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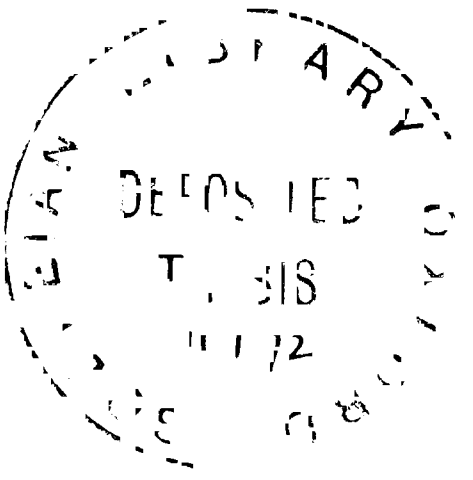
FACIES ANALYSIS OF THE PORTLAND BEDS

A description and interpreted environmental history of the Portland Group in England and Northern France with particular emphasis on the exposures in Dorset

By

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"Unlike the Kimmeridgian and Corallian rocks, the Portland Series has been frequently examined in all its localities by competant observers and there might seem, at first sight, to be little additional or desirable information to obtain. Yet when all the extant materials are put together they seem to serve but slightly towards the history of the deposits in their varying relations to each other and to similar rocks abroad."

Blake 1880

ABSTRACT

The Portland Group, previously known as the Portland Beds, is the highest division of the regressive marine Jurassic succession in England. The strata are well exposed on the coast of Dorset and the Bas Boulonnais of North-east France and poorer exposures occur in Wiltshire, Oxfordshire and Buckinghamshire. The rocks are also known from boreholes in Hampshire, Surrey, Sussex and Kent. This thesis comprises a facies analysis of the Portland Group using stratigraphical, sedimentological and palaeo-ecological data.

In spite of being familiar to most geologists, if only in name, these rocks are surprisingly poorly documented and there was ample scope for a detailed study of the sediments. Because refined correlation by fossils has not been established a regional approach is used and the successions in each area are described and interpreted in turn. Correlations are suggested between the widely separated areas.using phases of regression and transgression, supplemented by ammonite evidence as much as possible. The thickest sections exposed are in Dorset where the sequence reaches nearly 80m. This area provides the basis for description and interpretation of the areas where the successions are thinner, reaching a minimum of 6m in the far north-eastern outcrop in Buckinghamshire.

The Portland Group in Dorset is divided into the Portland Sand Formation overlain by the Portland Limestone Formation, described in separate chapters. The Portland Sand Formation is an upward continuation of the sandy and silty development in the Upper Kimmeridge Clay. The sediments are dolomitic and the highest beds are virtually pure fine grained dolomite which is interpreted as having formed in relatively deep water. An environmental model for the deposition of the Portland Sand Formation is discussed.

The Portland Limestone Formation follows this dolomite and sponge-rich, fine-grained cherty limestones pass up into high energy biocalcarenites and oolites. These are overlain by non-marine, hypersaline to brackish, Purbeck Beds. The Portland

Group in Dorset is regarded as having been laid down during three main phases of shallowing of the sea. These can be recognised throughout the basin of deposition and are regarded as being essentially synchronous; the ammonite distribution supports this interpretation.

Within the Dorset Area there was a swell, or region of minimum subsidence, separating a minor West Basin from a major East Basin which extends to south Hampshire. The thickest succession of the Portland Group is probably between the Isle of Purbeck and the Isle of Wight. The water was shallower over this swell than in the basins and, as the sea level fell, this local difference in depth had a considerable effect on the pattern of sedimentation. The description and interpretation of the influence of the swell on the carbonate facies of the Portland Limestone Formation is a major part of this thesis.

The nearest exposure to Dorset is in the Vale of Wardour to the north where the succession is nearly half the thickness. Despite poor exposure, the sediments have been studied in detail and a correlation between this area and Dorset is given. The Vale of Wardour was nearer to land in the west with the result that terrigenous sediments occur at higher horizons than in Dorset. In the South Midlands, the succession is even thinner, very glauconitic in places and there is a breaknear the base which represents approximately 100m of sediment in Dorset. The thinness and presence of terrigenous material almost throughout indicates that these were also deposited marginally. The change to non-marine conditions is thought to have occurred earlier in the Vale of Wardour and the South Midlands than in theDorset Basin.

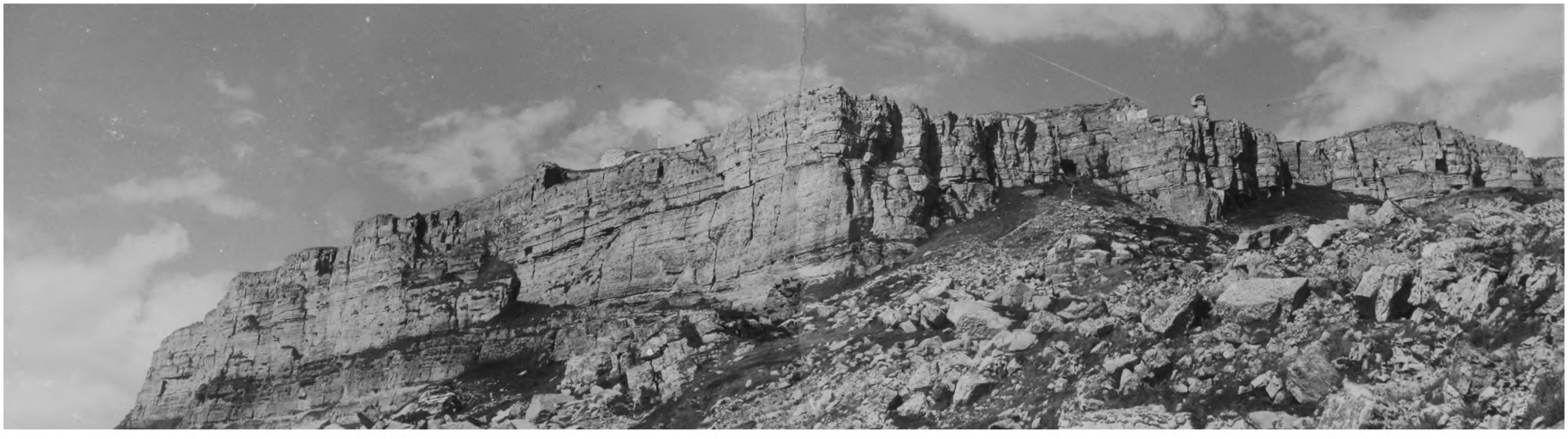
The Portland Group is exposed on the coast near Boulogne and there the succession is similar to that in the South Midlands. Land was nearby and clay, quartz, silt and sand predominate throughout, and at one horizon there is a conglomerate of Palaeozoic pebbles. The change to non-marine conditions probably took place earlier than in Dorset. In South-east England the borehole evidence is not very satisfactory and only generalisations can be made. There is a gradation from the Kimmeridge Clay, as

in Dorset, and it is supposed that the lowest Purbeck Beds were deposited at the same time as the higher levels of the Portland Limestone Formation in Dorset, thus eliminating the necessity for a break as has been suggested.

The fauna of the Portland Group is mollusc dominated. The rarity of brachiopods, corals, echinoids, and absence of belemnites and crinoids is thought to be partly due to a slight increase in salinity at times. Another controlling factor was the energy of the environment. Soft lime muds deposited in quiet water eliminated epifaunal bivalves and mobile carbonate sands were virtual deserts.

The presence of Palaeozoic pebbles in the Boulonnais and South Midlands indicates land not far to the north and east, whereas the heavy mineral assemblages of Dorset suggest a source in an Armorican area to the west. Thus the Portland Group Basin was mostly enclosed by land but there was a connection to the north-east, south and possibly south-west during uppermost Kimmeridge Clay times. As the regression continued probably only the connection with the Paris Basin remained.

The history of deposition in the Portland Basin is one of shallowing which eventually restricted both the circulation of the sea and of the life within it. This culminated in hypersalinity and the deposition of evaporites, except where rivers brought in fresh water. Judging from the presence of cycads, rare corals, thick shelled bivalves and the precipitation of evaporites, the climate was probably sub-tropical throughout Portland Group times and the change from terrigenous to carbonate deposition upwards in Dorset was due to a move from deposition in a clastic trap on to a carbonate shelf, rather than a major climatic change.



FRONTISPIECE. ST. ALBAN'S HEAD, DORSET.

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CHAPTER 1

INTRODUCTION

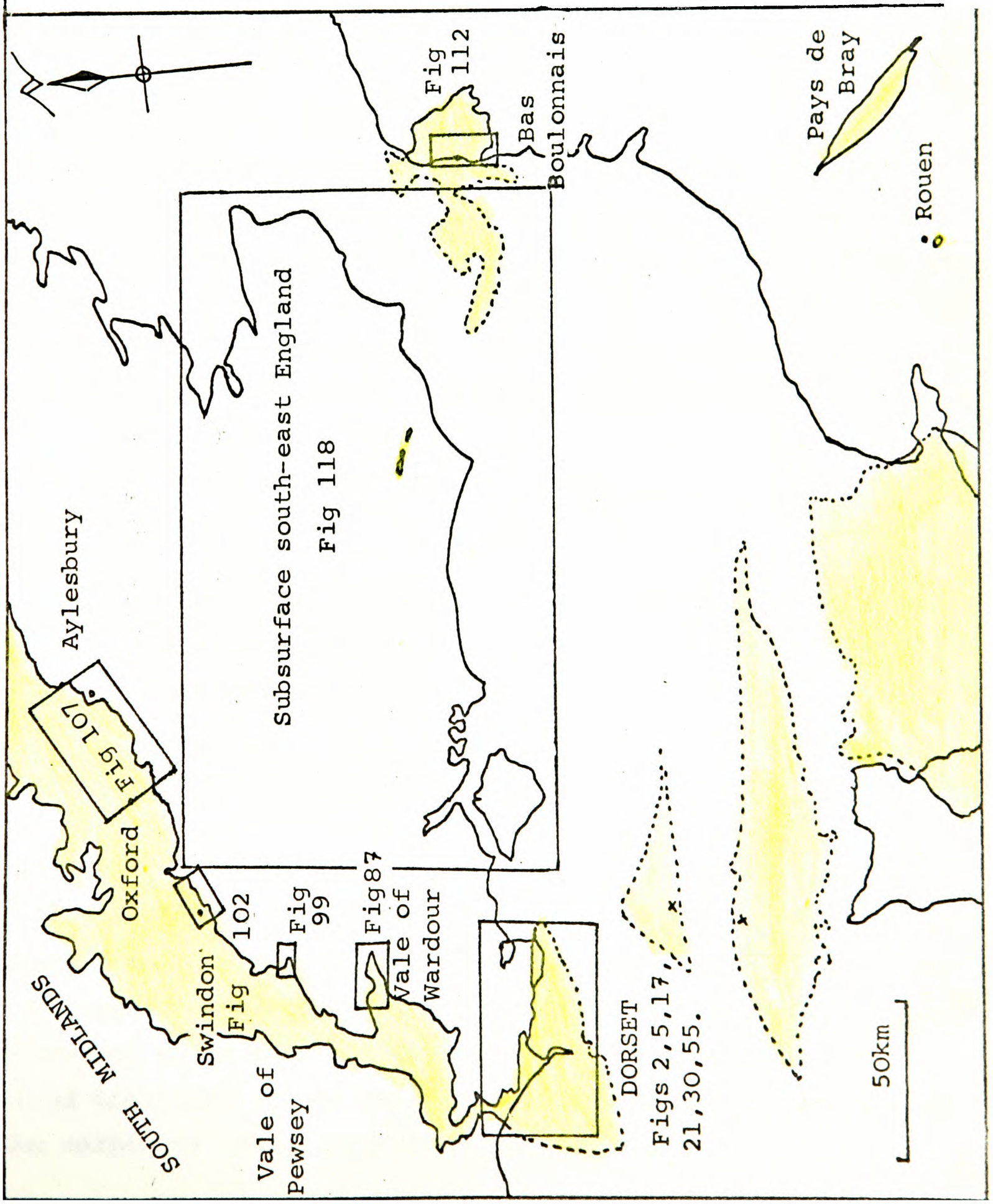
The Isle of Portland, a few square kilometres of rock off the Dorset coast, has long given its name to a heterogeneous group of Upper Jurassic strata which outcrops in Southern England and Northern France. It has also supplied a universally adopted chronostratigraphic term, the definition of which has yet to be agreed upon. The Portland Beds are defined by the following ammonite zones (Cope in Torrens 1969):-

Purbeck Beds (non-marine)	
Portland Beds	Titanites giganteus Glaucolithites gorei Progalbanites albani
Topmost part of the Upper Kimmeridge Clay	"Epipallasiceras sp." Pavlovia rotunda Pavlovia pallasioides "Pavlovia sp." Pectinatites pectinatus

These three zones are correlated by Casey (1967) with the Middle part of the Volgian stage of North-east Europe and the U.S.S.R., and by Zeiss (1968) with the Upper Tithonian of Central and Southern Europe. The "Portlandian" and "Kimmeridgian" stages have been defined in many different senses and these terms are avoided in this thesis (for details see Cope et al 1962).

Despite the recognition of the Portland Beds as an important horizon in world stratigraphy nothing has been previously written on their origin. The present state of knowledge is summarised in the works of Arkell (1933, 1947a & b) which are almost purely biostratigraphical. The prime object on starting this project was to study the history of deposition of the rocks included in the three zones, on the understanding that at least a lithostratigraphy had been established. However, even within the best exposed and thickest succession in Dorset a correlation of the strata along the outcrop had to be made in order to eliminate the existing different bed names at different localities (see Arkell 1933, p.495, 1947a, p.120). It was also found that the ammonite ranges were less rigorously delineated than supposed

MAP OF THE OUTCROP OF JURASSIC STRATA IN SOUTHERN ENGLAND AND NORTHERN FRANCE SHOWING THE AREAS WHERE THE PORTLAND GROUP WAS STUDIED IN THE COURSE OF THIS THESIS FIG 1



and hence a groundwork of basic "exploration geology" was required. This has resulted in the inclusion of a considerable amount of bulky detail in order to have all the known facts in one place for the first time.

The term Portland Group is introduced to distinguish between the definitions of the Portland Beds by previous workers and those used in this study. The terms Group, Formation and Bed (but not Member) are employed to supply a more acceptable stratigraphic nomenclature. The Portland Group is restricted to Southern England and although it is not known whether it ever existed further north there is a general indication of non-deposition in the uppermost Kimmeridge Clay which probably resulted in the basin being confined to the south following the time of the Pavlovia rotunda zone.

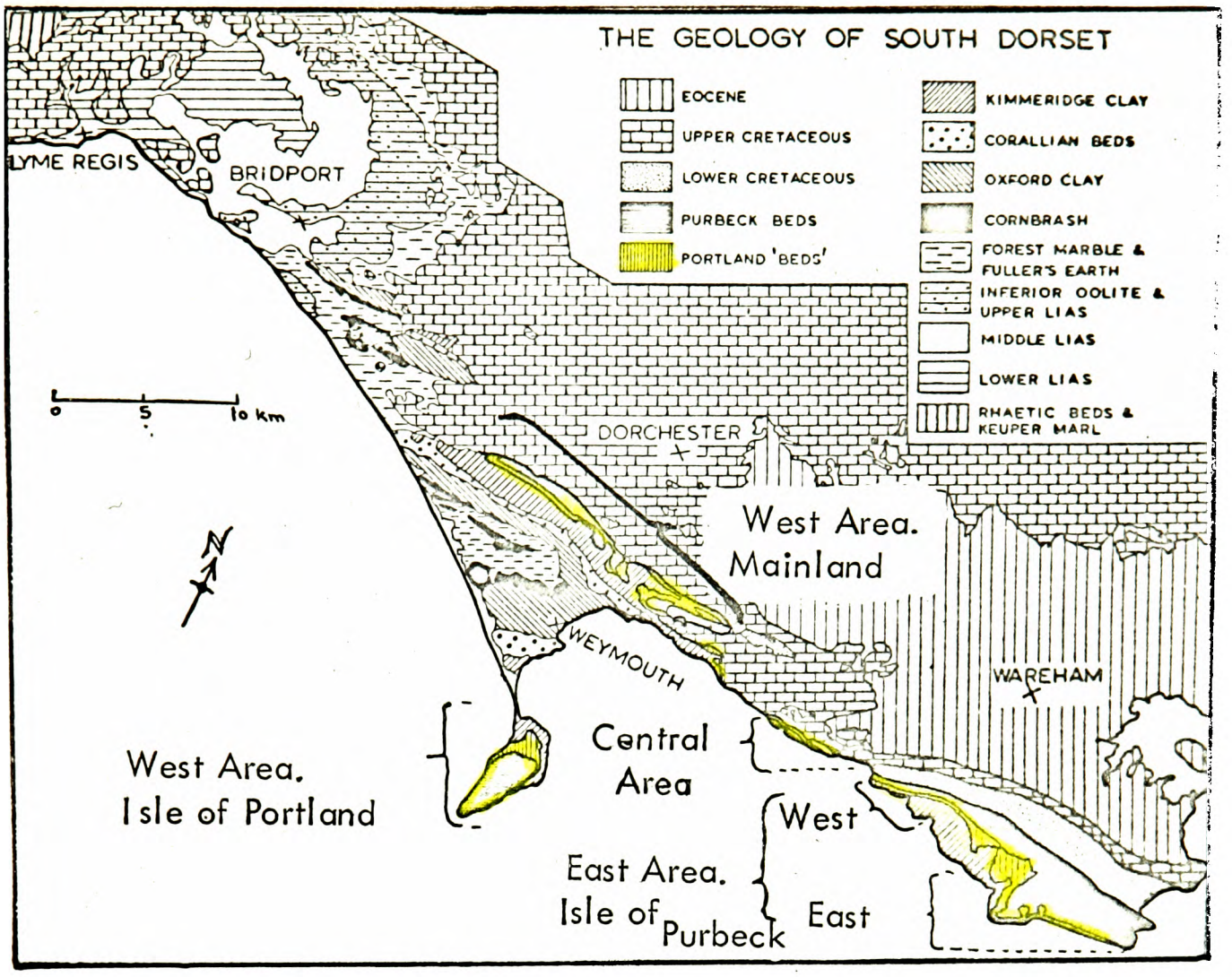
The Portland Group Basin is defined as including the area between Dorset in the west and the Boulonnais in the east and extending southwards from the South Midlands of England into the Paris Basin. Outcrops are very limited within this area and are confined to the belt of Jurassic strata which runs from the Dorset coast in a north-east direction and to a few scattered inliers in North-east France (Fig. 1).

The main study has been made in Dorset where the succession is as follows:-

Purbeck Beds (Lulworth Beds of Casey 1963)	Maximum thickness
Portland Limestone Formation	38m
Portland Sand Formation	40m
Sandy Upper Kimmeridge Beds	40m
Upper Kimmeridge Clay Beds	

The outcrop is divided into East, Central and West Areas (Fig. 2) and the two Formations are described and interpreted in Chapters 2 and 3. Due to rapid lateral facies variation it has been necessary to describe the successions for each Area in turn instead of an overall description. The Chapter on the Portland Limestone Formation starts with a detailed description of the carbonate facies and their components.

FIG 2



The nearest outcrop to Dorset is in the Vale of Wardour where the Portland Group is thinner and less well exposed. In spite of this over a dozen sections were measured in the course of three weeks fieldwork. The general succession is as follows:-

Purbeck Beds	
Wardour Limestone Formation	21m
Wardour Sand Formation (including the Sandy Upper Kimmeridge Beds?)	18m
Kimmeridge Clay	

The sequence here is described and interpreted in Chapter 5 and sections are figured for the first time. Included in this chapter is a summary of what is known of the minute outcrop in the Vale of Pewsey to the north. The remaining outcrops are a series of outliers which emerge from the Cretaceous cover in the South Midlands, from Swindon to Aylesbury; they are described and interpreted in Chapter 6. The succession in this Area is thin with a basal unconformity which has eliminated the top four zones of the Upper Kimmeridge Clay. The rocks are sufficiently similar throughout the South Midlands Area to be described in terms of one set of Beds and are not divided into Formations.

Twenty days were spent on fieldwork in the Area and ten sections were measured; the remaining details were obtained from an exhaustive study of past records. The remaining outcrops studied are in North-east France (Fig. 1), principally in the Bas Boulonnais. Here the succession is also thinner than in Dorset and has a basal non-sequence. The Group is divided into the Assises de Croi overlain by the Grès des Oies, succeeded by "Purbeckien" and "Wealdien". Rocks equivalent to the Portland Group are also recorded from the Pays de Bray and Rouen but none were found exposed in the former and the latter was not visited. A total of three weeks was spent in France and ten sections were measured. The results are given in Chapter 7.

The only other area where the Group is known is in South-East England where several boreholes have penetrated Upper Jurassic strata. Because the successions are inadequately known, the Sandy Upper Kimmeridge Beds and the Portland Group are considered together and the latter is not sub-divided. Rocks from eight cores were examined at the Institute of Geological Sciences and the results together with information from published accounts is given in Chapter 9.

The Facies Analysis approach involved direct study in the field at all the outcrops over a wide area. Approximately 250 vertical sections were measured and many rock samples and fossils were collected. Approximately 850 thin sections were personally cut and stained; sometimes the staining techniquewas used in the field. The fossils were studied in situ from a palaeoecological viewpoint and measurements were made in some cases for statistical analysis. Chapter 2 describes the fauna and flora in terms of their mode of life and their relationship with the sediments in which they are found. Fossils were also collected for laboratory study in the hope that a means of correlation might be established. However, in the case of the ammonites this attempt was somewhat thwarted by their size. The distribution of the other fossils appears to be largely facies controlled.

The laboratory study included petrographic study of thin sections and a scanning electron microscope was used to a limited extent. Some of the rocks were analysed by "wet" chemical methods.

Despite the existing inadequate correlation between the outcrops in the Portland Group Basin the detailed groundwork has enabled a time correlation to be suggested using environmental models. The changing environment of deposition in each Area is described using the sedimentological and palaeoecological data and the concluding Chapter discusses the environmental history of the whole basin and touches on the wider European context.

