two regions, about 100 miles west of Warsaw, drilling in the Sompolno area failed to prove the Serpulite but instead entered an expanded sequence of freshwater and brackish shales and sandstones, separated arbitrarily into Purbeck and Wealden, in which marine strata locally replace the upper part of the "Wealden" (Raczynska, 1961). But the most illuminating borings of all were sunk at Rogozno, about 170 miles west-north-west of Warsaw, and showed that the 70 feet of strata beneath the *Platylenticeras* level and equivalent to the "Wealden" of Sompolno have a marine upper half with Ryazanian ammonites (Marek, 1961). The ammonites are *Riasanites* and "*Subcraspedites*" (*recte Surites*) of the *spasskensis* and *stenomphalus* types comparable with those found in the mid-Spilsby nodule-bed. They occur about 8 feet above the "Wealden", the top beds of which yield foraminifera and ostracods identified with Martin's *Kliena alata*, *Cyprideis polita* and *Cypridea sowerbyi*, and an undescribed form. All the named ostracod species were obtained by Martin (1940) originally from the lower part of the Serpulite penetrated in borings in north-west Germany, though the first two have also been recorded (sometimes under different names) from above and below this level. Added to what has been seen in the neighbouring areas of Poland, the evidence from Rogozno suggests that here the lower part of the Serpulite passes laterally into "Wealden", the upper part into normal marine basal Cretaceous (Ryazanian).

In the Moscow basin the Ryazan beds, the prototype of the Ryazanian stage, cut across the underlying rocks down to Middle Jurassic and even lap on to the Carboniferous in places. Formerly it was believed that these beds could be divided into a lower zone with the ammonite *Riasanites* and an upper zone with *Surites spasskensis* and allies, and erroneous reports of *Riasanites* in the Tithonian of France led some geologists to put the lower zone in the Jurassic. It is now known that *Riasanites* occurs with *S. spasskensis* in the lower part of the Ryazan Beds around Moscow and with other Cretaceous (Berriasian) ammonites in the Caucasus (Gerasimov and others, 1962; Sazonova, 1961). The Ryazan transgression in the Moscow basin thus falls into line with the basal Cretaceous movements detected or inferred in Western Europe and Poland.

The Hastings regression

We now return to the Spilsby basin for the final stage of this enquiry. In the middle of the basin, at the southern end of the Lincolnshire Wolds, the Spilsby Sandstone is overlain without sharp junction by the Claxby Ironstone, which has Ryazanian ammonites at the base. Northwards towards Caistor, however, the whole of the Ryazanian disappears and phosphatized fossils from the underlying Upper Volgian part of the Spilsby Sandstone occur in a bed of nodules at the junction with the Claxby Ironstone, which here has yielded no ammonites earlier than Valanginian. Yet farther north, at Melton Ross, similar derived fossils at the base of the Cretaceous are the only clue to the former presence of Spilsby Sandstone. A supposed synclinal relic of Spilsby Sandstone a few miles beyond this point has turned out to be Lower Kimmeridge in age and has been renamed " Elsham Sandstone " (Kent and Casey, 1963). Evidently sometime between the close of the Volgian and the beginning of the Valanginian the sea retreated and the feather-edge of the newly-formed Spilsby Sandstone was cut back in the Caistor region. At the southern end of the basin, at West Dereham in Norfolk, Sandringham Sands (with *Hectoroceras*) of late Ryazanian age rest on the basal Cretaceous nodule-bed in which a few water-worn Ryazanian *Tollia* have been found jumbled in with masses of Upper Volgian debris (Casey, 1962*b*). This means that marine regression took place during Ryazanian times.

Dealing with the Southern basin, Allen (1954, 1955, 1959) has correlated the change from limestone and shale deposits of the Purbeck to the sandy type of sediment that begins the Wealden (Hastings Beds) with uplift of the London landmass and retreat of the sea southwards from the Paris basin in Ryazanian (" Infravalanginian " or " Berriasian ") times. There are good grounds for this dating. Allen's conclusion that the upper part of the German " Wealden " was laid down at the same time as the lower part of our Hastings Beds has been endorsed by work on the bivalves (Casey, in Allen, 1955) and the ostracods (Anderson, 1955). And since marine basal Valanginian deposits (with *Platylenticeras*) are introduced into the top of the German " Wealden ", a Ryazanian age for what lies next below seems a reasonable inference. The picture that

begins to emerge is thus of a single phase of uplift in England late in Ryazanian times that was expressed in the Southern basin by the arrival of the Hastings Beds and in the Spilsby basin by the Claxby Ironstone. Presumably this coincided with the appearance of the Deister Sandstone in the margins of the Hanover basin.