CHAPTER 2

PALAEOECOLOGY

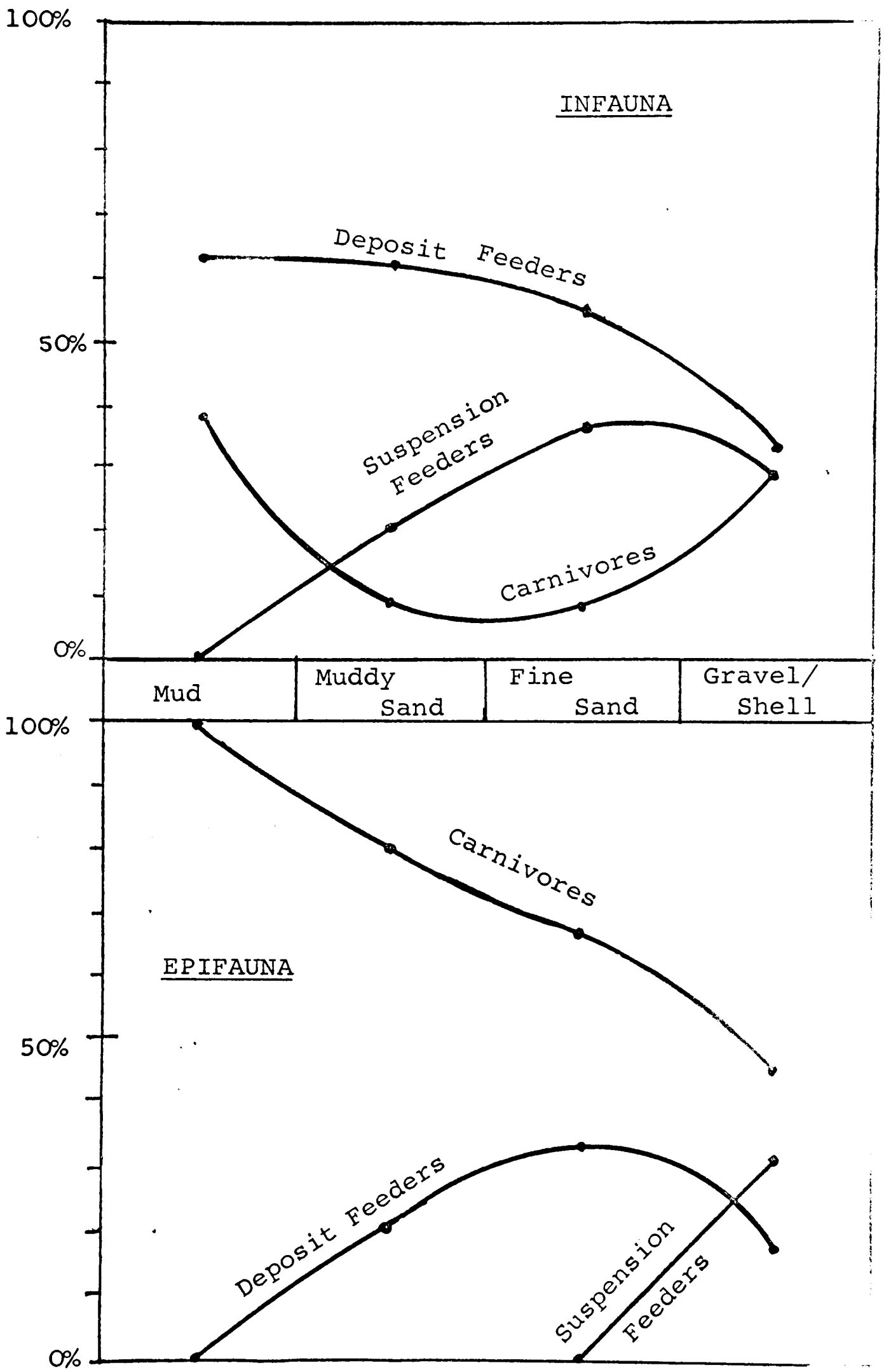
1. Introduction

When interpreting the environmental history of a sequence of fossiliferous sediments, important information can be obtained from a study of the enclosed organisms. This chapter gives ecological notes on common or particularly significant genera found in the Portland Group in order to supplement the information obtained about palaeoenvironments by studying the sediments.

The distribution of organisms in the sea is controlled by physical, chemical and biological factors. The most relevant physical factors are those related to depth, temperature and to substrate conditions. Salinity and Eh are important chemically. Relevant biological factors are food supply, competition and predation. Most benthonic marine animals obtain food either by filtering suspended material from sea water (infaunal and epifaunal suspension feeders) or by eating detritus in sediment on or below the sea bed (infaunal and epifaunal deposit feeders). Some animal groups eat growing vegetation and others are carnivores. Marine algae sustain themselves by photosynthesis.

Filter feeding animals are common in high energy environments which have a lot of material in suspension and a relatively low rate of sedimentation. In areas where deposition is slow and the concentration of suspended matter is low, faunas tend to be less diverse and infaunal detrital eaters are dominant (Fig. 3 Data from Craig & Jones 1966). Rhoads and Young (1970) found this to be true in Buzzards Bay, Massachusetts, where suspension feeders are largely confined to sandy or firm mud bottoms, while deposit feeders attain high densities on soft muddy substrata. They conclude that this is due to re-working of the top layers of the mud by deposit feeders which produces an easily suspended faecal-rich fluid. This is unstable and clogs filter mechanisms, buries larvae and prevents sessile epifauna from attaching to the bottom. In this way many suspension feeders are excluded from areas which have an available source of food. Seilacher (1967) considers that there is a direct bathymetric relationship between feeding methods and depositional environments and concludes that in general suspension feeders tend to live in shallower water than

The Relationships between Feeding Type and Grainsize for Invertebrates in the Irish Sea. Data from Craig & Jones 1966. FIG 5



deposit feeders.

The palaeoecology of the Portland Group fauna and flor is described in terms of the physical, chemical and biological factors discussed above.

2. Bivalves

These are the most common faunal elements in the Portland Group which, including ammonites and gastropods, can be described as almost entirely mollusc-dominated. Unlike most other English Jurassic strata, brachiopods,belemnites, corals, crinoids and echinoids are very rare or absent. The bivalve fauna has been monographed by Loriol and Pellat (1866, 1874) and Cox (1925, 1928).

According to Orlov (1960) 88% of Mesozoic bivalve superfamilies, 63% of families and 30% of the genera are still living today. This means that direct comparison can be made with many recent forms and to supplement this, considerable deductions about life habits are possible by a study of functional morphology (Kauffman 1969, Stanley 1970).

Bivalve feeding groups are described by Stanley (1968) as:

(a) Labial palp deposit feeders
(b) Epifaunal suspension feeders
(c) Infaunal siphon feeders
(d) Infaunal non-siphonate suspension feeders
(e) Infaunal mucus tube feeders.

Stanley (1970) concludes that 74% of all Recent bivalve genera are infaunal burrowers in soft substrata. Infaunal forms in all substrate types comprise 84.8% of all genera, 13.4% are infaunal and 1.8% are semi-infaunal.

Most of the interpretations of salinity tolerance of certain fossil genera given here are taken from Barthel (1969) and the term "euryhaline" means that the organisms were capable of tolerating a wide range of salinity from brackish through marine to hypersaline waters. A similar approach is used here to that by Hudson & Palframan (1969) for the Oxford Clay fauna and some of their interpretations are given. The classification of Newell

(1969) is used to group the genera into higher categories:-

PALAEOTAXODONTA

ORDER NUCULOIDA

Nucula, Nuculana

These are shallow infaunal forms which deposit feed by means of primitive labial palps (Yonge 1939 Morris 1967, Stanley 1968). Modern Nucula is a slow burrower whereas Nuculana moves moderately fast and lives vertically or at a high angle. Both fossils are found in fine-grained sediments in the Portland Group but are not common.

PTERIOMORPHA

ORDER ARCOIDA

Arca, Parallelodon, Barbatia

These are bysally attached, non-siphonate, epifaunal suspension feeders which nowadays live sublittorally on hard substrates and can withstand high energy turbid conditions (Kauffman 1969, Hudson & Palframan 1969). They occur in what were carbonate muds and sands.

ORDER MYTILOIDA

Pinna, Falcimytilus, Modiolus, Musculus, Lithophga

These are byssally attached non-siphonate suspension-feeders. Modern Pinna and Modiolus are semi-infaunal and solitary whereas Mytilus (c.f. Falcimytilus?) is closely attached epifaunal. Pinna has adapted its byssus for firm anchorage in soft sediment (Kauffman 1969) and Lithophaga is an example of forms which bore into hard carbonate substrates by secreting acid. Mytiloids can withstand considerable salinity fluctuation and Barnel (1969) considers this to have been true of Upper Jurassic forms. They occur in the Portland Group in what were carbonate and clay muds, fine carbonate and quartz sands, and mixtures of both. Lithophaga bored into corals, small algal-oyster patch reefs, thick shelled bivalves and hard-grounds.

ORDER PTERIOIDA

Isognomon, Inoceramus, Pteria, Oxytoma, Buchia, Camptonectes,

Plicatula, Plagiostoma, Anomia, Ostrea, Exogyra.

These are all epifaunal suspension feeders and many are byssally attached "free-swingers" living in shallow, exposed sublittoral water (Kauffman 1969). Camptonectes and Plagiostoma have a well developed mechanism for clapping their valves for feeding and cleaning purposes. They are attached to the substrate when young and live in shallow water, but when adult they free themselves and move to deeper muddy areas (Allen 1953). This is significant as it would produce an assemblage of large individuals naturally without invoking selective loss of juveniles by current action and probably explains why large numbers of Isognomon and Camptonectes seen on bedding planes are adults of approximately the same size.

The valve-clapping habit makes swimming possible and Camptonectes with its scallop-like morphology was probably a fairly efficient, if spasmodic, swimmer. Recent Anomia is closely bysally attached and adapted to exposed conditions. Plicatula lives cemented like an oyster and in the Portland Group occurs in association with Ostrea and Exogyra which encrust each other and ammonites and various bivalve shells in fine grained sediments and encrust red algae to form small patch reefs in certain high energy environments (see plates 61, 62). Isognomon, Plagiostoma, Camptonectes, Ostrea and Exogyra are ubiquitous in the Portland Group. in all facies from mud to medium sand. The other genera occur in what were muds, muddy sands and fine sand.

According to Barthel (1969) Jurassic Camptonectes could withstand fluctuations in salinity and Plagiostoma was euryhaline living in shallow water. Ostrea and Exogyra were "very euryhaline" as is the modern oyster. A study was made of Exogyra accumulations in the Portland Sand Formation of Gad Cliff, Dorset and details are given in the appendix and chapter 3.

PALAEOHETERODONTA

ORDER TRIGONIOIDA

The common trigoniids are now referable to the genera Laevitrigonia and Myophorella. They are interpreted as being sluggish moving, non-byssate shallow infaunal filter feeders.

The ornamentation aids burrowing and anchorage in the substrate (Stanley pers. comm.). They are ubiquitous in the Portland Group and lived together in both shallow water high energy sands and low energy muds, and seem to have been capable of withstanding salinity fluctuations, as was suggested by Barthel (1969).

HETERODONTA

ORDER VENEROIDEA

Isocyprina, Anisocardia, Eomiodon, Astarte, Tancredia, Corbicellopsis Lucina, Protocardia, Mactromya, Eocallista, Quenstedia, Eodonax

These are infaunal suspension or detritus feeders which have only weakly developed siphons or none at all, the pallial line being only slightly sinate, or integrepalliate. Modern Astarte is semi-infaunal living in soft muddy sand (Saleuddein 1965). Lucina is a moderately slow, deep burrower with a mucus tube and thin shell. They can live where food supply is low and Eh inhibits other genera; they cannot, however, compete with more efficient suspension feeders under normal conditions (Allen 1958). Protocardia was a shallow burrower and less efficient than anomalodesmatids. Quenstedia was a sessile detritus feeder. Eomiodon is considered to have lived in seas of reduced salinity (Casey 1955, Huckreide 1967) and Eocallista was marine, although recent species live in brackish and fresh water (Barthel 1969); its distribution in the Portland Group suggests it was euryhaline and could probably withstand hypersalinity. All the Veneroids in the Portland Group occur in what were muds and sandy muds. Astarte, Carbicellopsis, Lucina, Eocallista, Quenstedia and Eodomax are found together in the upper part of the "Portland Roach", the topmost shell bed of the Freestone Beds on the Isle of Portland, which is interpreted as a deposit formed in very shallow water, probably of raised salinity. Barthel (1969) considers that Isocyprina, Astarte, Corbicellopsis, Lucina, Mactromya and Eocallista were all euryhaline in the Upper Jurassic.

ORDER MYOIDA

Corbula

Modern Corbula is inequivalve with a small pallial sinus or none at all and they live semi-infaunally in soft mud

(Kauffman 1969). This was probably also the case for those in the Portland Group which occur in what was once mud and muddy fine sands. One species is found in the "Portland Roach" mentioned above.

ANOMALODESMATA

ORDER PHOLADOMYOIDA

Pleuromya, Pholadomya, Thracia

These are moderately deep-burrowing sessile infaunal suspension feeders with thin shells, deep pallial sinuses and a siphonal gape. Recent Thracia is a rapid burrower which constructs mucus lined tubes enabling it to live deeper than its siphons alone would allow (Yonge 1937a): the other genera probably burrowed more slowly. Bivalves with this deep habit are dependent on the quantity of food in suspension (Yonge 1923) and consequently on the strength of bottom currents. Thus, the higher the energy level, the more food that is available (Driscoll 1969) but at velocities >2cm per second traction transport fills burrows which is obviously a disadvantage (Sanders 1958). Pleuromya and Thracia are common in vertical life position in what were carbonate muds at certain horizons in the Portland Group and Pholadomya is more common in sands and muddy sands. Barthel (1969) considers these genera to have been euryhaline forms living subtidally to intertidally. Pleuromya is another genus found in the possibly suprahaline "Portland Roach".

3. Gastropods

The common marine forms in the Portland Group are Prosobranchs. According to Purchon (1968) and Morton (1967) members of this sub-class feed in a wide variety of ways; some are herbivores feeding on algae by browsing and grazing, and by rasping coated rock surfaces; others are detritus feeders which collect organic deposits or plankton. Carnivorous forms feed on colonial and sedentary animals or scavenge, whereas others are active benthonic and planktonic hunters.

The Portland Group gastropods have been monographed by Loriol & Pellat (1866, 1874), Blake (1880), Hudleston (1881b) and Cox (1925) but revision of these authors' genera and species in the absence of a comprehensive "Treatise" volume has proved difficult.

ORDER ARCHAEOGASTROPODA

Pleurotomaridae

Recent pleurotomariids are herbivores and deposit scrapers. Fossil representatives occur in the Portland Group in what were originally silty muds and sands and usually in a fairly shallow carbonate environment.

ORDER MESOGASTROPODA

Naticidae

These are carnivorous forms which plough through soft substrata and bore into bivalves and other gastropods by rasping with the radula, probably aided by chemical secretions (Purne 1953, Carikker 1961). Various species of the naticidae occur in mud and sand facies of the Portland Group, preservation being best in the fine grained carbonate sediment.

Aporrhaidae

These are herbivores and Portland Group forms probably lived in a similar fashion to that described by Yonge (1937b) for the Recent genus Aporrhais. This is a shallow sessile burrower which eats detrital algal matter and diatoms in the sediment by extending its proboscis. It is regarded as an unusual gastropod because it constructs mucus-lined "siphons" similar to those of some infaunal bivalves.

Cerithacea

This is a large superfamily and includes many morphological types from low to high spired varieties. Modern forms which resemble those of the Portland Group are herbivores, mainly algal grazers which live off blue-green algal films on the sediment surface. Some live semi-infaunally or are motile within the sediment. In the Portland Group the small forms are mostly preserved only in micrites but the large high-spired Aptyxiella

is found in the muddy carbonate sand facies just below the junction with the Purbeck Beds in Dorset, the Vale of Wardour and South Midlands. Cerithid gastropods are generally regarded as being very shallow water forms and are common in carbonate environments in the marine grass zones between the strandline and open sand areas further offshore (Lewis & Taylor 1966, Taylor 1968).

4. Sponges

Members of two families of Demosponges are common in the Portland Group, especially the Portland Limestone Formation of Dorset - these are the geodiid Rhaxella and the halinid Pachastrella. Most sponges are sessile epifaunal filter feeders but little is known of the ecology of the Demospongea except that they live in water depths from intertidal to abyssal (pers. comm. R.E.H. Reid). Sponges colonise areas of lime mud in deeper water away from carbonate sand banks off Florida and these areas are practically barren of any other benthos (pers. comm.E.G. Kauffman).

The Rhaxella spicule-rich micrites of the Portland Limestone Formation contain little other fauna except burrows but the Pachastrella-rich beds generally contain a moderately diverse and dense molluscan fauna and lived in shallower, more aerated water.

Borings in loose shells and in the consolidated framework of patch reefs may be in part attributable to clionids but the distinctive pattern of these boring sponges was not observed.

5. Ammonites

The ecology of ammonites can be interpreted directly only by analogy with living Nautilus (Stenzel 1964) which is a semi-necktonic scavenging carnivore. It is possible that the larger ammonites in the Portland Group (up to 1m across) were semi-benthonic and pulled themselves over the sea-bed with their tentacles. They occur in all sediments but are less common in the high-energy carbonate sand facies of the Portland Limestone Formation, and are not known from the same facies of the Wardour Limestone Formation or the upper part of the Grès des Oies. They are found in very shallow water shelly ostracod-rich limestones in the South Midlands and occur directly below the intertidal and

supratidal Purbeck Beds in Dorset, suggesting that they could probably withstand a slightly saltier sea than normal.

Absence of ammonites from the horizons mentioned above may be due to a slight local lowering of the salt content of the sea water at those times or to the water being very shallow (intertidal?). Ammonites apparently were intolerant of turbulent waters and are found in the Portland Limestone Formation only at levels which are considered to represent quiet periods. This is also true for similar facies in the Corallian Beds and, in fact, for the British Jurassic as a whole (Arkell 1933, chapter 18).

6. Belemnites

These are unknown from the Portland Group but occur in the Upper Kimmeridge Clay and as derived fragments in the Tour de Croi nodule bed. Records of single specimens from West Dorset and Buckinghamshire (Fitton 1836) have not been verified; it is probable that they were eroded from earlier rocks. By analogy with Recent squids and cuttlefish, belemnites were probably mobile carnivores. It has been postulated that there was, in Upper Jurassic times, a division into Boreal and Tethyan faunal realms and faunas migrated north and south when the climates changed (Arkell 1956). Stevens (1965) considers, however, that it is likely that there was little difference in water temperature between the southern part of the Boreal seas and the northern part of the Tethys and the major control on migration was the existence of physical barriers such as land or deep water.

The absence of belemnites from the Portland Group was probably mainly due to land barriers preventing migration from the north and south. The water temperature during the deposition of the Portland Limestone Formation was probably warmer than that of the belemnitiferous Basal Spilsby Sands of Upper Jurassic and Lower Cretaceous age in Norfolk. The salinity of the sea may have been slightly raised at times which could have been a contributory factor in the exclusion of belemnites.

7. Brachiopods

These are rare in the Portland Group and are known only from the Portland Sand of Dorset and equivalent beds in South-east England and the Boulonnais, although a doubtful record exists of a terebratulid in the "Building Stone" of Portland (Blake 1880). Both Articulate and Inarticulate genera occur but the best preserved are rhynchonellids and terebratulids from the Exogyra Beds of Dorset, where they occur as "nests" associated with Exogyra and Ostrea.

Brachiopods are generally sessile epifaunal suspension feeders which are strictly confined to water of normal marine salinity (Rudwick 1970). Lingulids, a few of which are recorded from the Upper Kimmeridge Clay, are capable of withstanding conditions of variable or reduced salinity but usually live in normal marine conditions. Present-day Articulate brachiopods are most abundant in temperate waters and can live at all depths from the abyss to the intertidal zone. Many can tolerate quite muddy water but they cannot live in an environment in which mud or silt is being actively deposited (Rudwick 1970).

The rare occurrence of Rhynchonella (sensu stricto) and terebratulids in the Portland Group may be directly due to a salinity control and/or substrate conditions. Although there is no clear indication which of these two factors was the more significant it seems likely that substrate conditions played only a minor role and a combination of the effects of physical, chemical and biological factors were more effective.

The presence of ammonites, rare corals and rare echinoids suggests that, at times, salinity was not far from normal but if it was changed then it is suggested that the salt content was slightly higher than usual. According to Ager (1965) rhynchonellids and terebratulids were typical inhabitants of sub-littoral sand-grade sea-floors and the Portland Group forms occur in what was such an environment.

8. Echinoderms

Crinoids are not known from the Portland Group and the only

signs of Asterozoans are occasional indeterminate ossicles. Echinoids are scarce but representatives of the orders Hemicidaroidea and Echinoidea are known from the Portland Limestone Formation, the lower part of the Portland Group in the South Midlands and from the Assises de Croi.

The Hemicidaroids were epifaunal and genera of the Echinoidea lived semi-infaunally; members of both orders were carnivores and scavengers. The rarity of echinoderms may be yet another indication that conditions for life in the sea during these times were not normal. Echinoderms are generally sensitive to salinity changes (Binyon 1966, Nichols 1969) and these may have been the main factors controlling their distribution.

9. Bryozoa

These are colonial sessile epifaunal suspension feeders which catch planktonic food with the aid of a circlet of ciliated tentacles. They are mostly confined to waters of normal marine salinity (Ryland 1970). Members of the family Diastoporida (Order Cyclostomata) have been described by Lang from the lower part of the Portland Limestone Formation of the Isle of Portland (in Cox 1925). These are also common in the uppermost beds where multilamella encrusting forms bind the red-algae and oysters of small patch reefs (Plates 61,64,65)

10. Arthropods

Decapod fragments are common and Glyphea and "Callianassus" have been recorded. At some horizons these remains are common and are often associated with burrows (especially Thalassinoides). Preservation potential is highest in fine-grained sediments and broken chelae are common at certain levels in the South Midlands and the Portland Limestone Formation of Dorset (e.g. "Shrimp Bed" of Arkell 1935).

Ostracods (order Diplostracea) are common at the junction with the Lower Purbeck Beds in most areas but are rare in the more normal marine sediments below. The Lower Purbeck forms were previously regarded as fresh water but are now known to be

hypersaline species (Anderson in Wilson et al 1958, Barker 1966). Ostracods were not studied in detail in this thesis and the work of Barker (1966) is the latest published information. Mr. R. G. Clements is working on the ostracods of the Purbeck Beds.

11. Annelids

The only preserved annelid found are serpulids which are epifaunal suspension feeders. They are common in the Portland Group, especially the small Glomerula gordialis which forms "serpulites" at some horizons in the Portland Limestone Formation. This serpulid encrusts bivalves, ammonites and hard-grounds (Plates 15,71) but most commonly they lay on the sea bed unattached, encrusting themselves in a knotted fashion when currents rolled them over (Plate 46).

Larger Serpula species more often encrusted shells and are less common than Glomerula. Barthel (1969) considers that the latter was capable of withstanding brackish water and it is thus probable that it could also live in slightly hypersaline conditions.

12. Corals

The scleractinian compound coral Isastrea occurs in shallow-water medium-energy horizons of the Portland Group at three localities. These are rare appearances, however, and the general absence of corals may be due to a salinity control or to limited suitable substrate conditions. Jurassic corals, as a whole, in the British Isles are less diverse than in south-central Europe and this is considered by Arkell (1947b) to be due to isolation from the dispersal centre along the northern margin of the Tethys Sea, combined with the shortness of the periods of clear water available for colonisation.

13. Foraminifera

These are seen occasionally in thin sections but no study was made of the forms present as Dr. A. Lloyd of University College, London is in the process of doing so.

14. Trace Fossils

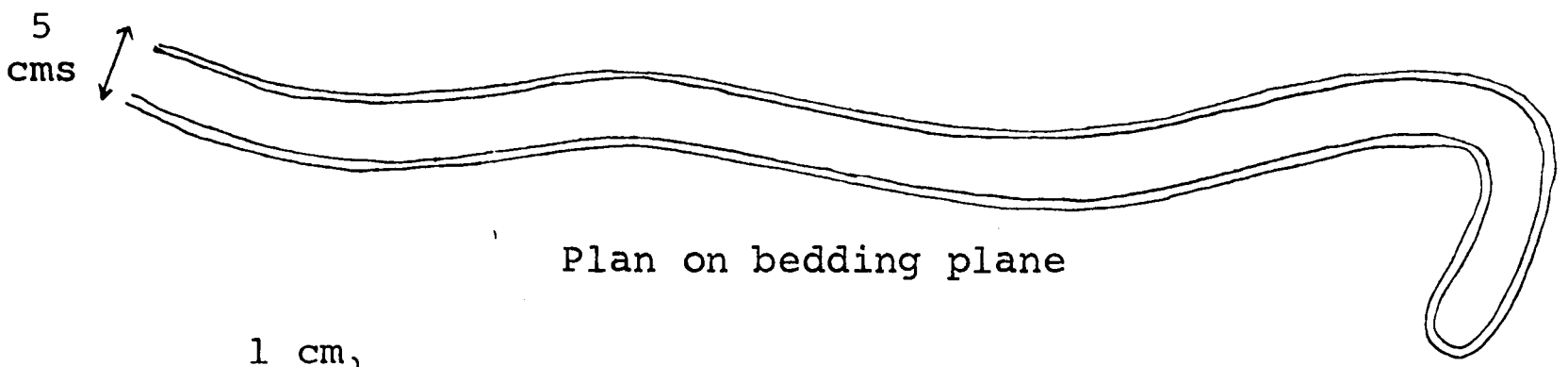
Most of the original depositional structures in beds of the Portland Group have been partly or wholly destroyed by burrowing organisms. The common well-preserved burrows are Thalassinoides and Rhizocorallium but Chondrites and other less easily recognised ichnogenera also occur. In the high-energy cross-stratified sands high angle or vertical single-tube burrows are sometimes found but nothing resembling the U-tubes of Diplocraterion was discovered.

Rhizocorallium (Fig. 4)

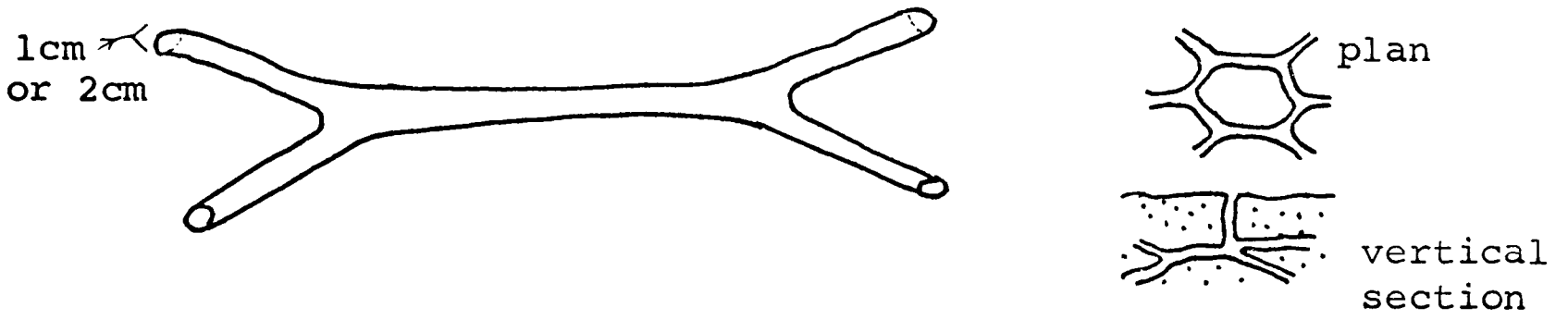
This is a U-shaped burrow which lies parallel or slightly oblique to the bedding. The sediment between the two tubes is reworked resulting in the presence of curved structures parallel to the end of the "U", and which are best described as having the three dimensional shape of bicycle mudguards (Plate 14). These form what is known as the "spreite" by German authors. The animal which produced Rhizocorallium is thought by Seilacher (1967) to have been a sediment-eating infaunal crustacean but Sellwood (1970) considers that the animal changed to suspension feeding once the burrow was dug.

This trace-fossil is common in the Black Dolomite Beds of the Portland Sand Formation of Dorset whereparallel tubes up to 2m long are seen on bedding planes (Plate 8). It is postulated in this thesis that these beds were deposited slowly as lime mud in an environment generally inamicable to benthonic life. Rhizocorallium is the only common preserved fossil, except unencrusted ammonites, and although the burrows are common the sediment between them still retains depositional laminations (Plate 3). The long tubes suggest that the Rhizocorallium-animal was eating the sediment and had to search a wide area to sustain itself. The lack of complete homogenisation of slowly deposited sediment suggests that burrowing was a rare occurrence in spite of the abundance of the fossil. Upward movement of Rhizocorallium (vertical retrusion) has been taken to be a reaction to the deposition of sediment, the animal moving up to maintain a constant distance below the sea bed (Sellwood 1970). Such structures occur

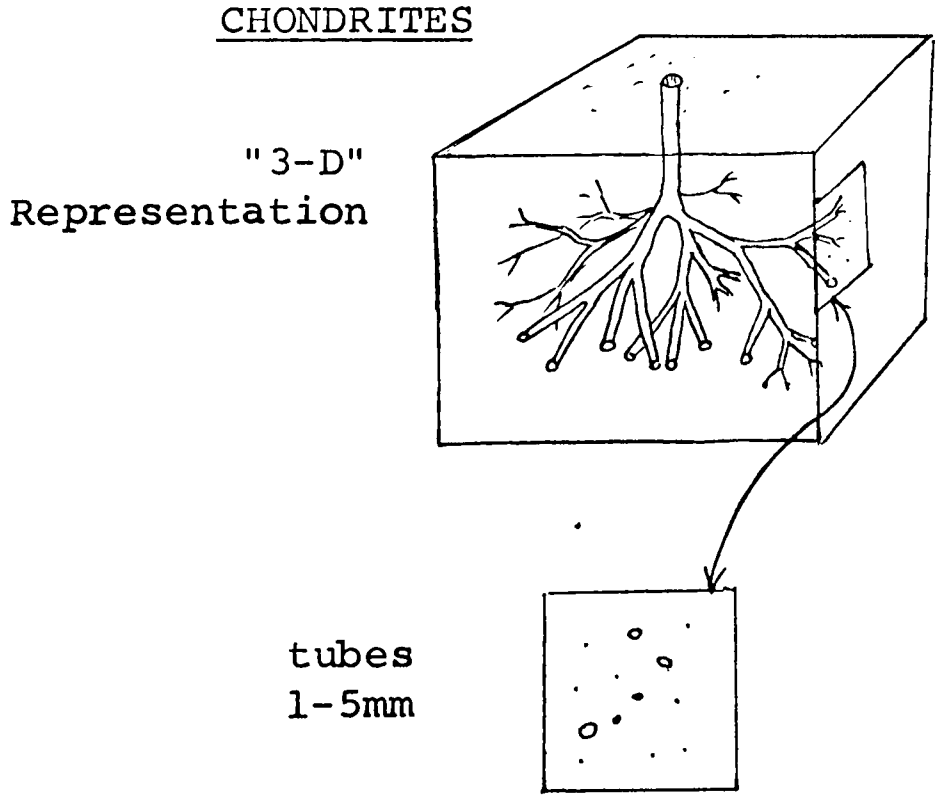
RHIZOCORALLIUM



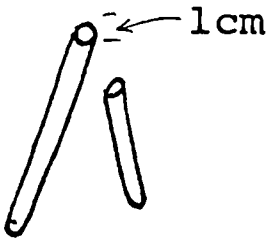
THALASSINOIDES



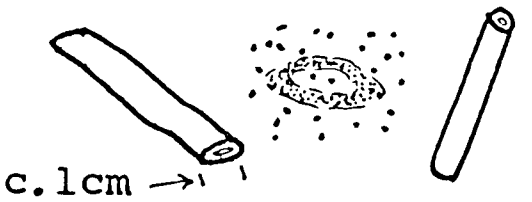
CHONDRITES

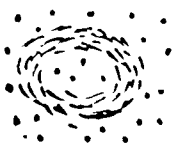


"SKOLITHOS"



"Siphonites"





"Terebella"

at certain levels in the Black Dolomite Beds and superficially they simulate small scale cross-stratification (Plate 18). It is thought in this case at least, that the animals moved to a higher level when the food supply of one workable area at a certain depth was depleted.

An important general conclusion, except in cases of very rapid deposition, is that intense bioturbation indicates a sea bed with a normal population density only if the original depositional texture is completely destroyed. The last inhabitants usually leave discrete burrows but these cut previously bioturbated sediment. The degree of bioturbation is not only an indication of rate of deposition in that slowly deposited beds are often more burrowed than rapidly formed ones, but it can also be an indication of the number of organisms living in the sediment.

Rhizocorallium also occurs in Portland Group Sands in the South Midlands, associated with crustacean fragments (Plate 83), and in the sands and clays of the Assises de Croi of the Bas Boulonnais.

Thalassinoides (Fig. 4)

These are single, mainly horizontal burrows with Y-shaped branches which often connect to give a polygonal pattern (Plates 37, 56). Vertical tubes connected this system to the surface but these are not often seen except in the high-energy carbonate sands of the Isle of Portland and in a rare example in the Bas Boulonnais where the tubes radiate from a central point (Plate 88). The burrows are similar to those produced by recent callianassid and alpheid crustaceans (Shinn 1968, Farrow in press) and remains of such animals are often found with the burrows in the Portland Group. Thalassinoides is common in the Portland Limestone Formation of Dorset in both lime mud and carbonate sand facies. (Pl. 4 57) The tubes of these are on average 10mm in diameter but in the Bas Boulonnais larger forms occur as well as small ones (this thesis and Ager & Wallace 1970) (Plate 87).

Rhizocorallium and Thalassinoides are mutually exclusive in

the Portland Group of Dorset and the Boulonnais, the former burrow occurring in deeper water sediments than the latter on. Ager & Wallace (1970) postulate that these burrows were made in the following environments:

Small Thalassinoides: Low energy, intertidal.

Rhizocorallium: Low energy, infralittoral.

Large Thalassinoides: High energy, infralittoral.

The deposits in which small Thalassinoides of the Portland Limestone Formation are common are thought to have been laid down in quiet water, deeper than intertidal and possibly of slightly abnormal salinity.

Chondrites (Fig. 4)

These are root-like branching systems which have a few vertical and many horizontal or inclined tubes 1.5mm across. The animal responsible for these is unknown but Simpson (1957) suggests that they might have been deposit-feeding sipunculoid worms. Complete burrow systems were not seen in the Portland Group but sections of the tubes were found in cut surfaces of the argillaceous sands and silts of the lower part of the Portland Sand Formation.

"Teichichnus" (Fig. 4)

This is a single horizontal tube which often has a curved concordant structure below indicating upward movement of the whole burrow. The status of this ichnogenus is in doubt and some examples described have proved to be one tube of a retrusive Rhizocorallium (Sellwood 1970). Such straight or curved tubes are visible on bedding planes in the lower part of the Portland Limestone Formation in East Dorset (Plate 47), and seen to be distinct from Rhizocorallium. They are associated with Thalassinoides but apparent branching is due to crossing over of the tubes.

"Skolithos" (Fig. 4)

This name can be given to straight tubes at a high angle to the sediment which occur in the carbonate sand facies of the upper part of the Portland Limestone Formation. These burrows are deep

in order to protect the animal from effects of a mobile sea bed. Richter (1928) interprets these as being tubes of Sabellarid worms.

"Siphonites" and "Terebella"

These are mud-lined tubes approximately 1cm across which generally lie at a high angle to the bedding. They occur in the carbonate sand and mud facies in the upper part of the Portland Limestone Formation and in argillaceous fine sands in the South Midlands. They are similar to those produced by Recent terebellid worms and some have shell-fragments arranged in a concentric pattern in the wall, as seen in Cretaceous examples studied by Kennedy (1970).

Borings

The "crypts" of lithophagous bivalves are common in the small patch reefs of the Portland Limestone Formation on Portland and in the hard-ground in the Grès des Oies. Some thick-shelled bivalves and the rare corals have also been bored in this way. Other borings attributable to annelids are common in the carbonate facies of the Portland Group and casts of these are well preserved when aragonitic skeletons have dissolved leaving empty moulds.

Small borings attributable to sponges are also fairly common (Plate 61) but none closely resemble those of Cliona described by Bromley (1970). "Pseudoborings" are common in the red algae of the Portland Group in Dorset. Serpulids encrusted the surface of the growing algae, which responded by growing around and over them, eventually enclosing the serpulids completely. This gives the appearance, when sectioned, of a boring through the algal skeleton, but when seen under a microscope the growth pattern is revealed (Plate 67).

15. Vertebrates

Generic names of fish and marine reptiles (e.g. Chimaera, Pleisosaurus) appear in the monographic lists but bones are rare except in the Tour de Croi nodule bed where they have concentrated by slow deposition. Fish spines, scales and teeth can be found in the "Basal Shell Bed" of the Isle of Portland, but this again

is thought to have accumulated over a relatively long period of time compared with the Portland Limestone Formation in general.

A conglomerate in the Gres des Oies contains terrestrial vertebrate remains (e.g. Iguanodon) as well as aquatic forms, indicating the proximity of the land. Reptile footprints are well-known from certain horizons of the Middle Purbeck Beds in Dorset (Oppe 1965).

16. Trees, seeds and pollen

Miospores have been studied from the Upper Jurassic strata of Southern England by Norris (1969) who found restricted spore-pollen assemblages in the Upper Kimmeridge Clay, Portland Sand Formation and Purbeck Beds but found the Portland Limestone Formation to be barren. Norris attributes the restricted nature of the assemblages to the contribution of several factors. He thinks that considerable sorting by wind and water was likely and that the relative inpoverishment may have been accentuated by an extremely limited flora which occupied the coastal regions.

Tree stumps, trunks, branches and seeds of Cycads and Araucarians are common at one horizon at the base of the Purbeck Beds in Dorset. The Tour de Croi nodule bed contains vegetable remains recorded as being Cycads, Pines and Sequoia (Dutertre 1927); if this latter genus is a true record then it is the oldest known form (Sequoia portlandica). Apart from these, plant remains are unknown from the Portland Group.

17. Marine algae

Although blue-green and green algae undoubtedly lived in the carbonate environments of the Portland Group they are not preserved except as microscopic borings in skeletal fragments and ooids (Plates 24,28). Some of these are probably fungal borings but as the sediments are considered to have been formed in water shallow enough for light to penetrate it is reasonable to expect that many were formed by algae. Blue-green and green algae are common in the basal Purbeck Beds where they were responsible for the accumulation of several metres of algal

limestones, but red algae are rare (Brown 1963, Pugh 1968).

Solenoporacean red algae are common in the topmost horizons of the Portland Limestone Formation where, encrusted by oysters and bryozoa, they formed small patch-reefs up to a metre or two across (Plate 61). "Solenopora and its allies are believed to have liked clear shallow warm waters of normal salinity, often agitated, and they are frequently found in reef and shoal deposits. They are believed to be the ancestors to the Recent melobesoids which like the oxygenated sub-zone of reef-fronts, though not confined to this" (G.F. Elliott, pers. comm.).

The difference in the types of algae between the beds of the Portland Limestone Formation and the basal Purbeck in Dorset is an obvious reflection of the change from normal or slightly raised salinity to marked hypersalinity (Brown 1963, Pugh 1968). These algae are further discussed in the appendix.

A general point which can be made here, is that Clypeina (a euryhaline dasycladacean green alga) is absent from the Portland Group, and apparently from all the British Jurassic. These occur interbedded with, but separate from, Solenoporoids in the South of France and are common from Switzerland to the circum-Mediterranean Tethyan Jurassic, the Middle East and Mexico, whereas Solenoporoids are rare in these areas. If the sea water was slightly diluted in northern Europe during Jurassic times, as suggested by Hallam (1969) then one might expect dasycladacean algae to be common in the British Isles, or at least to appear.

CHAPTER 3

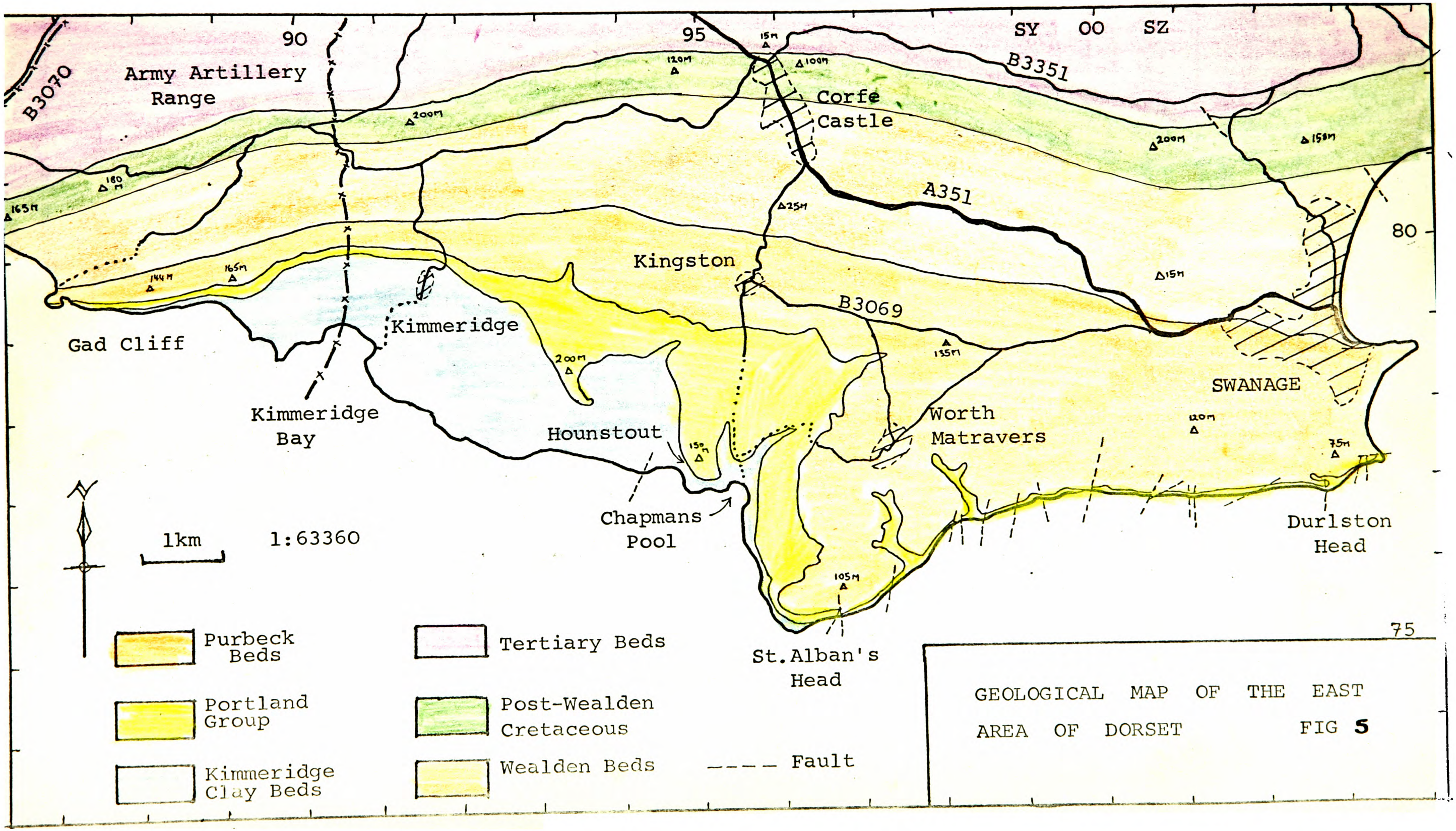
THE PORTLAND SAND FORMATION OF DORSET

1. <u>The Portland Sand Formation in the East Area, Dorset. Isle of Purbeck.</u>

A. <u>Introduction</u>

The beds below the Portland Limestone Formation have been studied over many years by earlier workers in both east and west Dorset but no precise correlation between the two areas has ever been published. Consequently, until now the bed nomenclature has been different in the west (West Area and Central Area) to that in the east (Isle of Purbeck). As a result of this study a lithostratigraphical correlation has been made and the beds in the west have been traced across to equate with those of a different name in the east. The western sections can be tied in with the Gad Cliff section (West Isle of Purbeck) and so can the sections east of this (East Isle of Purbeck); thus, this locality is used to indicate the nomenclature employed in this study (Figs 5, 6). When discussing the Portland Sand Formation as a whole, the more widespread names are used. However, as the old bed divisions in the Isle of Purbeck are more readily recognisable in the field, they are used in describing sections in that area, but it is hoped that the terms St. Alban's Head Beds and Emmit Hill Beds (both formerly 'Marls') will be abandoned in favour of the divisions which can be used throughout Dorset. The reason for retaining the old terms for the descriptions in the east part of the Isle of Purbeck is that the Exogyra Beds are less distinct than in West Purbeck and, although <u>Exogyra</u> can be found in layers, as depicted by Arkell (1935 fig. 42, 1947 fig. 21), (Fig. 12), they form a less distinct unit than the St. Alban's Head Beds.

The only two localities where complete successions are visible from the Kimmeridge Clay through the Portland Sand Formation to the Portland Limestone Formation are (a) from Hounstout to St. Alban's Head in the east (Grid ref: SY 9575) (Plates 1, 2 and Frontispiece); and (b) at Gad Cliff in the west (SY 8879) (Fig. 5 Plates 10, 11). The position of the junction between the Kimmeridge Clay and the Portland Sand Formation has



GEOLOGICAL MAP OF THE EAST AREA OF DORSET FIG **5**

BED NOMENCLATURE OF THE PORTLAND SAND FORMATION IN DORSET.

FIG 6

WEST AREA CENTRAL AREA EAST AREA. Purbeck West.	GAD CLIFF West Purbeck	EAST AREA Isle of Purbeck West and East
Townson 1971	Arkell 1935	Townson 1971
Portland Limestone Formn.	Portland Stone	Portland Limestone Formn.
Lower Cherty Beds	Cherty Series	Lower Cherty Beds
BLACK DOLOMITE BEDS	BLACK SANDSTONE	BLACK DOLOMITE BEDS
	Upper / Middle / Lower PARALLEL BANDS	
CAST BEDS	ST. ALBAN'S HEAD MARLS	ST. ALBAN'S HEAD BEDS
EXOGYRA BEDS	"layers with Exogyra"	
	White Cementstone	
UPPER BLACK NORE BEDS	EMMIT HILL MARLS	EMMIT HILL BEDS
	MASSIVE BED	
? ?		
KIMMERIDGE CLAY		

SECTION IN THE UPPER PART OF THE KIMMERIDGE CLAY BELOW THE PORTLAND SAND FORMATION IN THE EAST AREA, DORSET.

HOUNSTOUT, ISLE OF PURBECK, EAST.

FIG 7

		Portland Sand Formation. Emmit Hill Beds.	SEDIMENT	FOSSILS (excluding ammonites, trace fossils & microf.)
Upper Sandy Kimmeridge Beds. about 34m		HOUNSTOUT MARL c.18m	Fine grey quartz sands with varying amounts of clay matrix and carbonate cement. Argillaceous bed at the top (2.5m). Some thin cemented horizons separated by thinly bedded, soft sandy mudstones. Similar to Emmit Hill Bds, facies A and A'.	None found or previously recorded?
		HOUNSTOUT CLAY c.6m	Dark silts and fine sands with clay, or black thin bedded mudstones - some bituminous.	
		RHYNCHONELLA MARLS c.10m	Black, laminated silty mudstones.	Oxytoma, Rhynchonella (ss) Small belemnites 'Cidaris' spines.
Part of the Upper Kimmeridge Clay Beds. about 31m		LINGULA SHALES c.15m	Thin bedded grey to black mudstones and clay with occasional calcareous nodules, passing down into soft, laminated black mudstones	Lingula 'Protocardium'
		ROTUNDA CLAYS c.16m	Soft laminated black mudstone and clay with calcareous mudstone nodules. Rotunda Nodule Bed at base comprising at least two main horizons of calcareous nodules. (c.0.5m)	Pleuromya Astarte Lucina Modiola
		ROTUNDA NODULE BED		

After Arkell and others.

long been disputed, but since the Geological Survey work of 1880-90 the base of the Massive Bed has been the level taken (base of Emmit Hill Beds). However, as this horizon cannot be recognised in the Central and West Areas of Dorset, the succession for the upper part of the Kimmeridge Clay is given below and briefly described in Fig. 7 . The three topmost units of the Upper Kimmeridge Clay contain v.f. quartz sand and silt and are referred to as the Sandy Upper Kimmeridge Beds, following the use in the South Midlands for a similar sandy development at the top of the Kimmeridge Clay Succession there, albeit of a different age (Arkell 1944).

PORTLAND LIMESTONE FORMATION	Lower Cherty Beds
PORTLAND SAND FORMATION approx. 40m	Black Dolomite Beds St. Alban's Head Beds Emmit Hill Beds
SANDY UPPER KIMMERIDGE BEDS approx. 34m	Hounstout Marl Hounstout Clay Rhynchonella Marls
part of the UPPER KIMMERIDGE CLAY BEDS approx. 31m	Lingula Shales Rotunda Clays and Nodule Bed

The St. Alban's Head Beds and Black Dolomite Beds are most easily examined under both sides of St. Alban's Head. The junction with the Lower Cherty Beds is best seen under Emmetts Hill (SY 9576) and at the furthest east of the sections under St. Alban's Head. Detailed examination of the Portland Sand Formation in all sections in the East Area showed that there are no appreciable changes between them in facies or thickness. Thus, the details described below, and in Fig. 11 are compiled from several different exposures, the lowest beds being measured in the west and the highest in the east.

The only other exposure of the complete succession in the Isle of Purbeck is approximately eight kilometres to the west, under Gad Cliff. Here the beds dip north at angles from 25-35° and are visible in a strike section along the whole length of the cliff, a distance of two kilometres. This exposure has received less attention from previous workers than that in the East Area, mainly because it is difficult to get to and dangerous to examine in detail (Plates 10, 11). Since 1943 the area has been an artillery range with restricted entry, thus new hazards have therefore deterred all but the most perverse.