Until recently it was firmly believed that in Southern England the base of the Wealden (Hastings Beds) was " the only available datum-line at which to draw the important boundary between the Jurassic and the Cretaceous Systems ". Though there is no sharp dividing-line between Purbeck and Wealden, this choice of datum-line seemed right for two reasons: firstly because sands mapped as basal Wealden overlap the Purbeck in the margins of the Southern basin, and secondly because in the Jura region, on the French-Swiss border, Jurassic ammonites (*Berriasella*) had been recorded from the top of the Purbeck: and the dating of these ammonites as early Upper Tithonian and the underlying strata as basal Middle or Lower Purbeck left room to accommodate the rest of the English Purbeck in the Tithonian.

The alleged Wealden overlap can be seen in the north-west part of the basin, notably near Oxford, where the Shotover Ironsands step from Lower Purbeck on to Portland Beds. Only long-ranging molluscs and plants have been found in place in these sands and they were put in the Lower Wealden because they looked like a Hastings Beds type of sediment and because their attitude to the Lower Purbeck suggested a big difference in age (Lamplugh, 1908; Arkell, 1947). Whatever the age of the Shotover Sands may turn out to be, the discovery that in nearby Buckinghamshire and Wiltshire sands of similar character and stratal relations carry a Middle Purbeck fauna (Casey and Bristow, 1963) disposes of this line of argument. The old idea that the Wealden once stretched north into Bedfordshire has no valid basis (Casey, 1961). Similarly, we do not know if certain transgressive sands found in the buried eastern margin of the basin in Kent really belong to the Hastings Beds. It is true that in the Boulonnais, which, from the geologist's point of view, is a detached piece of Kent, ferruginous sands described as Wealden cut across folded and faulted Lower Purbeck and Portland Beds. But the fossils found at the base of these sands are Cinder Bed types such as occur in the marine Middle Purbeck sands of Wiltshire and Buckinghamshire (Casey and Bristow, 1963), and it is not surprising that Allen (1959) was unable to fit this Boulonnais " Wealden " into the general picture of Wealden sedimentology. Thus the trend of research is to give the Cinder Bed the transgressive role usually accorded the basal Wealden.

Turning now to the ammonites, we find that an equally radical change of view has taken place concerning the *Berriasella* found intercalated in Purbeck strata at Cluse de Chaille and Mont Salève in the Jura. They have been re-assessed by Donze (1958) as a Cretaceous assemblage and placed in the " Middle Berriasian ".

Together with data derived from study of the micro-organisms, this has led Donze to conclude that the time-plane representing the base of the Cretaceous in the Alpine-Mediterranean province falls somewhere in the Lower Purbeck of Dorset. Since this level has no stratigraphical meaning in north-west Europe and suggests that the Berriasian and Ryazanian time-scales are out of step, we must look closer at Donze's use of the term " Berriasian ".

Strata at the Jurassic-Cretaceous junction in the Mediterranean province are enormously thick compared with what is seen in Northern Europe and the ranges of many of the fossils, even the ammonites, very long; many species of *Berriasella*, for example, cross the Tithonian-Berriasian boundary. Kilian (1907-10) long ago saw that the only practicable base for the Berriasian (and for the base of the Cretaceous) in this part of the world was the lower limit of the Zone of *Thurmanniceras boissieri*. Subsequently it was found that he had recorded the entry of this ammonite too early and that it did not appear until the middle of the three subzones into which the zone is at present divided (Mazenot, 1939). Nevertheless, Mazenot, Donze and others still adhere to the stratal line drawn by Kilian — so far as this can be recognized. It would seem that delimitation of the Berriasian stage to conform with the succession at Berrias (the type-locality of *T. boissieri*) and in accordance with the palaeontological definition proposed by Kilian offers the best hopes of bringing the base of the Mediterranean Cretaceous into line with the base established in Northern Europe. The association of *T. boissieri* and *Riasanites rjasanensis* in the Caucasus (Renngarten in Sazonova, 1961) provides a vital link between the two provinces and gives assent to this proposal, which involves removing to the Tithonian the bottom third of the Berriasian stage as currently conceived. In this re-alignment the Purbeck ammonite bed of the Jura comes out as lying on the Jurassic-Cretaceous border, and from the age of the underlying beds we know that the marine incursion it bears witness to occurred at about the same time as that of the Cinder Bed of Southern England.

Some final considerations

All lines of evidence lead to the idea that a single advance of the sea initiated the Cretaceous Period in Northern Europe and that the Ryazanian transgression in Russia, the Serpulite transgression in Poland and Germany, the arrival of the Speeton Clay in Yorkshire, and the formation of the mid-Spilsby nodule-bed in Lincolnshire and East Anglia were all timed with the Cinder Bed invasion in the Middle Purbeck of Southern England (cf. Casey, 1963). Metaphorically and in reality in Southern England the Cretaceous Period came in on a flowing tide. Barriers were washed away and the whole of the Purbeck swampland from Dorset to Kent was turned into a brackish sea like the approaches to the present-day Baltic. Here *Laevitrigonia* and *Hemicidaris* lived on in their old Jurassic