Access to the sections is physically possible only at the eastern, central and far western parts but detailed examination at these places has shown that there is no appreciable variation over the two kilometres, and thus a single, composite, section is given (Fig. 11).

B. <u>Lithofacies of the Portland Sand Formation in the East Area and the Central Area</u>

Two major lithofacies, A and B, have been defined, based on petrography and sedimentary structures. 135 thin sections were cut and stained; many were also point-counted. Calcium carbonate content was determined for some specimens by titration (see appendix). Structures were examined in the field, in polished hand specimens and in thin sections.

(i) Lithofacies A and associated rock types:-

Composition: This sediment could be termed anything from a light to dark grey <u>Impure Dolomite</u> to <u>Impure Argillite</u> but is simply referred to as Facies A (Fig 8). <u>Clay</u> comprises 30-60% and is defined as non-calcareous matter of grain size <4μ, but in practice refers to clay minerals. Organic matter of this size also occurs but can be regarded as subordinate to clay minerals unless specifically mentioned. <u>Quartz</u> is present from 10-30% as subangular coarse silt to very fine (v.f.) sand (Wentworth scale). <u>Carbonate</u> is present from 20-50% as calcite and/or dolomite; the former with the same grain size range as the quartz, and the latter as finely crystalline rhombohedra, associated with the

clay. Accessory minerals include less than 1% glauconite and feldspar occurring in direct proportion with the quartz sand; pyrite or hydrated iron oxides resulting from destruction of shells containing pyrite-filled algal borings; and rare heavy minerals (Neaverson 1925, Latter 1926) including garnet, staurolite, kyanite and epidote.

Sand-size bivalve shell fragments of original calcitic composition occur and some are recognisable as broken Exogyra. Some are partially silicified and in one horizon where Exogyra is abundant and brachiopods make a rare appearance, whole and fragmented shells are often completely preserved as beekite, including the brachiopods (Plate 4).

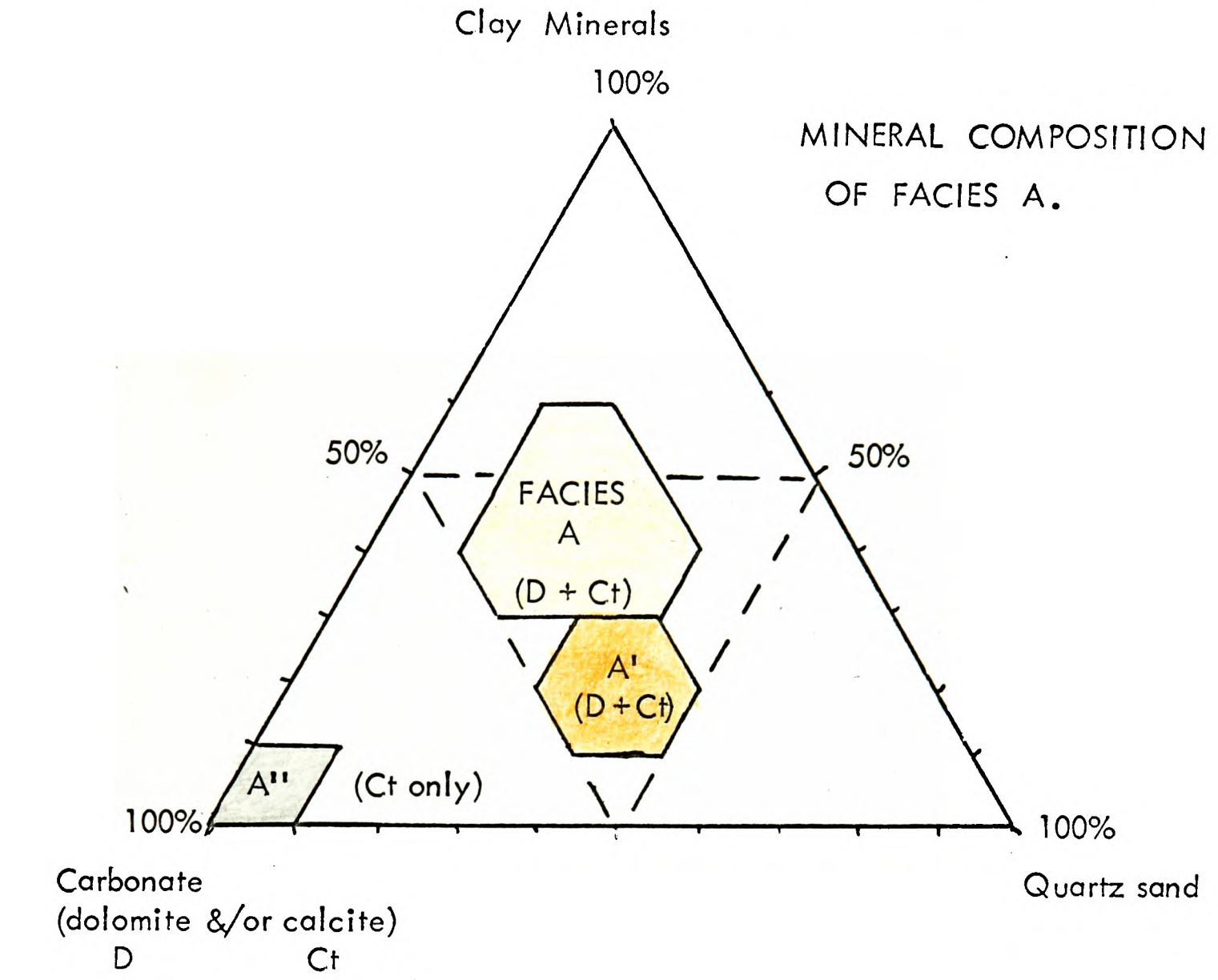
Microstructure: The sediment has been highly burrowed but remnants of original laminations are visible. The laminations are 0.2-0.5mm thick and are due to the presence or absence of clay (which probably can have a fairly high bituminous content) in a "background" of sand-sized quartz and calcite, elongate grains of which usually have long axes aligned (Fig. 9). The clay-rich laminae contain euhedral dolomite crystals between the quartz grains. It is inferred that sand-grade quartz and calcium carbonate were deposited, with periodic settling of clay-grade material forming the laminae, and then the calcium carbonate with a clay matrix was selectively dolomitised.

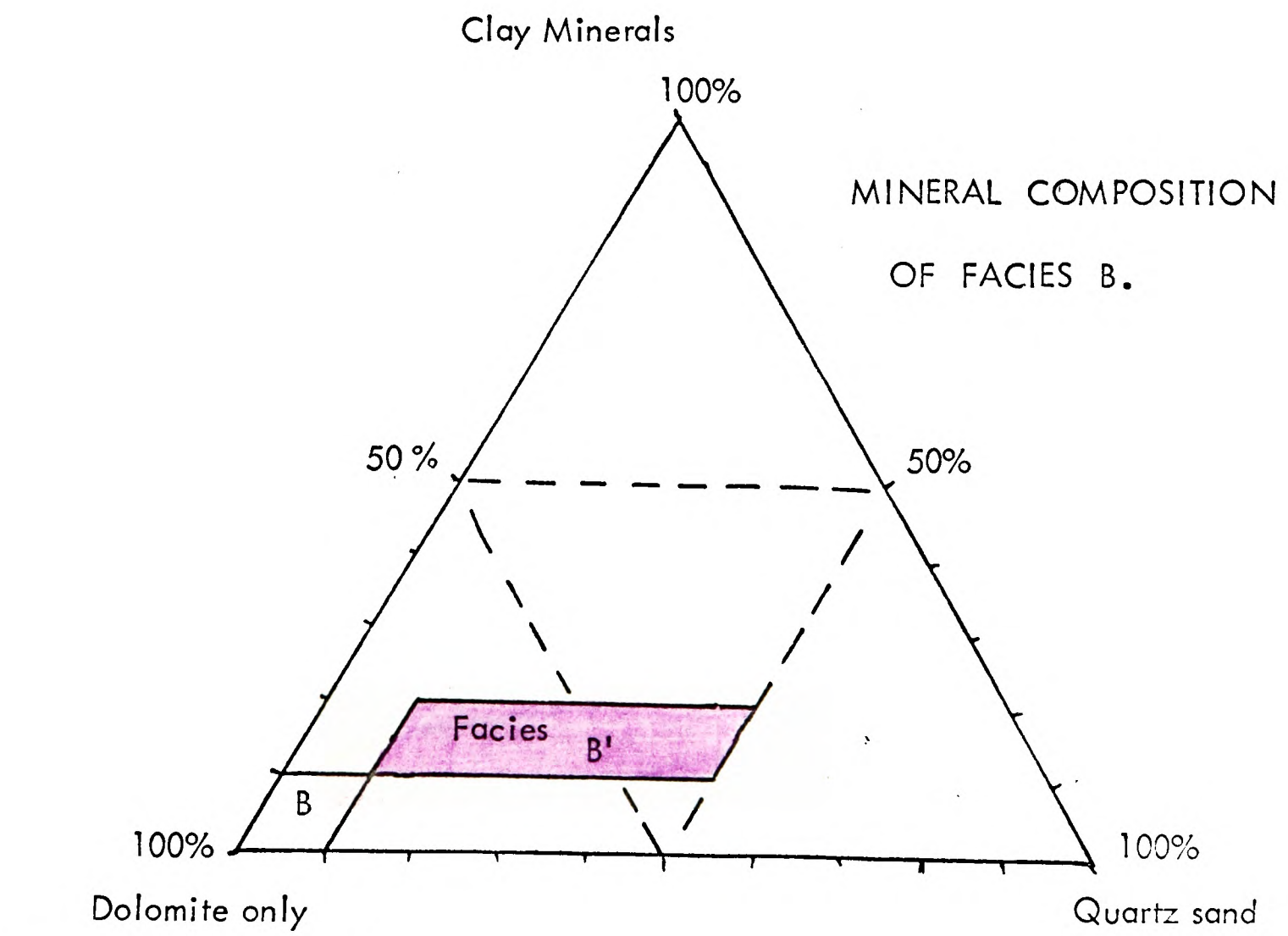
There is no indication that the dolomite rhombohedra were primary precipitates and it is suggested that the relationship with the fine clay laminae may indicate selective dolomitisation along impervious layers. The laminae are very thin, however, and this may suggest a more direct relationship with the clay, possibly even that it was a source of magnesium ions.

Disruption of the laminae by burrowing is seen at a microscopic level and faecal pellets up to 2mm long are common (Fig. 10).

Macrostructure: Horizontal bedding demarcates the repeated junction between Facies A and the associated rock types described next, forming beds varying in thickness from 0.5-4.0m. In the

FACIES OF THE PORTLAND SAND FORMATION, DORSET. EAST AREA, (ISLE OF PURBECK.) AND CENTRAL AREA. FIG 8



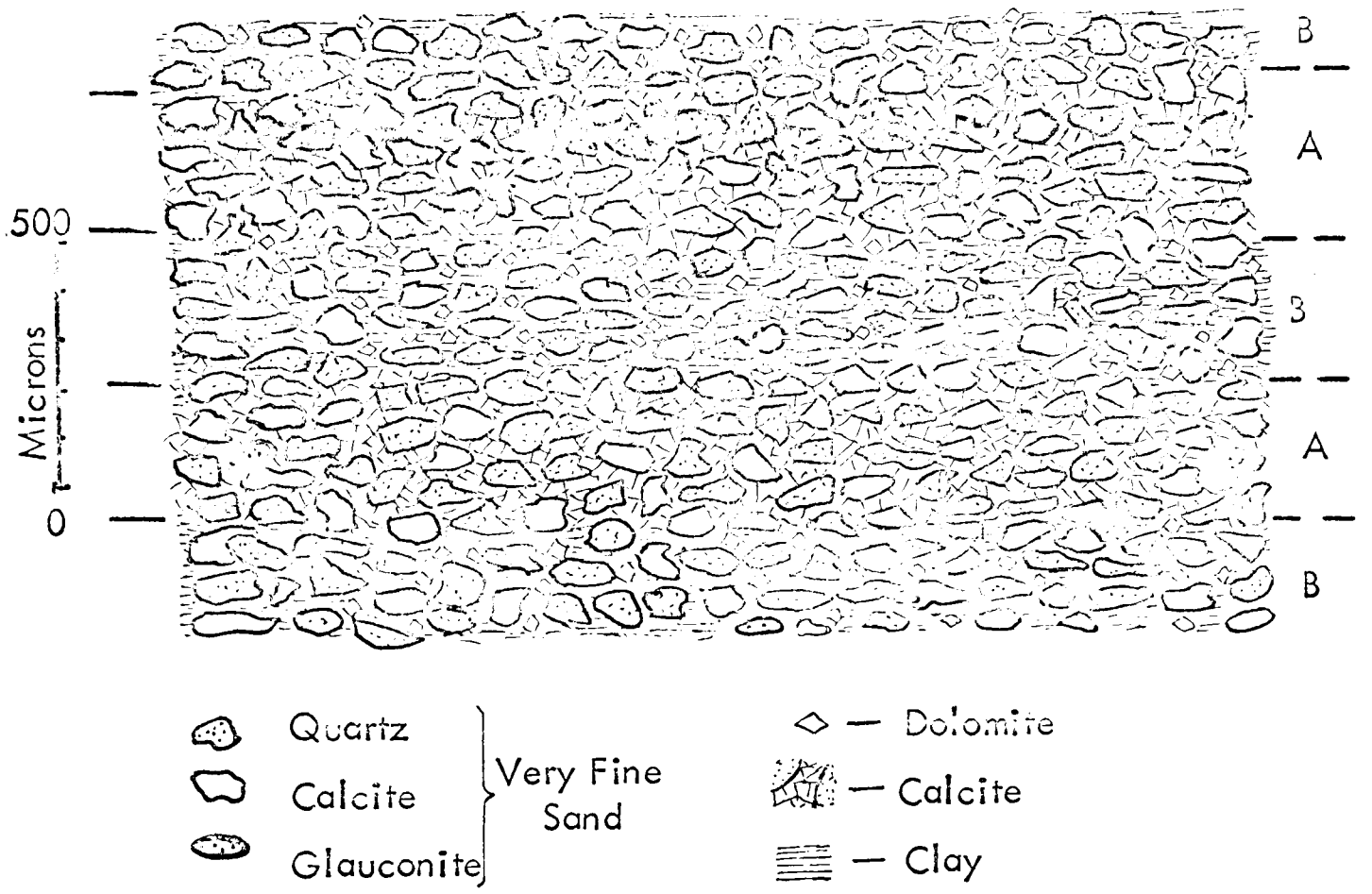


NOTE:- Although the composition of facies B' overlaps with that of facies A', the carbonate content of B' is dolomite and that of A', when dealing with such low clay content, is detrital calcite grains.

PORTLAND SAND FORMATION, DORSET. EAST AREA, ISLE OF PURBECK

Laminations of Facies A , Magnified fifty times. FIG 9

A = Laminations with Calcite cement. B = Laminations with clay and dolomite matrix.



PORTLAND SAND FORMATION, EAST AREA (ISLE OF PURBECK). DORSET.

Bioturbation structures seen on cut surfaces of Facies A, showing clay burrow-walls and faecal pellets. True size.

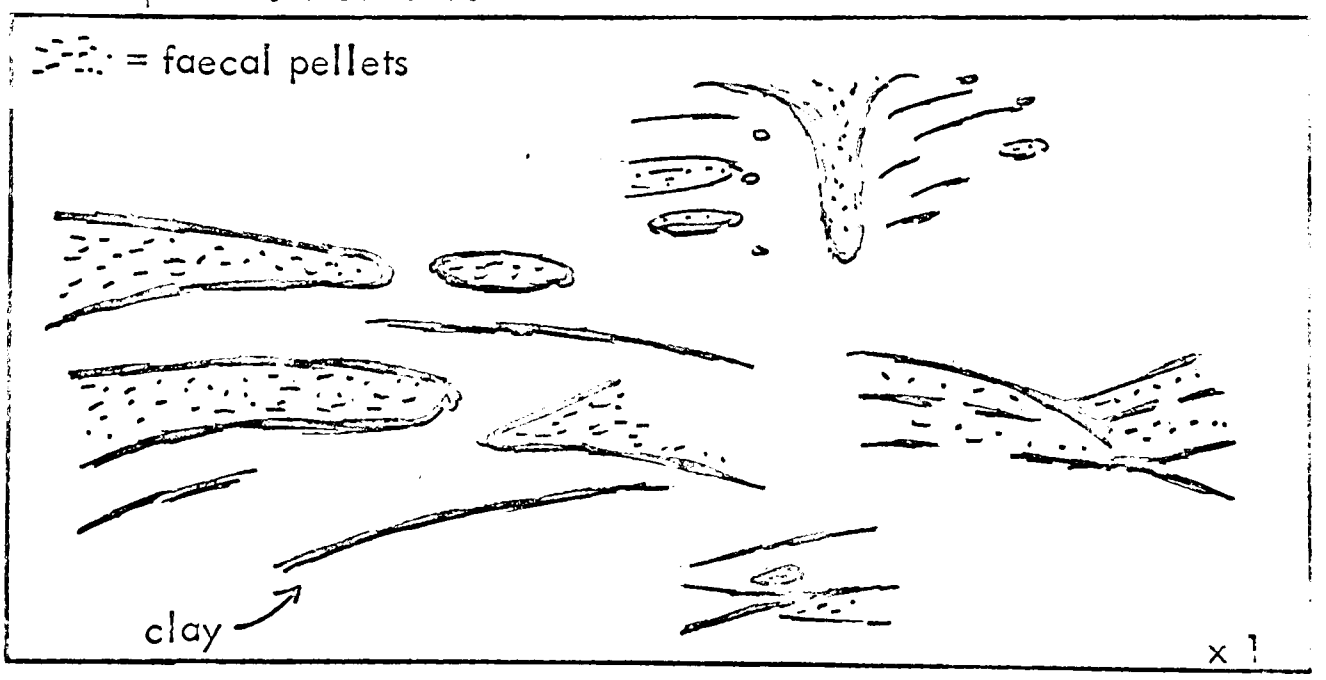


FIG 10

field weathering of the thick beds reveals bedding due to compositional variation. Beds shown on the section (Fig. 11) as thicker than 4.0m are probably composed of more than one bed but the exposure and/or access did not enable this to be detected. Intense bioturbation has produced mottling of the light and dark grey sediment and sometimes parts of the trace fossils Chondrites and Rhizocorallium can be distinguished, as well as indeterminate straight burrows about 10mm in diameter. In spite of the high degree of biogenic homogenisation of these beds, original fine lamination enables its effects to be observed, and this fact suggests that infaunal density was never very high and that sedimentation was slow.

Associated rock types A' and A" and their relationships with Facies A:

A' Impure quartz sandstone (Fig. 6)

This is composed of 30-50% coarse silt and 10-30% clay. This sediment differs from Facies A only in having a lower clay content and subsequent dolomite to calcite ratio, all due to a higher proportion of "background" quartz and calcium carbonate sand. Structures are not very clear as the higher sand content renders the lamination less distinct, but the overall similarity to facies A makes it an associated variety rather than a different facies.

A" Quartzose limestone

This contains 90-100% calcite microspar and 0-10% coarse silt, very fine quartz sand and clay (usually < 2%), with accessory minerals as in facies A. The microstructure consists of indeterminate burrows 0.5-1.0mm across, showing as quartz-free patches of microspar of a slightly coarser or finer crystal size than that in the quartzose portions. There are a few sparite-filled moulds of originally aragonitic shelled bivalves, varying in maximum dimension from 300-500mm. Occasional foraminifera and ostracods occur as well as silicified fragments of Exogyra, and possibly, rare sparite casts of Rhaxella spicules.

This rock type occurs interbedded with Facies A in continuous

horizontal beds or nodule horizons 0.05-0.35m thick. Throughout the Emmit Hill and St. Alban's Head Beds this sequence of alternations of relatively thick beds with a high clastic to carbonate ratio (Facies A), with much thinner beds with a low ratio (Facies A'), is repeated up to approximately twenty-five times in a maximum thickness of twenty-eight metres. (Figs. 11).

(ii) Lithofacies B and Associated Rock Types: Dolomites

Composition: The diagnostic feature of this facies is that the rock contains > 80% finely crystallised dolomite rhombohedra or mosaic, with < 10% subangular coarse silt or v.f. quartz sand, and < 10% clay (Plate 5). The associated sand-grade minerals are as described for Facies A, and because Facies B follows Facies A in the ortland Sand Formation, this is a natural upward continuation of the presence of sand. Because the dolomite is finely crystallised it is suggested that this was originally a lime mud. The rhombohedra are often euhedral with spaces between indicative of the 13% reduction in volume which occurs when dolomitisation takes place after compaction.

A typical thin section of the rock consists of dolomite rhombs or mosaic, scattered quartz grains and occasional glauconite, but sometimes rare fragments of calcitic shells may occur as well as later, cross-cutting, ferroan-calcite veins. Dedolomitisation has taken place in certain horizons producing poikilitic calcite-cemented black nodules (the "Black calcite nodules" of Arkell 1935, etc.). These consist of calcite crystals 5-10mm across, which replace mosaic patches of dolomite but which the original micro-mosaic pattern and occasional rhombs is still visible (Plates 6, 17).

Microstructure: Very little is present except occasional burrows and rare remnant original laminations which are visible as variations in grain size and clay content (Plate 3); these show better in a hand specimen.

Macrostructure: Some hand specimens show remnant laminations but the sediment is very highly bioturbated. Good bedding plane surfaces occur on fallen blocks and abundant Rhizocorallium is

seen to account for the majority of the burrows (Plate 8). The fact that these are visible as discrete structures, often reaching a metre long, in a laminated sediment, means that bioturbation was spasmodic. Vertically retrusive Rhizocorallium occur and the disturbed sediment superficially resembles small scale cross stratification (Plate 18). No fossils occur, other than ammonite internal casts and external moulds 0.05-0.2m across. If large bivalves had existed in the original sediment they should have been preserved in a similar way and the absence of such preservable epifauna or infauna suggest that the sea bed was not habitable. It is probably incorrect, however, to suggest that there were no animals present, other than non-preservable burrowers, but it is probable that there was a very low abundance and diversity.

There are some problematical white "blebs" 5-20mm across at some levels which, on analysis, are found to contain organic matter and clay but not phosphate. (See appendix). They sometimes resemble bivalve remains but usually are not recognisable as such. Coatings of this material are found on some ammonites and this may suggest an association with aragonitic skeletons.

There is a less pure dolomite containing 10-50% coarse silt and v.f. quartz sand, and 10-20% clay. As the dolomite content can vary from 35-75% this rock type is termed a Quartzose Dolomite, or Facies B'. There is a gradation from B to B' and arbitrary limits are based on a study of the samples collected (Fig. 8). The essential difference between Facies A' (impure quartz sandstone) and B' (quartzose dolomite) is the nature of the carbonate content; the latter contains dolomite only but the former contains sand and silt-grade detrital calcite and only subordinate dolomite, probably due to a decrease in clay content. The structures and fauna are the same as described for B except that dedolomitisation nodules were not observed, although Arkell was apparently more fortunate in his findings (1935 p. 308).

C. The Isle of Purbeck Sections in the Portland Sand Formation (Fig. 11)

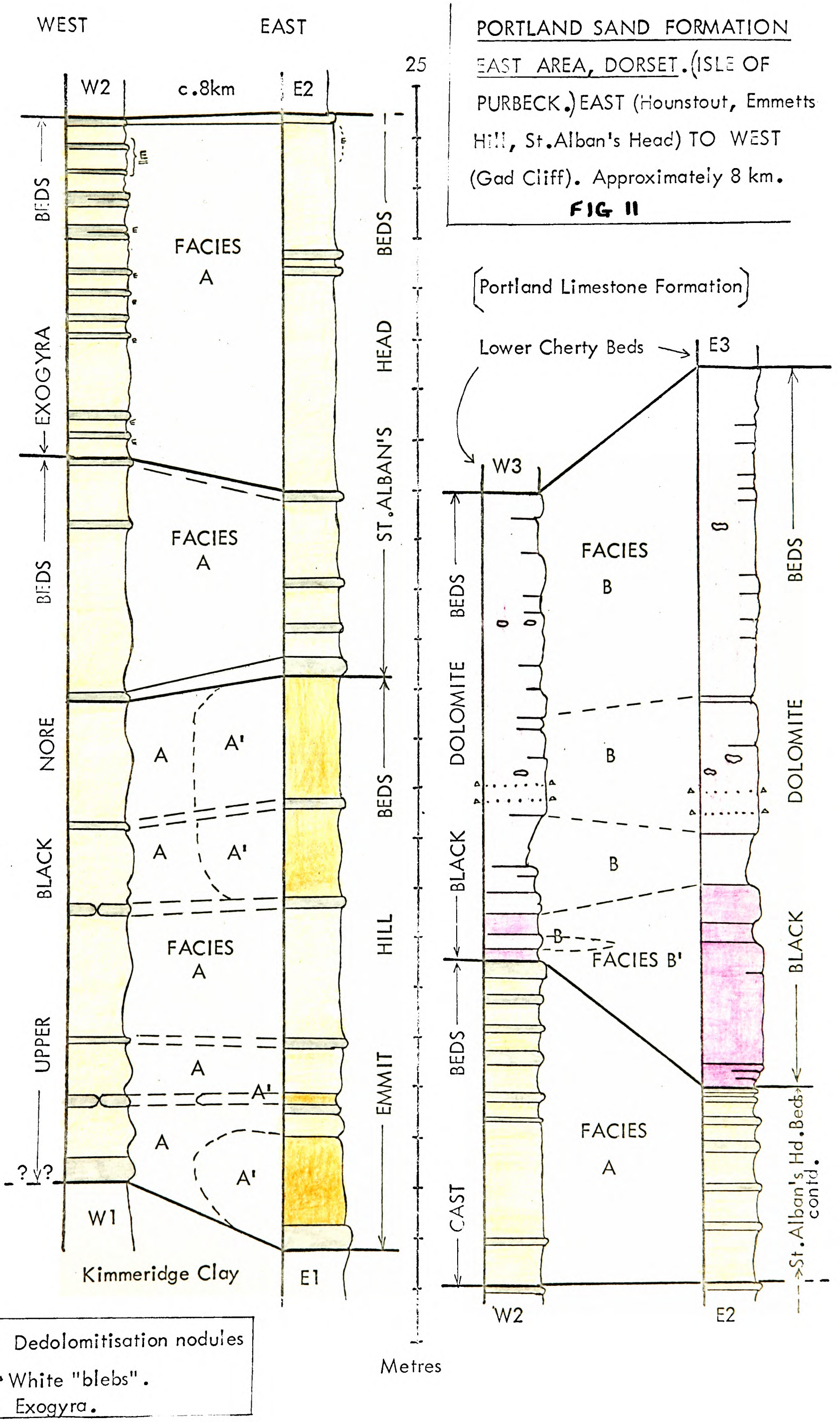
(i) Emmit Hill Beds

In the east there are 11.5m and in the west 9.5m of metre-bedded Facies A, with interspersed thin beds of quartzose limestone (A"). The base is traditionally defined as the "Massive Bed" which is 3.0m thick in the east and 1,5m in the west (Plate I). Facies A in the west is sometimes represented by impure quartz sandstone (A') in the east, due to a decrease in clay content in the east. In the case of the "Massive Bed" this change from A to A' is due to an increase in the proportion of quartz sand, but in the upper 4.5m of the Emmit Hill Beds it is a result of an increase in the carbonate content. The lowest two thin beds of quartzose limestone (A") in the west are presumed equivalent to impure quartz sandstone (A') in the east due to the presence of more sand and clay in that area.

There are five repeated Facies A or A'-A" sequences, best seen in the west, but in the east they are partially "swamped" by an increase of sand and clay. The basal thin bed of quartzose limestone in the west is the top of the uppermost sequence in the Kimmeridge Clay ("Hounstout Marl"), and the base of the quartzose limestone at the top of the Emmit Hill Marls is taken as the base of the St. Alban's Head Beds. (Note: the "Massive Bed" is recorded as containing Rhynchonellid brachiopods. Arkell 1933).

(ii) St. Alban's Head Beds

These are 15.5m thick in the east and 18.0m in the west. The upper limits are slightly different from those in the previous literature. The top of the beds in the east is taken as the base of the undercut immediately below the "Lower Parallel Band" (Arkell 1935). This is 0.5m lower than previously taken and coincides with the boundary between Facies A" and B' (Figs 11, 12). In the west, the junction is taken at the top of the highest bed of facies quartzose limestone (A", 0.3m thick) instead of its base. The St. Alban's Head Beds in both areas consist of sequences of Facies A-A" but in the east there is a slightly lower sand



PORTLAND SAND FORMATION

EAST AREA, DORSET. (ISLE OF PURBECK.) EAST (Hounstout, Emmetts Hill, St.Alban's Head) TO WEST (Gad Cliff). Approximately 8 km.

FIG 11

FIG 12

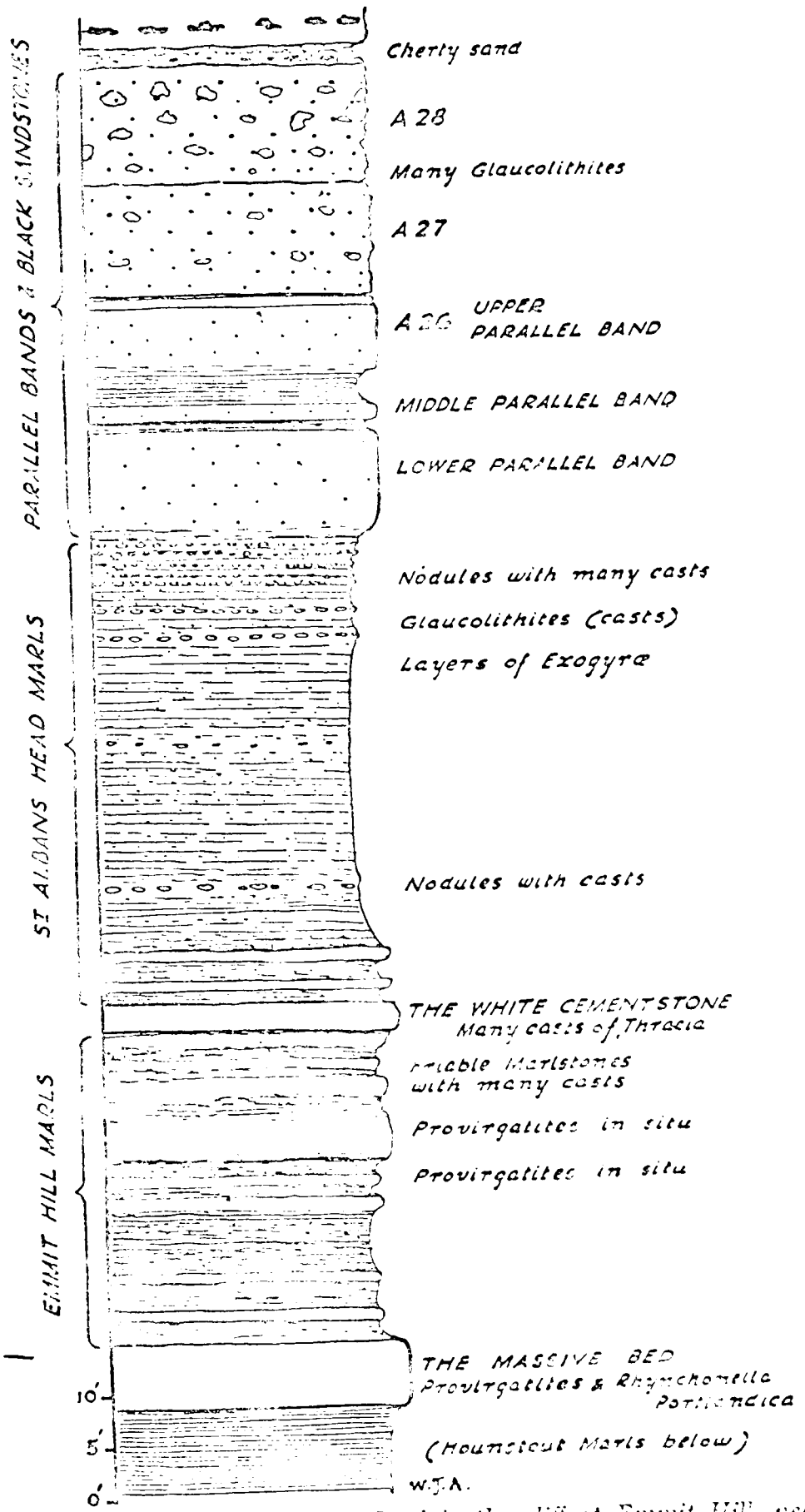


FIG. 21.—*Profile of the Portland Sand in the cliff at Emmit Hill, near St. Alban's Head.* Scale 1 inch = 20 ft. (Reproduced from *Proc. Geol. Assoc.*, vol. xlvi, 1935, p. 309.)

FIG 12

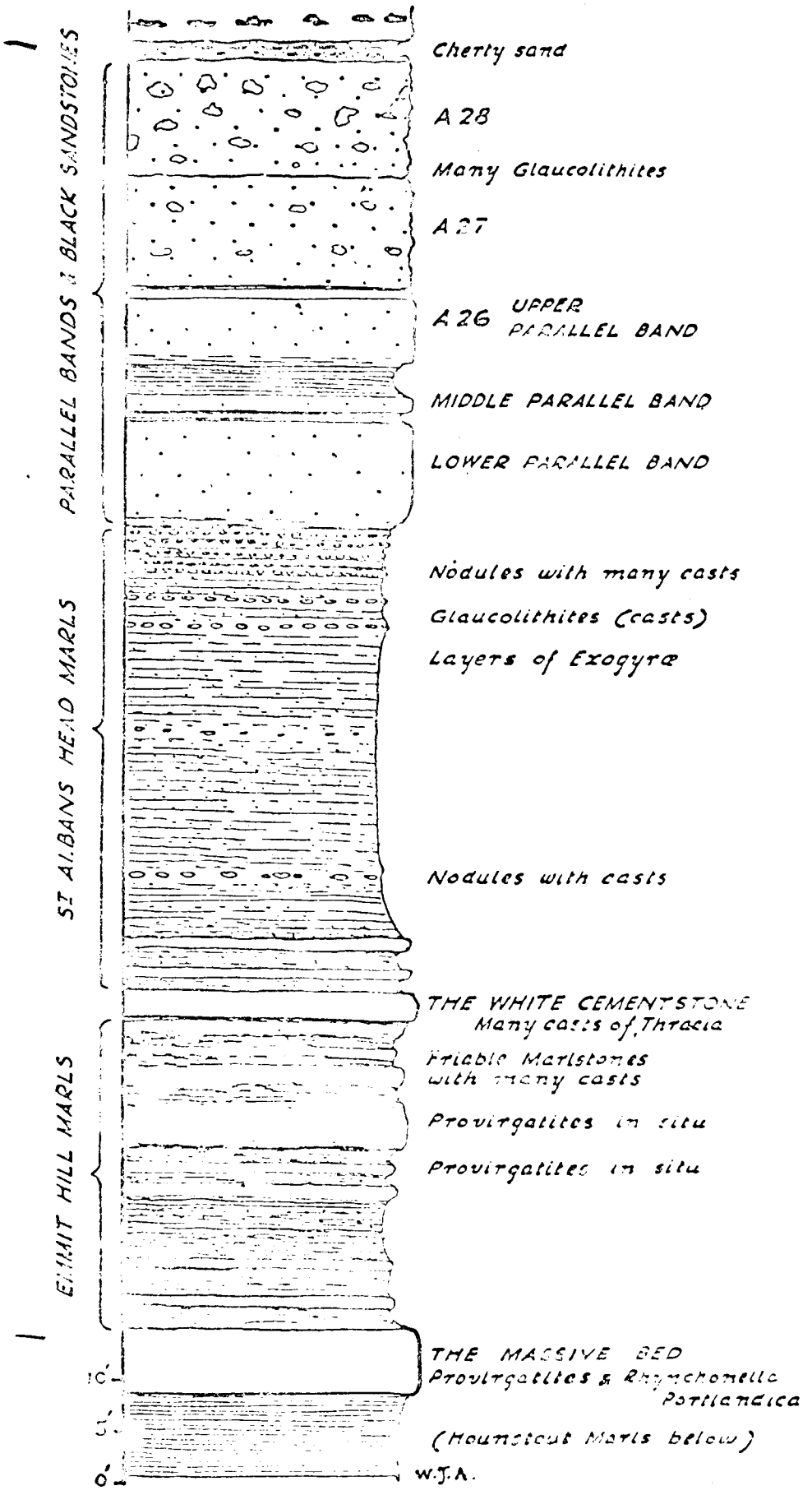


FIG. 21.—*Profile of the Portland Sand in the cliff at Emmit Hill, near St. Alban's Head.* Scale 1 inch = 20 ft. (Reproduced from *Proc. Geol. Assoc.*, vol. xlvi, 1935, p. 309.)

FIG 13

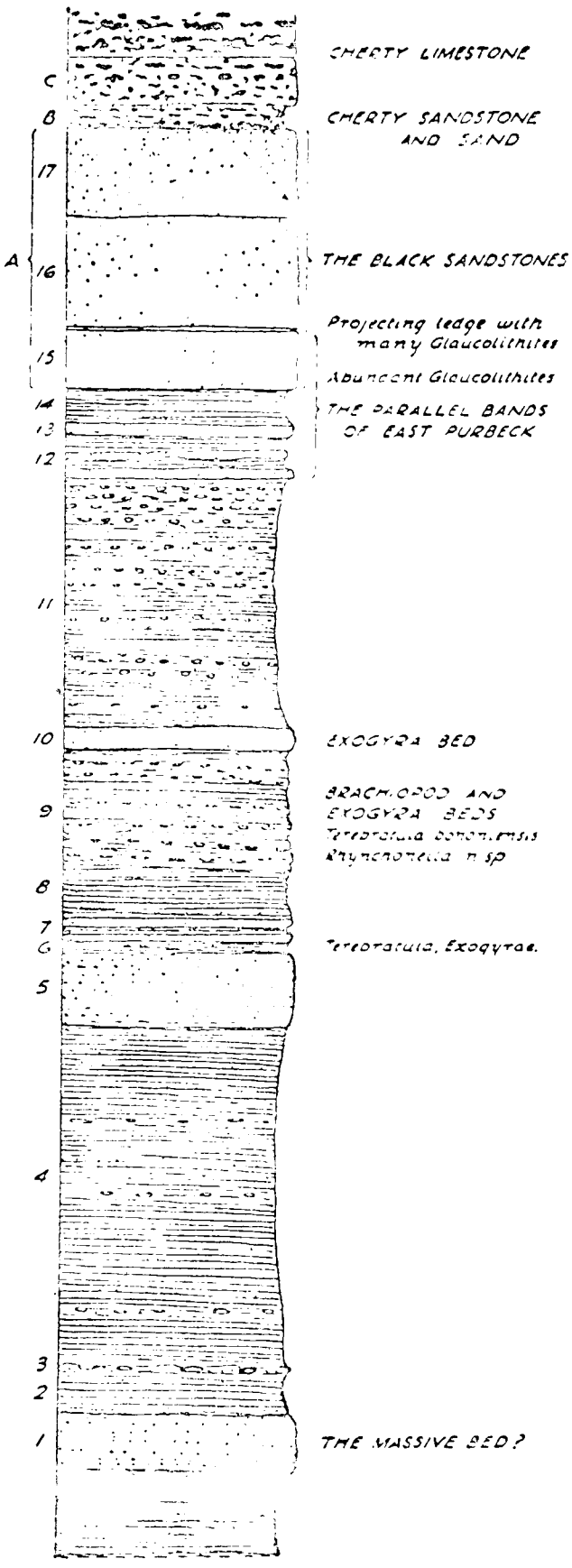


FIG. 22.—*Profile of the Portland Sand at Gad Cliff, showing the junction with the Cherty Series of the Portland Stone* (B, C) *and the position of the brachiopod and Exogyra beds.* Scale 1 inch = 20 feet. (Reproduced from *Proc. Geol. Assoc.*, vol. xlvi, 1935, p. 315.)

content and higher clay content. In the east there are about half the number of thin horizons of quartzose limestone and although some of these beds, both continuous and as lines of nodules, are not well exposed it is evident that the reduction in number from west to east is genuine.

In the west there are at least ten well-defined horizons with Exogyra (The Exogyra Beds) over a thickness of 6.8m half-way up the sequence. In the east, however, only thin, poorly exposed layers of Exogyra exist although at a similar level and over a thickness of approximately 7.5m. It is probable that the thin beds of quartzose limestone at the top and base of the Exogyra Beds correlate from west to east (Fig. 11). The details of the Exogyra Beds at Gad Cliff are described below.

The upper part of the St. Alban's Head Beds (equivalent to The Cast Beds) is Facies A in both areas but with a slightly higher clay and sand content in the west.

(iii) Black Dolomite Beds

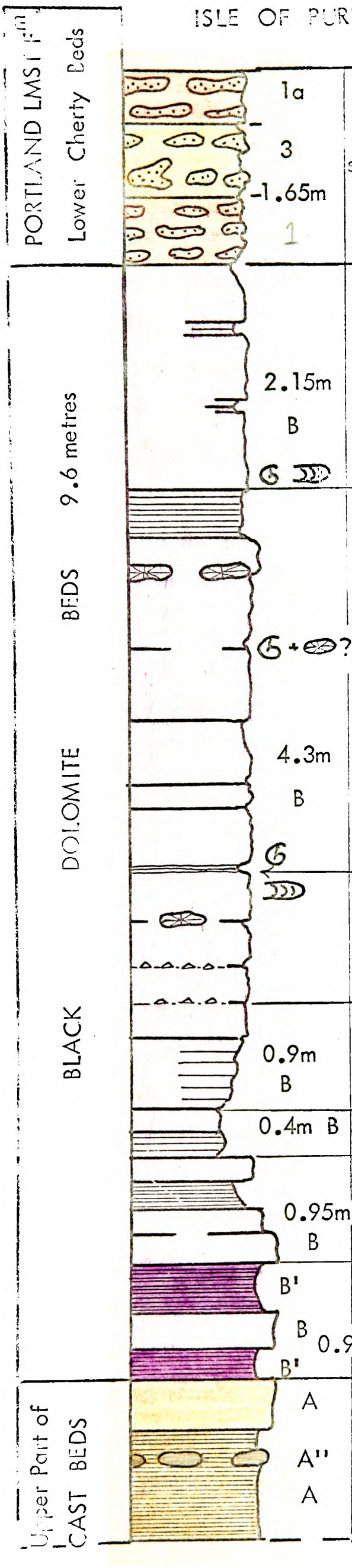
In the east there are 14.5m and in the west 9.6m of thick-bedded dolomite (Facies B) with a basal 4.1m of quartzose dolomite (B') in the east and 0.9m in the west which includes 0.3m of dolomite in the middle. (Plate 9 & Fig. 14). This basal difference is due to an increase in quartz in the east and clay content in the west. These are assumed to be stratigraphically equivalent on consideration of the similarity of the underlying succession. The rest of the sequence is remarkably similar in all of the Isle of Purbeck localities; the differences being a reduction in thickness from east to west, variation in the amount of dedolomitisation, and a slight increase in overall clay content, from <5% in the east to 5-10% in the west. Glaucolithites is common at various levels in the Black Dolomite Beds but these ammonites are not often encrusted with serpulids and oysters as is usually the case with those in the Portland Limestone Formation (Plates 17, 38).

(iv) The Exogyra Beds (West 6.8m; East 7.5m)

In the three sections in the east of the Isle of Purbeck (Hounstout, Emmetts Hill, St. Alban's Head) these Beds are not so

BLACK DOLOMITE BEDS, PORTLAND SAND FORMATION.

ISLE OF PURBECK WEST. GAD CLIFF. SY 8779. FIG 14



Lime mud with Rhaxella spicules, very fine biochem sand in a lime mud matrix.
Large nodules of light grey to black chert.
Basal part partly dolomitised. Quartz = 1-10%

Bioturbated fine grained dolomite. Less than 1% quartz, small amounts of glauconite and clay.

Ammonites and Rhizocorallium common at base.

Laminated fine grained dolomite. Less than 1% quartz.

Black nodules of poikilitic calcite due to dedolomitisation.

Bioturbated fine grained dolomite. Less than 1% quartz.
Ammonites. Calcite nodules?

Bedding plane with abundant ammonites and Rhizocorallium.

Dedolomitisation nodules of black calcite. Quartz <1%.

Horizon of white "blebs"

Bioturbated fine grained dolomite. 5-10% quartz.

Argillaceous dolomite. Very little quartz.

Laminated dolomite and clay. Less than 5% quartz.

Dolomite, clay and quartz. Facies B & B'

UPPER PART OF THE CAST BEDS

(Upper part of the St.Alban's Head Beds)

well exposed or as accessible as they are at the far west end of Gad Cliff. In the former area, Arkell described "24 feet" of "Dark grey bituminous shales and marls with two rows of nodules. Layers of Exogyra nana", in the St. Alban's Head Marls" (Bed 20 1935, p.310; 1947a p.103). These beds are easily recognisable in the three sections but only scattered, loose Exogyra were found during this study, in the summers of 1968 and 1969. Thus, the sediment (Facies A), as well as containing more clay and fewer horizons of Facies quartzose limestone (A") than in west Purbeck, is also less rich in Exogyra.

In Arkell's section for "Emmit Hill", reproduced here as Fig. 12 (Arkell 1935, fig. 42; 1947a, fig. 21), the "layers of Exogyrae" are shown to be in the upper part of the section, in a position which corresponds to the level at Gad Cliff where Exogyra is most abundant (Figs 11, 15). This position agrees with the correlation proposed in this present work. Arkell's section for Gad Cliff is also given here for comparison, as Fig. 13 (Arkell 1935, fig. 43; 1947a, fig. 22).