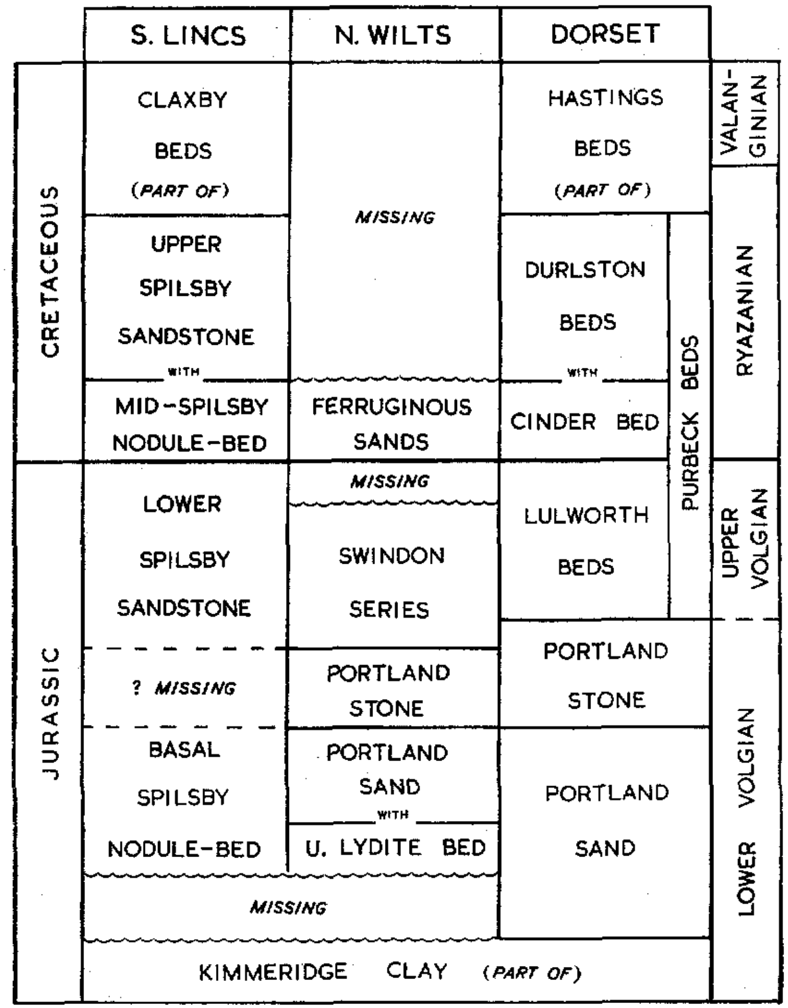

FIG. 3

Suggested correlation of some of the stratal units discussed in the text (thicknesses not to scale).

ways, but in the seas outside these land-locked waters the *avant-garde* of the molluscan world, the ammonites, had proclaimed the New Order. The sea retreated immediately after the Cinder Bed was formed and swamps and lagoons returned; the upper half of the Purbeck records an episodic but declining salt-water influence, leading up to the predominantly deltaic Hastings Beds. That the Hastings Beds continue without interruption a story begun in the Purbeck is clearly seen in the sediments (Allen, 1955, 1963).

From a practical standpoint the Cinder Bed is an ideal base to the Cretaceous in Southern England, for the ease with which it can be picked out contrasts greatly with our inability to fix anything more than an arbitrary local base to the Hastings Beds. If accepted as such, geological maps would be simplified in so far as virtually no Jurassic is exposed in the Weald (just as the whole of the German "Wealden" becomes Cretaceous). The placing of a System boundary in the middle of a formation sets no precedent, for the Headon Beds of the Hampshire basin, similar in character to the Purbeck, provide a parallel situation. Formerly placed wholly in the Oligocene, the freshwater Lower division is now referred to the Eocene and the Oligocene is regarded as commencing at a marine-band at the base of the Middle division. Unfortunately, nomenclatural difficulties arise over the proposed new boundary in the Purbeck, and Forbes's discoveries of 1850, which influenced the course of Purbeck research for the next century, are now seen as historically ill-timed. His divisions of Upper, Middle and Lower Purbeck were admitted not to correspond to obvious stratal units; nor can they now be related to significant faunal breaks (Anderson, 1963). The critical datum-line, the Cinder Bed, falls in the middle of the Middle Purbeck and it would only lead to confusion if we were to attempt to give the terms "Lower Purbeck" and "Upper Purbeck" new meanings in the sense of a Jurassic Purbeck and a Cretaceous Purbeck. In any proposed regrouping of these strata new names supplementary to "Purbeck" seem inevitable; I would suggest the name "Lulworth Beds" for the sequence between the Portland Stone and the Cinder Bed, and "Durlston Beds" for the sequence from the base of the Hastings Beds down to and including the Cinder Bed; the former would be grouped with the Portland Beds, the latter a subordinate and basal division of the Wealden Beds.

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