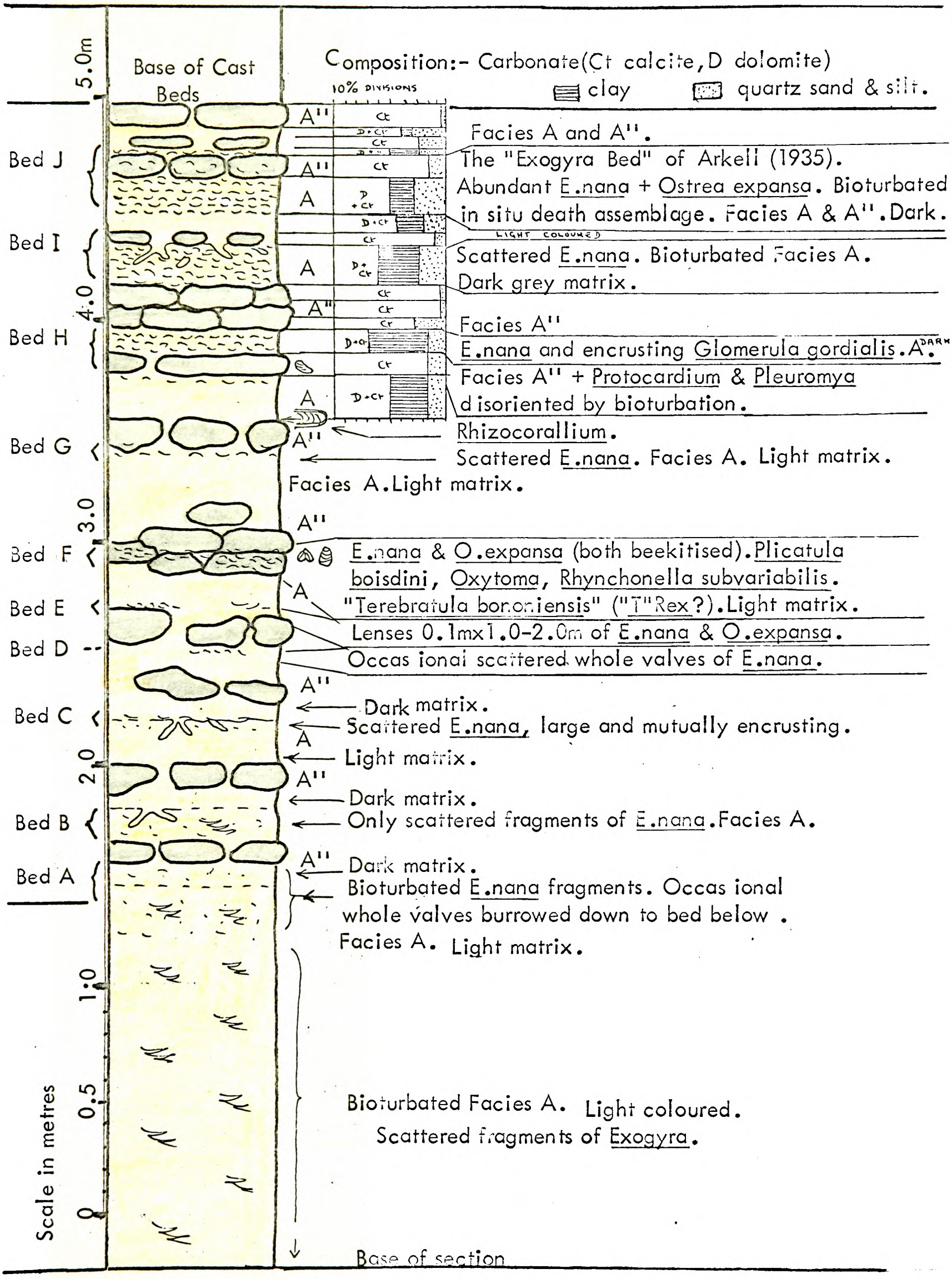
At Gad Cliff there is a very good exposure at the far western end (Fig. 5, SY 872795) which shows a maximum concentration of Exogyra in the top 1.25m of the Exogyra Beds (Plate 12, & Fig 15, Beds H, I, J) and a total of ten well-defined horizons in the upper 4.5m. Further east along Gad Cliff, other exposures show a further two or three Exogyra horizons below the base of the section at the western end, making a total of 12 or 13 in the overall 6.8m thickness of the Exogyra Beds.

This repetition of horizons of Exogyra is a more obvious form of the general repetition of facies A and A' with A" throughout the clastic sequence in the Portland Sand Formation (Fig 16). The distinctiveness of each repeated "cycle" is a function of the proportion of sand-grade material in the sediment. This implies that the cycles are the result of alternating deposition of clay and lime mud with fluctuating "background" content of sand.

Each Exogyra Bed cycle consists of three parts (Fig. 16):
(a) Lower part: 0.5 to zero metres of light grey bioturbated

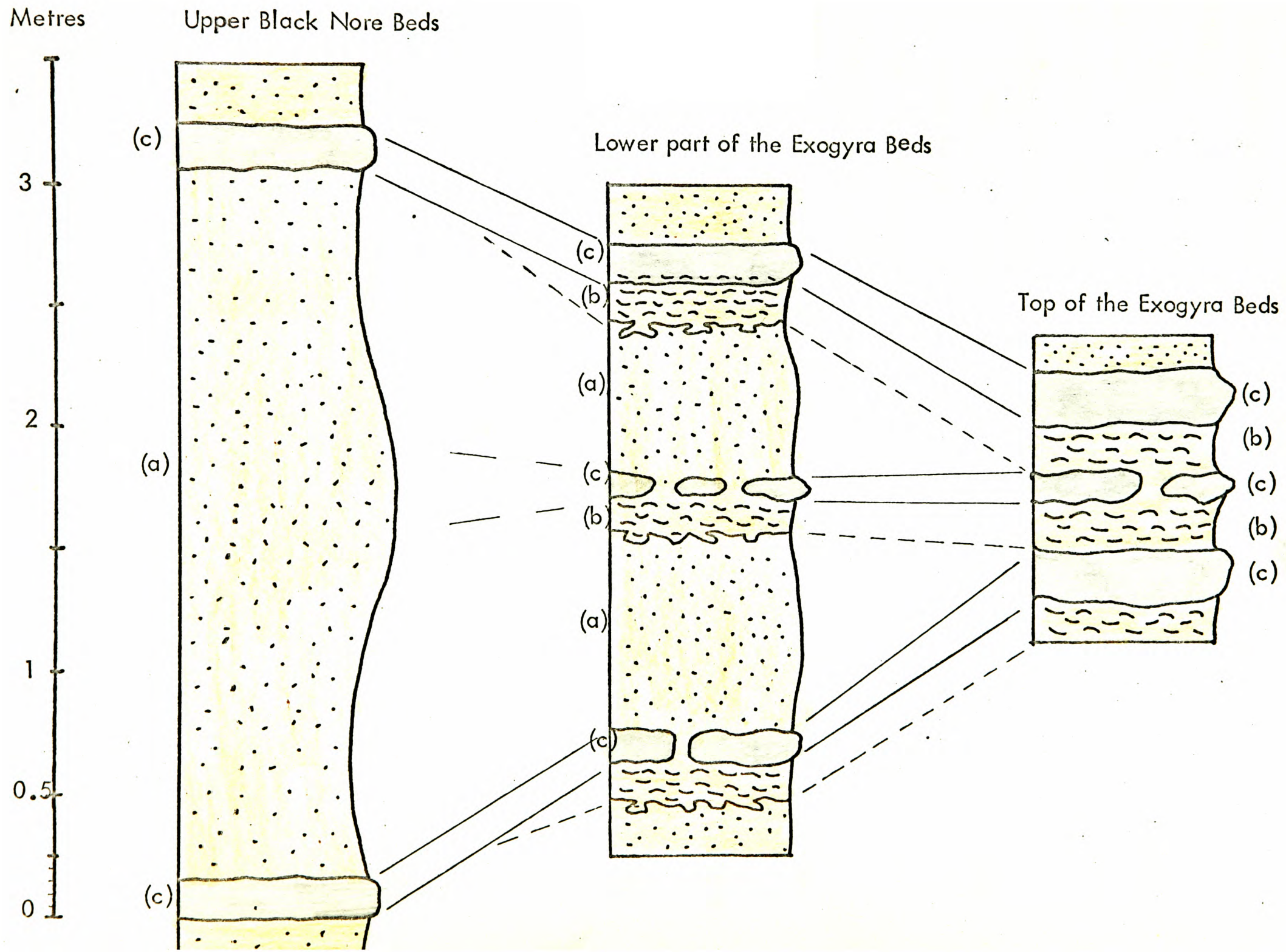
PORTLAND SAND FORMATION. EAST AREA, DORSET. ISLE OF PURBECK WEST.

EXOGYRA BEDS. GAD CLIFF. (Far west end). Fig 15



(Note:- Bed F. Oxytoma = O.octavia.)

PORTLAND SAND FORMATION. EAST AREA (ISLE OF PURBECK), DORSET. EXOGYRA BEDS AND UPPER BLACK NORE BEDS. VARIATIONS ON THE BASIC EXOGYRA BED "CYCLE". FIG 16



fine quartz sand with calcite, dolomite, clay and only fragments of Exogyra.

(b) Middle part: This is 0.24 to zero metres thick and sometimes lenticular. The sediment is the same as the Lower part, but light to dark grey and rich in Exogyra, with Ostrea, Oxytoma, Plicatula and rare Rhynchonella (ss) and "Terebratula". It has a burrowed basal contact. (Plates 15, 16).

(c) Upper part: 0.25-0.1 metres thick (continuous or as nodules). This consists of light grey to white layers of micritic limestone (originally lime mud) and contains Pleuromya, rare foraminifera and rare Rhaxella spicules.

Part (a) may be absent, but in the Upper Black Nore Beds Part (b) is not present and Part (c) may be "swamped" by a high sand content. The weathering profile of the cycles in the latter suggests that this is often true.

Exogyra Bed J (Fig. 15) was examined in detail on a clean bedding plane at the far western end of Gad Cliff and a size-frequency study made of the Exogyra shells on an area of one square metre. (See Appendix). The conclusions are that there was no evidence of current action and that the bed contains a bioturbated in situ life assemblage.

2. The Portland Sand Formation in the Central Area, Dorset

A. Introduction

The outcrop is confined to a strip of coast 3.6km long which extends westwards from Mupe Rocks (SY 840797) to Durdle Door (SY 805803) (Fig. 17), on the steep north limit of the Weymouth-Purbeck Anticline (Fig. 30). Six sections in the Portland Limestone Formation were measured but the underlying Portland Sand Formation is less well exposed. It appears below the steeply northward-dipping limestone of the sea-cliffs between the west side of Stair Hole (SY 821798) and Dungy Head (SY 816799), only 0.5km apart. (Fig. 17 , Plate 19).

The Upper Black Nore Beds are below sea-level at the east end and only poorly exposed to the west. Although it is likely that the Sandy Upper Kimmeridge Beds do occur at this locality, details of the succession were not available in summer 1969 or spring 1970. The Exogyra Beds occur in slipped blocks by the shore a little east of Dungy Head and is the only other locality, apart from the west end of Gad Cliff, where Rhynchonellid brachiopods were found by the author. Just west of Stair Hole, the Exogyra Beds form a steeply-dipping ledge about 5m offshore from the foot of the cliff, accessible at low tide. The Cast Beds are covered by vegetation and slipped material just east of Dungy Head, so details have been taken from Arkell (1935). At the east end, the Cast Beds are below sea level, between the more wave-resistant Exogyra Beds and the Black Dolomite Beds at the foot of the cliff. The latter are exposed at both ends of the outcrop and even over this short distance there are differences.

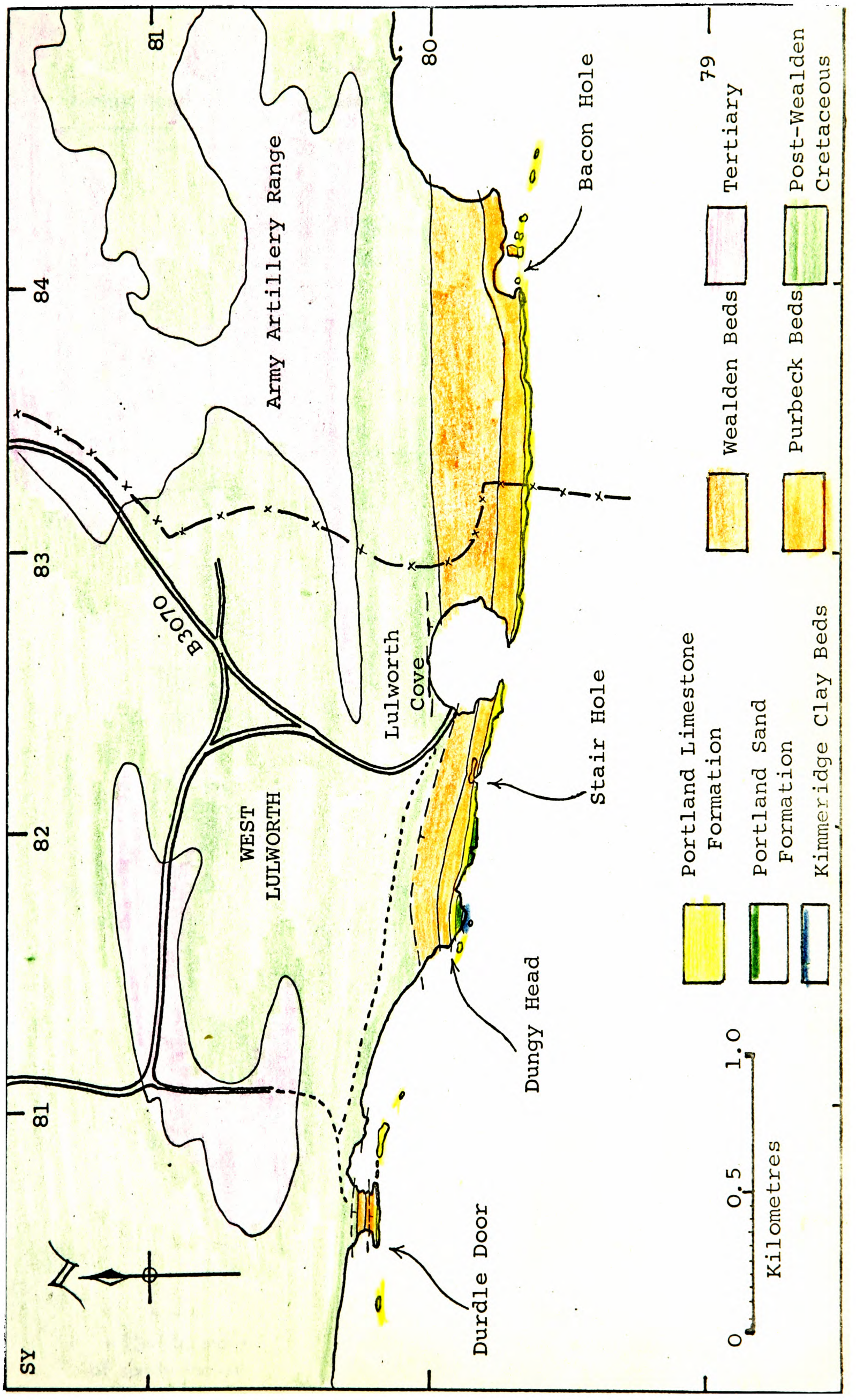
B. Description of the Beds

(i) Upper Black Nore Beds

It is not easy to locate the junction between the Upper Black Nore Beds and the overlying Exogyra Beds as the succession is not exposed at the appropriate level. At the locality just west of Stair Hole, about 5m of Exogyra Beds are exposed at low tide as a wave-resistant steeply-dipping ledge, but only 3.5m is exposed

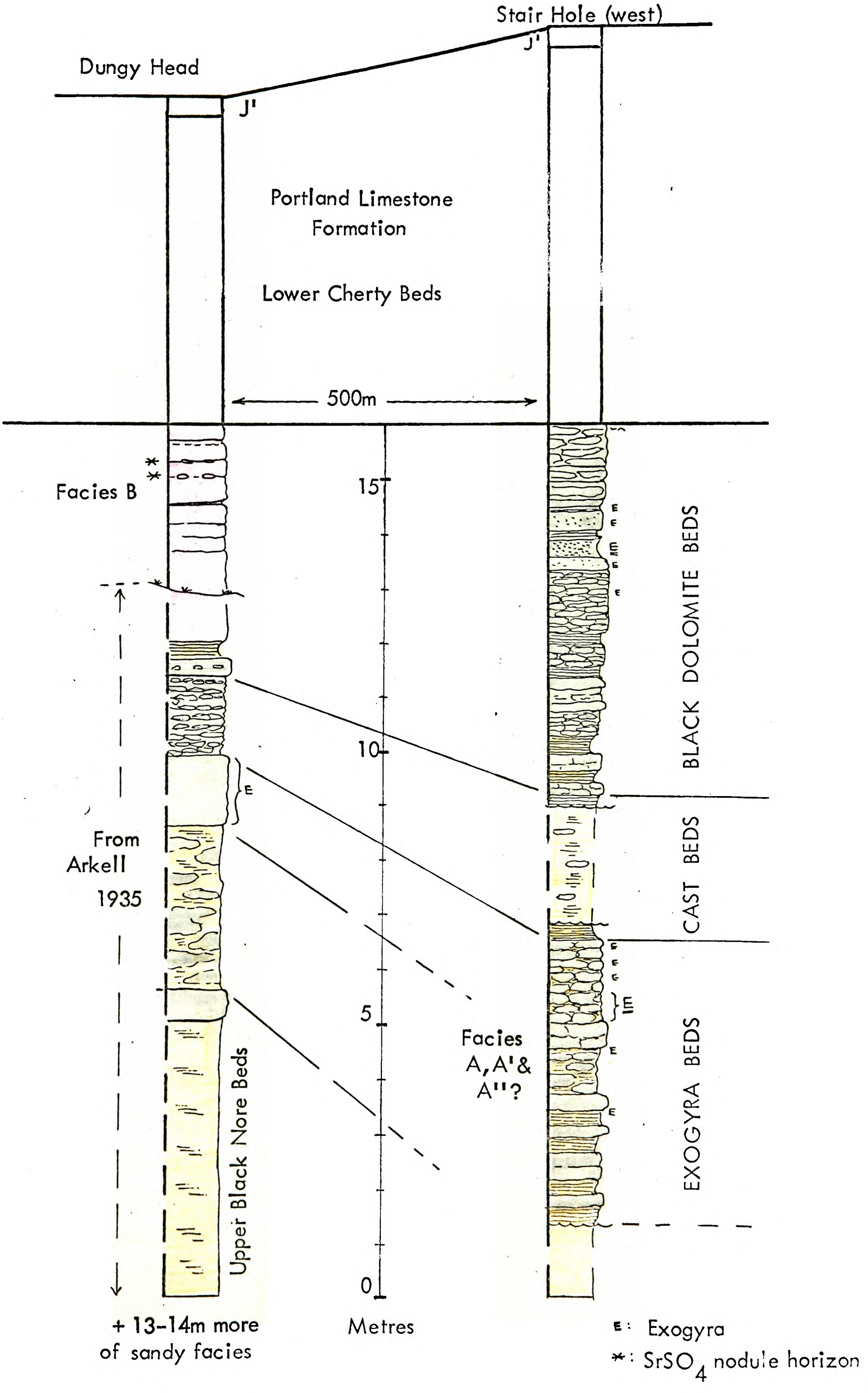
GEOLOGICAL AND LOCALITY MAP OF THE CENTRAL AREA OF DORSET.

FIG 17



PORTLAND SAND FORMATION. CENTRAL AREA, DORSET.

FIG 18



below the level of maximum concentration of Exogyra. At the locality just east of Dungy Head, the outcrop is overgrown and slipped which makes it unsuitable for measurement.

Such exposures that do exist show hard- and soft-weathering light grey fine sandy sediment like Facies A in the Isle of Purbeck. This outcrop is mentioned, but inadequately described by Fitton (1836), Woodward (1895) and Strahan (1898), so the only description that can be used is that by Arkell (1933, 1947), as given below (See Fig. 19. Arkell 1935, fig. 44; 1947a, fig. 23):

"Exogyra Bed: Cementstone, hard, grey, sandy, in large irregular, lumpy, semi-coherent masses among marl; crowded with Exogyra nana; also Serpula gordialis" (= Glomerula) "and Plicatula boisdini ... ... 4ft. 0ins." (1.2m)

"Black sandy marls with much nodular, irregular, grey, sandy cementstone like that above but lacking the profusion of oysters ... ... 10ft. 0ins" (3.0m)

"Grey-black sandstone ... ... 2ft. 0ins" (0.6m)

"Black sandy marls and sands with occasional more or less indurated bands and a few rows of cementstone nodules ... ... c. 50ft. 0ins" (c. 15m)

"Black sandstone ... ... 2ft. 0ins" (0.6m)

"Black sandy marls, seen to ... ... 6ft. 0ins" (1.8m)

Due to the poor exposure, neither Arkell nor the present author has attempted to define the base of the Portland Sand Formation in the Central Area. The typical dark laminated mudstone facies of the Kimmeridge Clay is not visible so it is not even possible to estimate the total thickness of the sandy development at the top of the Kimmeridge Clay and below the level of maximum concentration of Exogyra in the Exogyra Beds (i.e. Rhychonella Marls, Hounstout Clay, Hounstout Marls, Upper Black Nore Beds and most of the Exogyra Beds of the sections in the east of the Isle of Purbeck (Figs 7, 11) where the total is approximately 55m.)

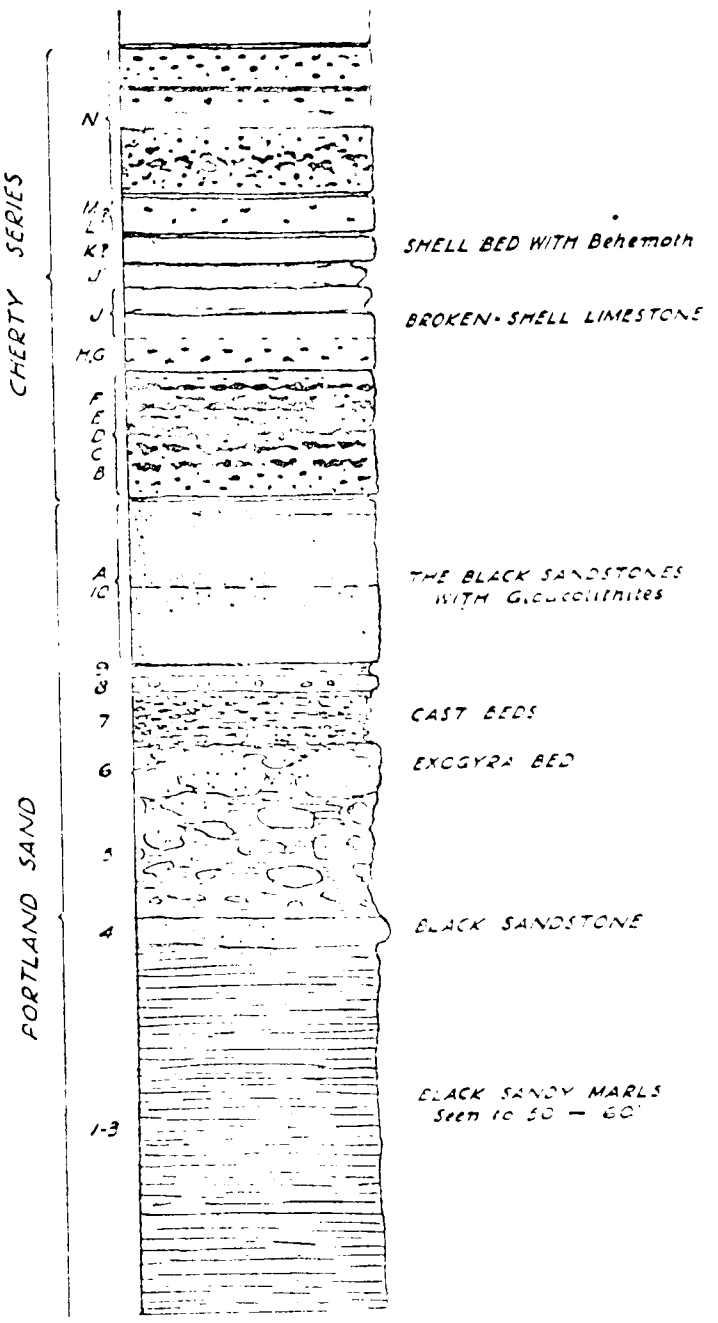


FIG. 19.—SECTION OF THE CHERTY SERIES AND THE UPPER PART OF THE PORTLAND SAND, DUNGY HEAD, LULWORTH. Vertical Scale 1"=20 ft.

(ii) The Exogyra Beds

As previously mentioned, these beds are only partially exposed at low tide just west of Stair Hole and as slipped blocks just east of Dungy Head. On comparison with the section at the west end of Gad Cliff(west Isle of Purbeck), the whole exposed section near Stair Hole should perhaps be included in the Exogyra Beds (Fig. 18).

The total thickness of the Cast Beds, Black Dolomite Beds and Lower Cherty Beds of the Portland Group decreases from approximately 32m in the east Isle of Purbeck, to 29m in the west, and to approximately 16m in the Central Area (Stair Hole) (Figs 11,18) If the measurements given by Arkell for the Black Dolomite and Cast Beds are up to his usual standard of accuracy, then the above total thickness of 16m decreases to approximately 12m in

the 0.5km between the two sections.

Thus, it is reasonable to suggest that the thicknesses given for the beds below the Cast Beds show a general decrease also. The level of maximum concentration of Exogyra is 2.0m at Stair Hole and 1.25m at Dungy Head (Fig. 18). The beds below this are exposed for at least 3m at Stair Hole and given as 3m by Arkell at Dungy Head. These lower beds contain more quartzose limestones (A") than at Gad Cliff and in the form of nodules rather than discrete limestone bands. At Stair Hole the abundant Exogyra are not obviously current-deposited fragments but it is not clear whether the bed was formed under the same conditions as postulated, after a size frequency study, at Gad Cliff. They seem to be more numerous and more concentrated in the former area and this may be a general result of the alternation and condensation of the beds due to a lower rate of basin subsidence in the Central Area, than to the east. Rhychonella subvariabilis was found a few metres below the level of maximum Exogyra concentration in a slipped exposure east of the main Dungy Head section.

(iii) Cast Beds

These are mostly underwater in the section just west of Stair Hole, ~~due to their be...~~ because they are soft and readily eroded. They comprise 2.6-2.7m of dark argillaceous sediment, probably Facies A as at Gad Cliff, and light coloured limestone nodules of quartzose limestone (A") can be seen and felt in the water. The details Arkell described for the 1.5m thickness at Dungy Head probably apply:-

"Cast Beds: Black shales with about 10 layers of highly fossiliferous soft cementstones nodules packed with lamellibranch casts. Glaucolithites common; also Modiola autissiodorensis, Pleuromya, Trigonia sp. and many others too badly preserved for identification. 4ft. 6ins."

(iv) Black Dolomite Beds

At the eastern locality these Beds are 6.85m thick and, according to Arkell, 4.65m thick at the western end. Only

approximately 3m were exposed at the latter in summer 1969 and Easter 1970. The two sections, although only 500m apart, are very different and the west one is described first.

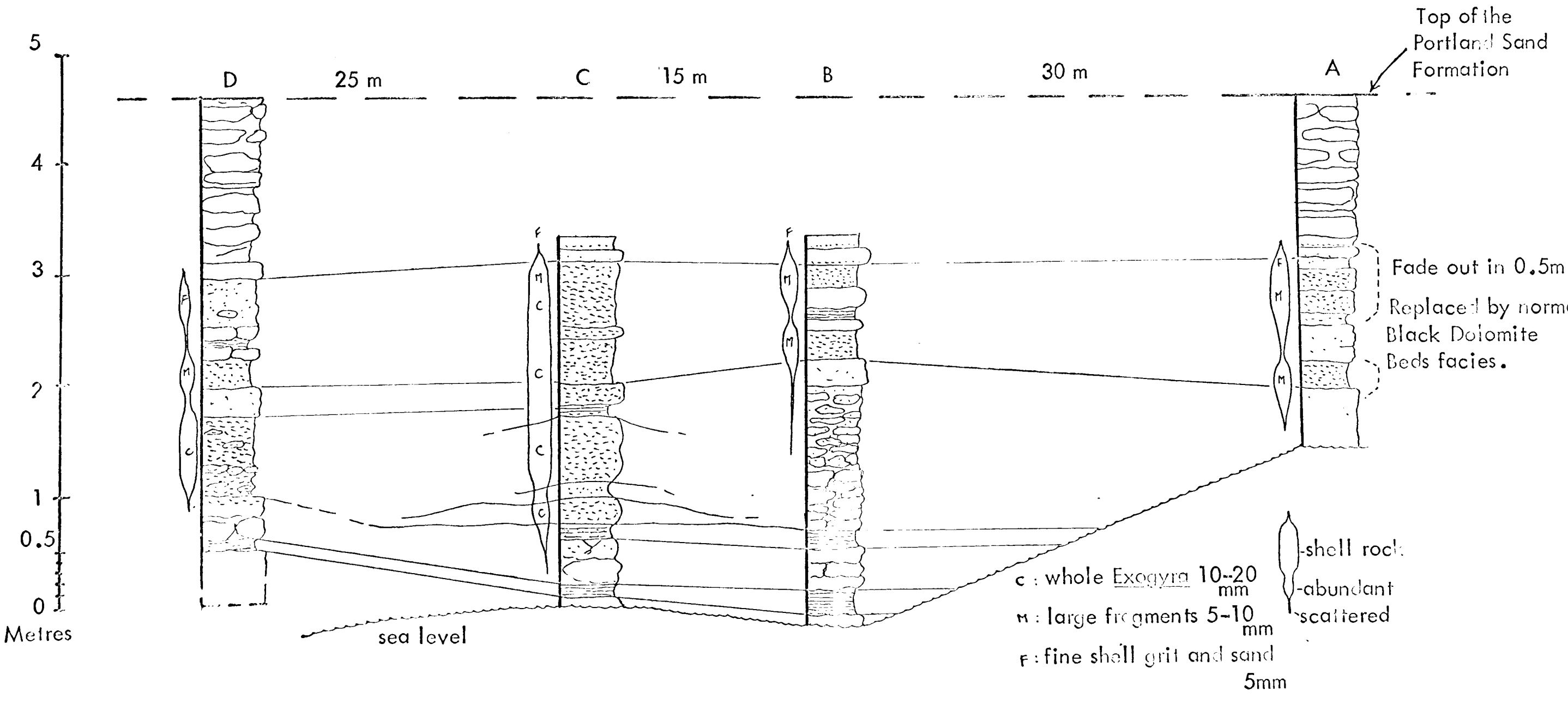
(a) Dungy Head: The Beds here are very similar to those at Gad Cliff, in spite of being over half the thickness. The rock is dolomite (Facies B), consisting of a mosaic of a mean crystal size of 20μ, with much less than 1% v.f. quartz sand and silt. There are a few high-angle veins of secondary ferroan-calcite. At a distance of 0.7 and 1.0m from the top are two horizons of dedolomitisation nodules of poikilitic calcite, as seen in the Isle of Purbeck Black Dolomite Beds. However, some of these nodules, or vugs, contain euhedral crystals up to 15mm long of a mineral identified optically and chemically as celestite ($SrSO_4$) (See Appendix). This is the first record of celestite from the Portland Group.

The beds are sometimes separated by thin argillaceous partings and some bioturbation is visible in the form of light and dark grey mottling. The lower 1.5m is no longer visible but Arkell's description does not suggest that the metre below differs from that now exposed above except he records that ammonites are common (Glaucolithites). The basal 0.6m he describes as "Clay, black sandy, with some light grey patches" underlain by "Black sandy cementstone with intensely hard nodules". (Figs 18,19).

(b) Stair Hole: The accessible exposed section is approximately 75m wide; the Beds are 6.85m thick. In the middle 2-2.5m there is a unique local development of abundant Exogyra nana, which extends from the west end of the exposure for about 75m eastwards (Plate 20). This then abruptly fades out over a distance of 0.5m and returns to the normal dolomite facies (Fig.20). The topmost 1.5m, above this Exogyra accumulation, consists of hard limestone with thick nodular patches, partly silicified and dolomitised. The lowermost 3m consists of hard and soft alternations of fine grained limestone (and dolomite?) and dolomitic silty mudstones, similar to the lowest 3m of the Black Dolomite Beds at Gad Cliff. These beds contain numerous ammonites, as they do at Gad Cliff and Dungy Head.

PORTLAND SAND FORMATION. CENTRAL AREA DORSET. FOOT OF SEA-CLIFF IMMEDIATELY WEST OF STAIR HOLE (SY 82157980). LOCAL DEVELOPMENT OF CURRENT DEPOSITED EXOGYRA LIMESTONES AT THE HORIZON OF THE BLACK DOLOMITE BEDS

FIG 20



Details are shown in Fig. 20. The coarsest grade material is whole valves of Exogyra nana which reach 20mm across and fragments over 10mm. This occurs in the lower part of section D and throughout most of section C. Medium grade material consists of fragments and smaller valves from 5-10mm and occurs in the middle of section D, top of C and throughout most of B and A (Fig. 20). Fine grade fragments, less than 5mm, occur in the upper part of D and the topmost part of the other three sections, as well as mixed with the other grain sizes in all the beds.

The fragments vary in size and concentration at different levels in these sections, but generally lie horizontally. The beds were current-deposited and laid down in a succession of depositional events rather than in one phase. This is a contrast to the Exogyra Beds lower down the succession at Gad Cliff, most of which are in situ deposits. Harder and softer beds occur which seem to be a reflection of the grain size and sediment type. The hard cemented limestones are finer-grained and lower in Exogyra content than the normal beds, whereas the soft beds have a silty clay matrix and few fragments. Where the fragments are few and the original sediment was a bioturbated mixture of lime mud a very nodular rock has developed. Thalassinoides was recognised in section B.

The thickest part of the beds (e.g. section C) consist of a shell-grit or conglomerate with little or no matrix. Some levels (e.g. the lower part of D) contain self-encrusting whole valves and these may be in situ accumulations but, on the whole, the beds were current-lain.

It is remarkable to note at section A that, not only do Exogyra limestones fade out to normal Black Dolomite facies over a distance of 0.5m, but also that this occurs at all levels in the section at the same point.

3. The Portland Sand Formation in the West (Mainland) Area. Dorset

A. Introduction

The West Area of Dorset is divided into the Mainland and Isle of Portland Areas (Fig. 2). The Mainland Area, which is considered first, contains two main outcrops and some isolated minor outcrops (Fig. 2). It is in this Area that the effects of the pre-Albian earth-movements and Upper Cretaceous overstep are best seen (Strahan 1898, Arkell 1947a). The Jurassic and Lower Cretaceous strata were folded into east-west striking symmetrical anticlines and synclines and are cut by high-angle strike and dip faults. The Upper Cretaceous was deposited unconformably and in the Tertiary period the whole area was again subjected to earth-movements which produced east-west trending monoclinal folds with steep north-facing limbs on the anticlines.

One of the two main outcrops of the Portland Group and Purbeck Beds runs as a continuous outcrop from Bincombe (SY 6884) westwards for 8km to Portesham (SY 6085) dipping north and striking east-west. This is the southern limb of the Upwey Syncline, the northern limb of which has been downthrown by the Ridgeway Fault. This has placed Purbeck Beds against Chalk and thus the Portland Group forms outcrops only on the southern limb, and on the western closure above Portesham.

The other main outcrop extends from Preston, eastwards for 5km to Moigns Down on the south side of the Sutton Poyntz pericline and on both sides of its eastward continuation, the Poxwell pericline. On the south limb of the corresponding Upton Syncline the northward dipping Portland and Purbeck strata are exposed continuously as far as the Upper Cretaceous overstep which covers them due south of Osmington village. They reappear as an unexposed inlier in the valley to Osmington Mills (SY 7382), and further east between Ringstead Dairy and South Down Farm (SY 7582). The easternmost exposure on the south limb of the Upton Syncline is an upfaulted outcrop above the east side of Ringstead Bay, below Cliff House and Holworth House (SY 7681).

GEOLOGICAL MAP OF THE WEST AREA OF DORSET (MAINLAND). FIG 21

SY 65 68 70 75 80 85

A354 A352 B3390 A353

Ridgeway Fault

Upwey Syncline

Portesham

Bincombe

Coombe Valley outlier

Sutton Poyntz Pericline

Poxwell

Moigns Down

Upton Syncline

Osmington

Preston

Osmington Mills

Ringstead Bay

White Nothe

Weymouth Bay

Chesil Beach

Chicksgrove

WEYMOUTH

Weymouth - Purbeck Anticline

Post-Wealden Cretaceous
Wealden Beds
Purbeck Beds
Portland Group
Kimmeridge Beds
Older Jurassic

1km

1:63360

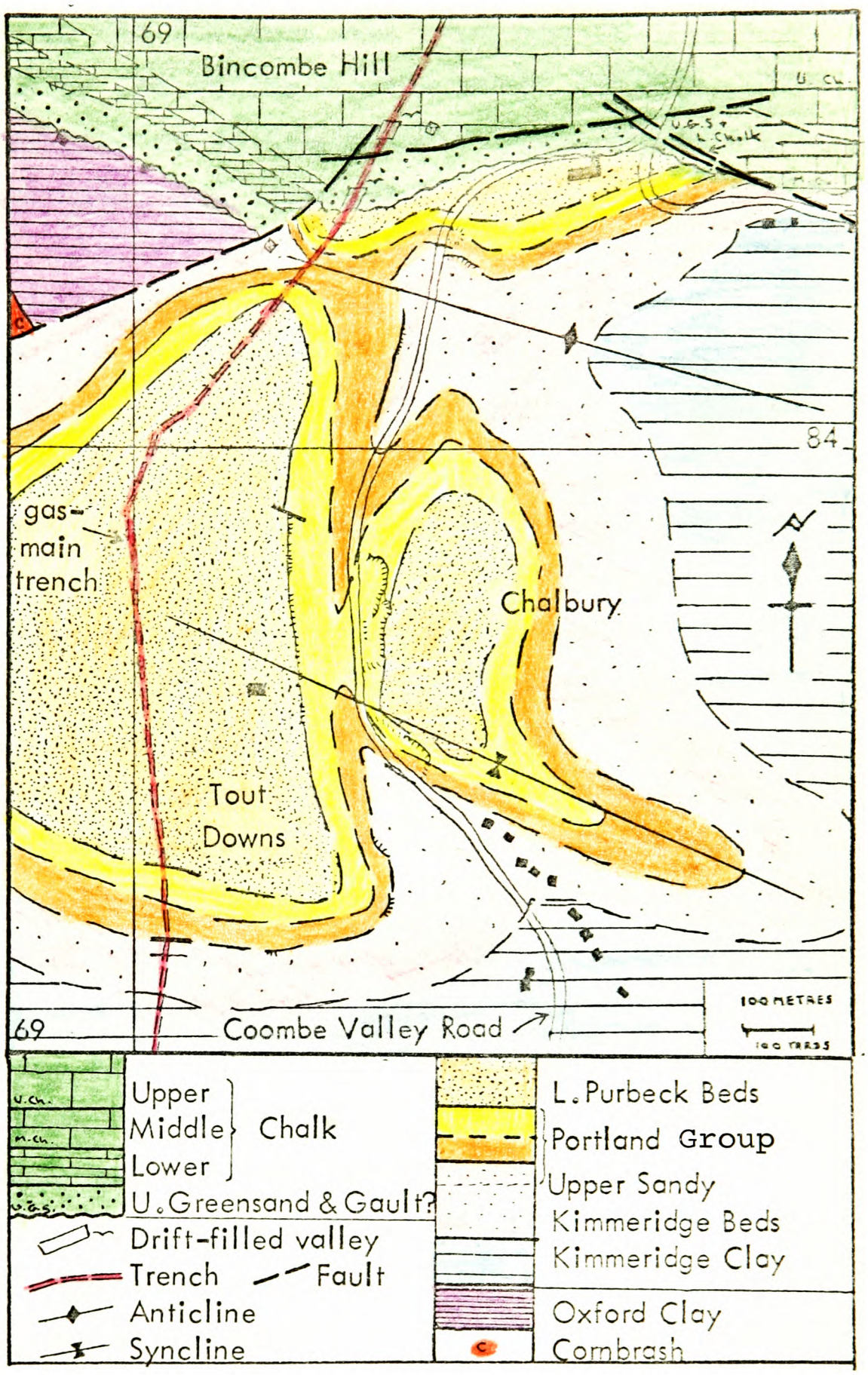


Fig: 22 Geological map of the area between Bincombe Hill and Coombe Valley.

Between the two main areas is an outlier separated from the Bincombe end of the westward outcrop by faulting which brings the Middle Jurassic to the surface, and from the Preston end of the eastward outcrop by the valley of the River Jordan. This is the Coombe Valley outlier of Portland and Purbeck strata forming Tout Downs and Green Hill, and upon which was constructed Chalbury hill fort (SY 6983) (Fig. 22). The Portland Group on the northern limb of the Sutton Poyntz pericline is lost from West Hill (SY 7084) to White Horse Hill (SY 7284) ~~due to~~ because the Upper Greensand rests directly on Oxford Clay and ~~being~~ is faulted against Kimmeridge Clay. There is, however, below East Hill (SY 7184), an upfaulted triangular outcrop of Upper Greensand and unexposed Portland Group.

The western limit of the West Area of Dorset is the most westerly outcrop of the Portland Group in England (and north Europe). This exposure is about 1km east of the village of Portesham, near where the Jurassic strata are faulted against Cretaceous. This is approximately 16km west north-west of the most easterly outcrop in the West Area, at Ringstead Bay. Although this distance is about the same as the extent of the East Area (Isle of Purbeck) there are no sea-cliff exposures. Only two sections show all the Beds of the Portland Sand Formation: the road-cutting to Corton Farm (SY 636855) and the landslip below Holworth House, Ringstead Bay (SY 764815). A temporary gas-main trench dug in October 1969 also exposed the succession at Tout Downs (Samuel 1969, Townson 1972) (SY 6983) and there are a few scattered small exposures of parts of individual Beds along the outcrop.

The <u>Upper Black Nore Beds</u> are partially exposed below Holworth House and in the cutting near Corton Farm but the base cannot be defined. The succession of sandy and silty clay below the Exogyra Beds right down to argillaceous Kimmeridge Clay was exposed in the trench near Chalbury and can be seen in a stream section near Coryates (SY 629856). This must be partly equivalent to the Hounstout Marl, Houstout Clay and Rhynchonella Marls of the Sandy Upper Kimmeridge Beds in the Isle of Purbeck. No obvious horizon

has been recognised which can be used to denote the base of the Upper Black Nore Beds and no correlation has been made biostratigraphically.

The Exogyra Beds are readily recognisable below Holworth House and are exposed, in a different facies, as several "scars" westwards from the Chalbury area to the westernmost outcrop overlooking Portesham. The best exposure is near Corton Farm.

The Cast Beds are never well exposed and were seen only in the trench near Chalbury and, when excavated, in an overgrown part of the Corton Farm cutting and by the track over Friar Waddon Hill (SY 694854).

The Black Dolomite Beds are traceable over the whole Area as far west as Portesham and the facies remains the same as it is in the eastern part of the Isle of Purbeck. Below Holworth House and on the south side of Osmington Hill (SY 716823/4) the original limestone is only partly dolomitised. At these localities the Black Dolomite Beds and Cast Beds cannot be recognised as separate units.

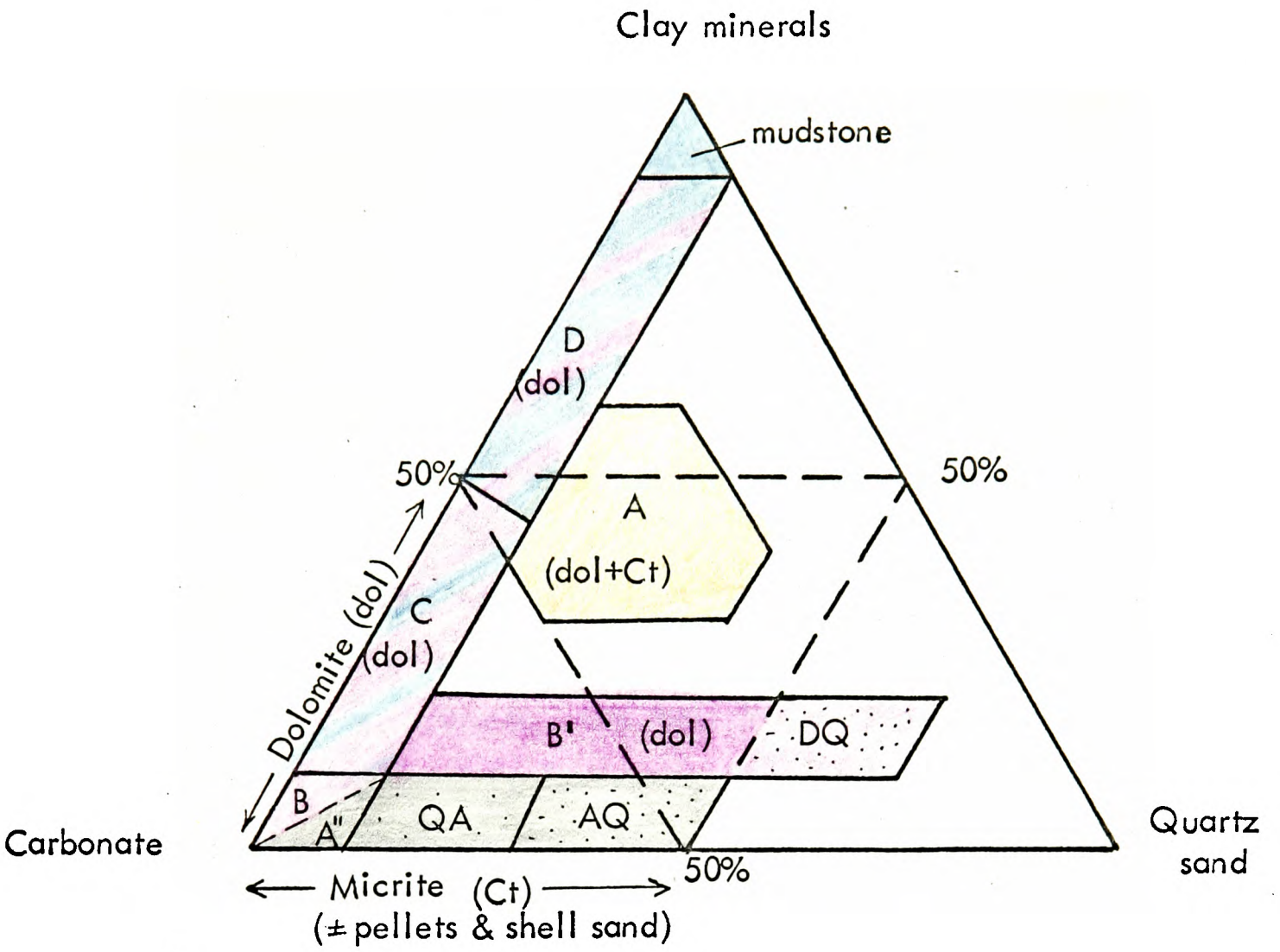
B. Lithofacies of the Portland Sand Formation in the West Area (Mainland and Isle of Portland) (Fig. 23)

The facies have been defined after a study of 115 thin sections and the same basic ternary classification as that for the East and Central Areas is used (Fig. 8). The sediments are mixtures of clay and carbonate (calcite or dolomite) with varying proportions of very fine quartz sand. Significant accessory constituents include glauconite and spicules of the sponge Rhaxella, both especially in the far western outcrops. Facies B and B', A and A" are the same as in the East and Central Areas but other facies exist with a higher or lower quartz sand content.

The Quartzose limestone (Facies A") composed of microsparite (originally lime mud or pelletal lime mud) can contain >10% very fine quartz sand. It is referred to in the Figs. of sections as Facies QA (Fig. 23). This changes to Facies AQ when the quartz sand is between 30% and 50%, usually with a higher proportion of lime mud pellets and fine shell sand.

MINERAL COMPOSITION OF FACIES OF THE PORTLAND SAND FORMATION IN THE WEST AREA, DORSET (ISLE OF PORTLAND AND MAINLAND)

FIG 23



If Rhaxella spicules = 1-5%, add rh
= > 5%, add Rh

If glauconite sand = 1-5%, add gl
= > 5%, add Gl

Note: Facies A'' = Facies 1 of the Portland Limestone Formation

Facies A''Rh = Facies 1a " " " "

The dolomite can have a quartz-sand content from 10-50% and becomes a quartzose dolomite (B'). If the quartz reaches 50-70% the sediment becomes a dolomitic quartz sand (Facies DQ) (Fig. 23). This is the only sediment in the Portland Group of Dorset with more than 50% sand, i.e. the only true sand. The sandy dolomites (B' and DQ) differ from the sandy limestones (QA and AQ) not only in containing dolomite instead of calcite, but also in having a higher proportion of clay (10-20% instead of 0-10%).

Facies A is a mixture of clay, quartz sand, dolomite and calcite and has been fully described in the section on the East Area. When the quartz content decreases, the calcite content also decreases and the dolomite increases in proportion. Depending on the amount of clay, the Facies becomes C or D (Fig. 23). Facies C (clay 10-50%) is an argillaceous dolomite and Facies D is a dolomitic clay or mudstone. As has been noted before, there seems to be a relationship between clay content and dolomitisation.

The accessory components glauconite and Rhaxella spicules are added to the Facies designation in the Figs of vertical sections as shown in Fig. 23.

C. Description of the Beds

(i) Upper Black Nore Beds and Sandy Upper Kimmeridge Beds

The thickness from the top of the Exogyra Beds to the junction between the Sandy Upper Kimmeridge Beds and the laminated mudstones of the Kimmeridge Clay Beds increases from 18m, below Holworth House in the east, to approximately 30-35m at Tout Downs, and then decreases to approximately 27-30m in the far west. (In the Central Area this thickness is >21m and in the Isle of Purbeck it is 55m.)

(a) Ringstead Bay outcrops: Holworth House (SY 764815): The beds dip at 30° to the north, on the south flank of the Upton Synclin and are overstepped by the Upper Cretaceous Upper Greensand and Gault (Fig. 21) which lie progressively on Purbeck Beds, Portland Group and Kimmeridge Clay Beds, southwards to White Nothe. It is not easy to delineate between the Exogyra Beds and the Upper Black

Nore Beds but the boundary between Facies B' and A is taken (Fig.24). Exposed below this are 6.5m of soft grey-brown argillaceous dolomitic sediment with <10% very fine quartz sand in the lower 3.5m and 10-30% above. Occasional thin clay horizons (10-20mm thick) are the only indications of bedding which has otherwise been destroyed by bioturbation. The original depositional structures were probably fine laminations of clay and quartz sand as described for Facies A in the East and Central Areas. The proportion of Glauconite is small and is approximately 10% of the quartz content. The sediment is poorly cemented and, because fossil preservation potential is low, only occasional unidentifiable fragments occur. The beds weather to a light and dark colour and this is the only reflection of cyclic deposition. Arkell (1935) records a further 6m seen below the present base of the section and a further estimated 3m to the "approximate base of the sands" (1947a, p.82).

South Down Farm (SY 757822), 0.9km to the north-west of the above: The south flank of the Upton Syncline reappears below the Cretaceous and there is a cutting and overgrown excavation in the Portland Sand Formation and lower part of the Portland Limestone Formation. The beds dip at 50° to the north and about 8m of the quartzose dolomite (B'), Facies A and argillaceous dolomite is exposed. There is, poorly exposed, a further estimated 5-6m below this. The upper 2-3m of the section is the harder quartzose dolomite (B') and is assigned to the lower part of the Exogyra Beds. The lowest part of the section includes Sandy Upper Kimmeridge Beds.

Ringstead Dairy (SY 753820): There is an overgrown quarry in the Lower Purbeck Beds and Portland Group at the west end of this outcrop. The beds dip at 45° to the north and a very weathered section shows about 4m of soft brown Facies A-C.

(b) Osmington district: The Portland Group and Purbeck Beds reappear from below the Upper Cretaceous overstep south of Osmington. An overgrown section (SY 716823) exposes approximately 12m of the Portland Sand Formation, of which the lowest 3m (argillaceous dolomite, Facies C) is considered to be the top of the Upper Black Nore Beds.

FIG 25

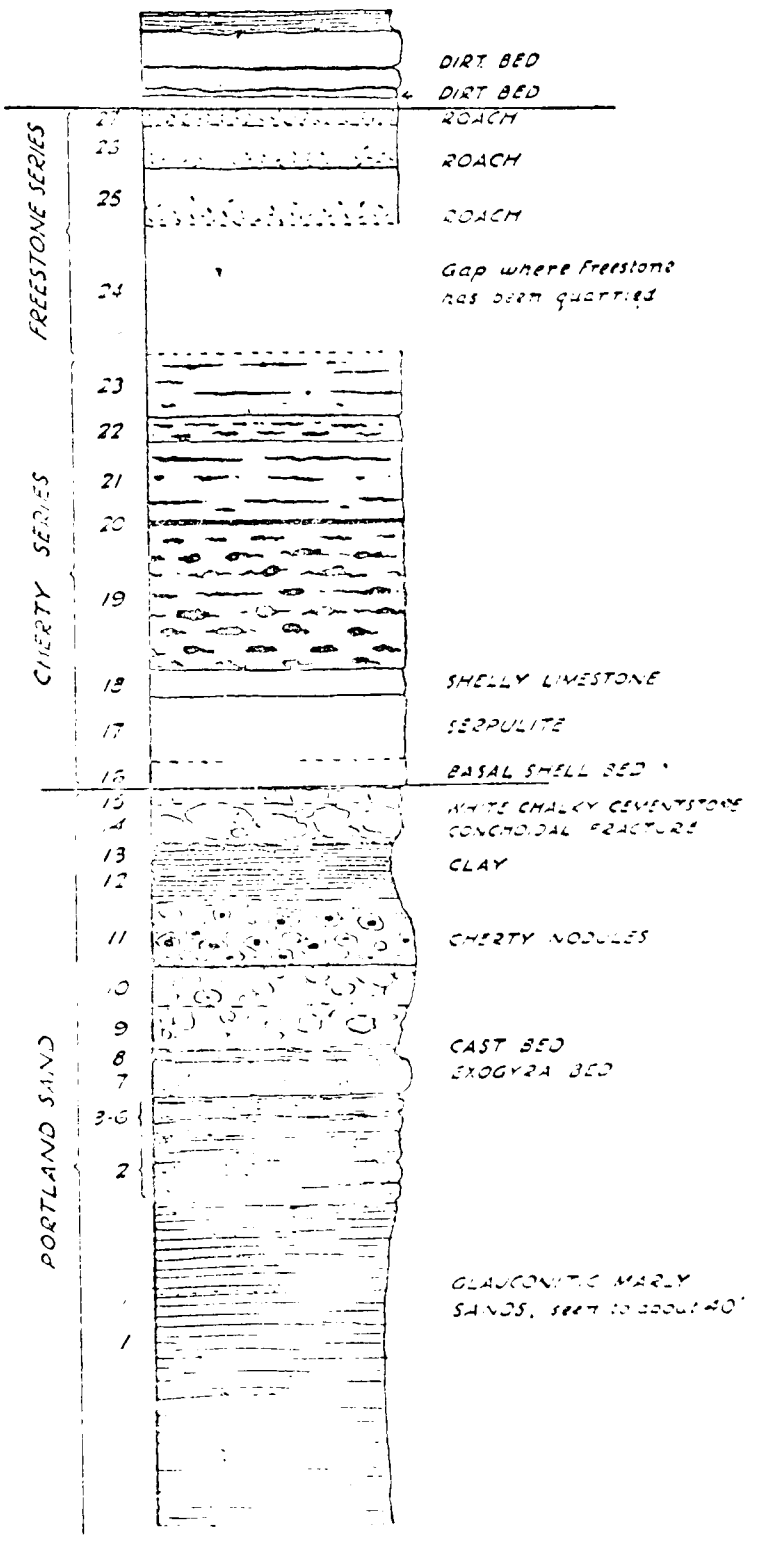


FIG. 45.—SECTION OF THE PORTLAND BEDS WEST OF HOLWORTH HOUSE, RINGSTEAD BAY. Vertical Scale 1"=20 ft.

PORTLAND SAND FORMATION. WEST AREA, DORSET. MAINLAND.

FIG 24

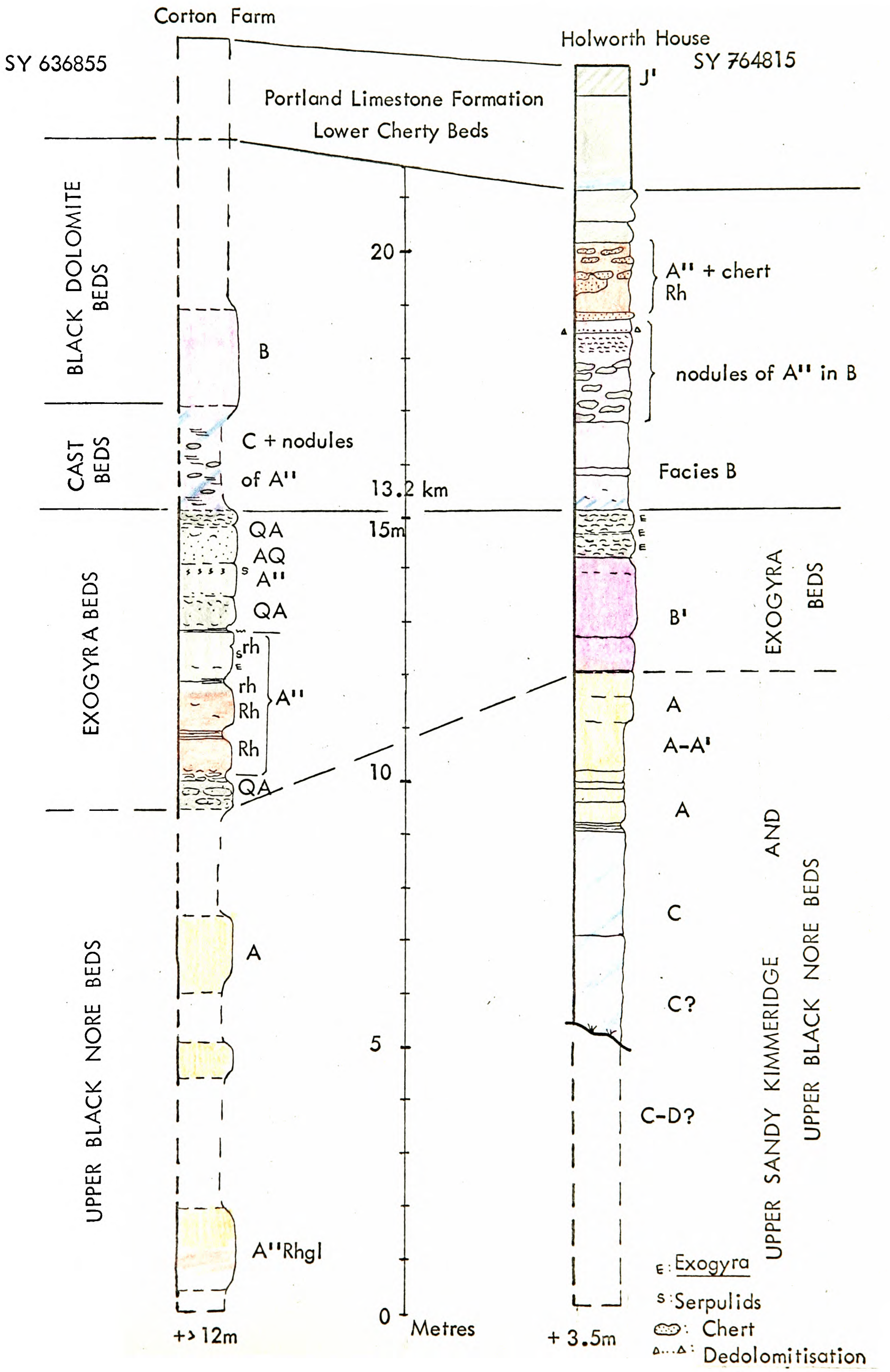


FIG 25

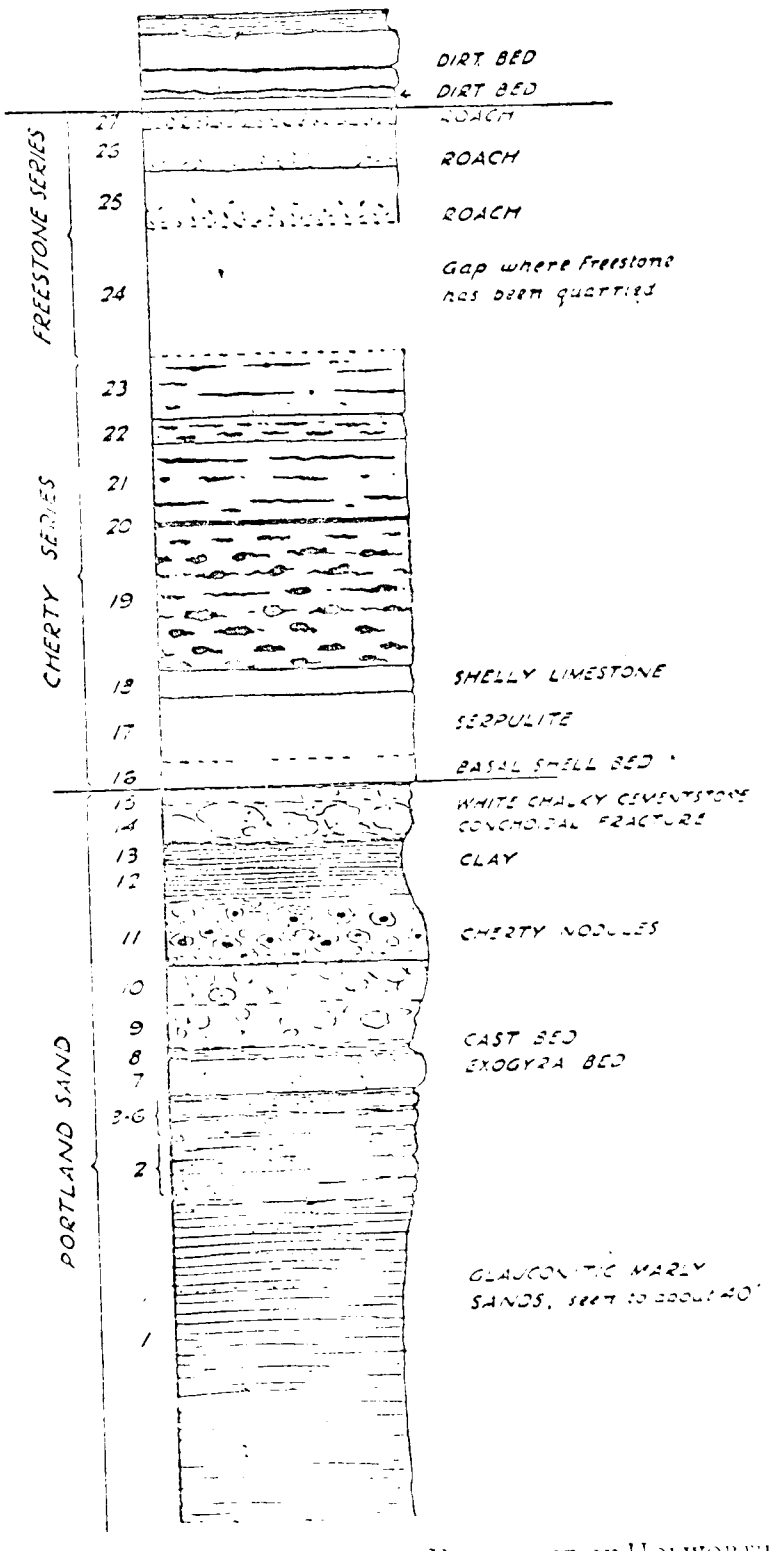


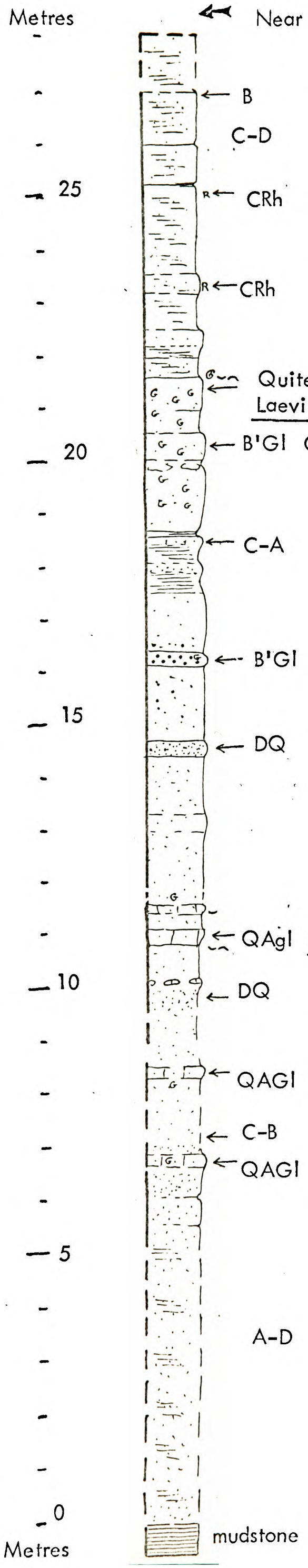
FIG. 45.—SECTION OF THE PORTLAND BEDS WEST OF HOLWORTH HOUSE, RINGSTEAD BAY. Vertical Scale 1"=20 ft.

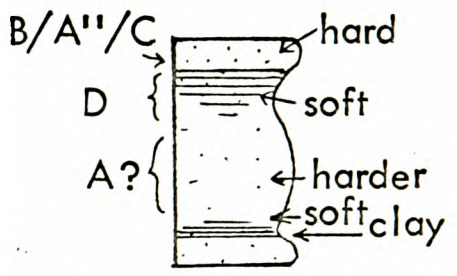
(c) Coombe Valley Outlier: The Upper Black Nore Beds and Sandy Upper Kimmeridge Beds were exposed in October 1969 when a gas main trench was dug over Tout Downs to Littlemoor Road (SY 690832-4). The beds are cambered and slipped on the steep hillslope but an estimated 30-35m of soft wet light brown sediment exists between the Exogyra Beds and the Kimmeridge Clay Beds. Above the Kimmeridge Clay mudstones the sediment becomes sandy and then, in the upper part, becomes a mixture of clay, dolomite and v.f. quartz sand. This is in general the situation in the section at Coryates (see below).

(d) Corton Hill district: The cutting to Corton Farm (SY 636855), between Corton Hill and Friar Waddon Hill, discontinuously exposes approximately 21m of typical sediment of the Upper Black Nore Beds and Sandy Upper Kimmeridge Beds. An exposure near the base was of Facies AQG1. The upper 8m is known to include Facies A and glauconitic Rhaxella-rich quartzose limestone (A" Rhg1). The rest is probably similar but is much better exposed near Coryates. The beds consist of hard and softer alternations which, as is seen in better exposed sections, reflect original compositional variation and thus are probably similar to the sections in the Isle of Purbeck.

Coryates (SY 629856): Part of the Upper Black Nore Beds and all of the Sandy Upper Kimmeridge Beds is seen between Corton Hill and Little Waddon in the banks of a stream (0.5km north of Coryates) and in a low cutting by the track to Shilvinghampton Basin. The change from grey-brown dolomitic sandy clay of the Sandy Upper Kimmeridge Beds to the blue-grey mudstones of the Kimmeridge Clay Beds is seen in the stream bed and above is an almost continuous section approximately 27m thick. (Fig.26). Arkell (1935) recorded that the "sands" must be at least 18-21m thick. The top of the section is probably just below the base of the Exogyra Bed and must therefore overlap with the corresponding beds at Corton (Fig. 24).

Above the change from the familiar dark grey mudstones of the Kimmeridge Clay Beds there is approximately 6-7m of soft wet grey Facies A-D, visible in the stream bed (Fig.26). This basal





CYCLIC SEQUENCE???

WEST AREA DORSET (MAINLAND). SECTION IN UPPER BLACK NORE BEDS AND SANDY UPPER KIMMERIDGE BEDS. STREAM NEAR CORYATES. (SY 629856).

FIG 26

argillaceous and dolomitic facies is overlain by approximately 12m of sediment with a fine to medium quartz sand content varying from 10-70%. These beds contain thin harder horizons of quartzose limestone (QA) which are similar to those (A") in the Upper Black Nore Beds of the Isle of Purbeck, except for a higher proportion of quartz sand. The thicker beds between are dolomite and argillaceous with a fluctuating quartz content > or < 10%. Glauconite content varies from 1-10%. Above these 12m, there is approximately 3m of very glauconitic sandy dolomite. The quartz is v.f. sand grade but the glauconite, which reaches 10%, is m-c sand. There is a fossiliferous level at the top with Laevitrigonia, Exogyra, Camptonectes, Isognomon and ammonites. If the top of the Sandy Upper Kimmeridge Beds were to be defined in this section then the top of this glauconitic sandy dolomite (Facies B'Gl) would be a recognisable horizon, making the "sands" below about 20m thick and the Upper Black Nore Beds above perhaps 10m thick.

The topmost 6.7m exposed consist of soft wet brown-weathering sediment, mostly dolomitic clay (Facies C). Vague bedding is discernible and, as at Holworth House, thin horizontal clay seams occur. Calcite casts of Rhaxella sponge spicules comprise 5-10% of the sediment in places. Slightly hard and softer bands are again indicative of original differences in composition (Fig.26).

(ii) Exogyra Beds

These Beds vary in thickness in the West Area but it is not always certain whether the lithostratigraphical correlation is strictly accurate. The overall impression, however, is of thickening to the west associated with a change of facies (Fig.28). The Exogyra Beds in the West Area become true limestones and have been in the past sometimes misidentified as parts of the Freestone Beds of the Portland Limestone Formation (Buckland and De la Beche 1836, Plate I; Strahan 1892, p.62). The true position in the sequence was recognised by Arkell (1935) but the mistake is understandable because some of the facies are the same as those in the Portland Limestone Formation, especially in the western

exposures. This fact is significant when discussing an environmental model for the Portland Group (see later).

(a) Ringstead Bay outcrops:

Holworth House: Arkell (1935) describes the "Exogyra nana Bed" as being 0.75m thick but in this study it was found to be 0.9m and the underlying 2.1m of sandy dolomite (Facies B') is also included in the Exogyra Beds. This lower 2.1m is harder than most of the underlying Upper Black Nore Beds and contains 10-20% v.f. quartz sand in the lower half and 5-10% above, all in a matrix of dolomite rhombohedra and 10-20% clay. The top contains empty moulds of unidentifiable decalcified bivalves. The topmost 0.1m is soft and forms a well-defined bedding plane. The 0.9m above is a hard quartzose shelly biomicrite containing abundant whole and fragmented valves of Exogyra nana, and is separable into a lower and upper part by a thin softer horizon 0.1-0.2m thick, just less than half way up. The matrix is micrite with 10% v.f.-f. quartz sand (Facies A"-QA) and fragments of calcitic and originally aragonitic bivalves; the latter exist as wholly or partly collapsed moulds. Pleuromya, occasional gastropods, serpulids (Glomerula) and ammonites (Glaucolithites?) are present.

It is not easy to tell how the bed was deposited as it can only be studied in vertical section. Bioturbation is visible and the concentration of Exogyra varies along the outcrop. Below Cliff House, 150m to the west, the bed is less rich in Exogyra but the discontinuity dividing the bed into an upper 0.5m and a lower 0.4m still exists. The bed was obviously not deposited by one event and may well be the result of in situ accumulation modified by bioturbation and possibly some current activity. The poorly sorted shell fragments and the presence of what was originally lime mud suggests fairly quiet deposition and any mixing of infauna and epifauna is probably due to bioturbation.

(b) Poxwell Pericline: Two small isolated exposures exist; one is at the far north-east end (SY 754837) 1.2m high, and the other is on the north side further west (SY 745837), about 2m high. Both expose quartzose limestone overlain by hard shelly limestone and these are considered to be part of the Exogyra Beds although Exogyra itself is not common.

SECTION IN THE LOWER PART OF THE PORTLAND LIMESTONE FORMATION AND THE UPPER PART OF THE PORTLAND SAND FORMATION. WEST MAINLAND AREA. RINGSTEAD BAY. CLIFF HOUSE AND HOLWORTH HOUSE. (SY 764815)

FIG 27

		Facies	M.	Sediment	Common Fossils
PORTLAND LIMESTONE FORMATION	UPPER CHERTY BEDS	1a	1·40	Lime mud with 5-10% *Rhaxella* spicule voids but also with high proportion (prob > 50%) very fine straight spicules. Horizons of black chert nodules and later, highly-inclined, tectonic sheets.	No fossils other than *Rhaxella*.
			0·7		
			c0·2	Q=0	
			c0·55	Lime mud with *Rhaxella* and a lot of *Pachastrella* voids.	*Pachastrella* *Rhaxella*
			c0·6	Lime mud with < 10% *Rhaxella*. Also *Pachastrella, biv & Gast frags.*	
		2	c0·5	Lime mud with shells and fragments. < 1% *Rhaxella*.	
		S 1a S	1·50	Lime mud with current oriented (?) serpulids. 10-20% *Rhaxella* voids.	*Glomerula*
	LOWER CHERTY BEDS — Basal Shell Bed	2	0·70	Bioturbated lime mud with shells and fragments of calc & arag bivs, gastropods, echinoderms & *Rhaxella*.	Bivalves, Ammonite.
		1	c1·30	Bioturbated lime mud. (soft chalky white micrite). Occ shell fragments.	Occ. fragments.
	Equiv. to Portland Clay beds		0·25-0·30	Argillaceous lime mud. <1% Q.	Occ calc biv frags.
			c0·55	Dedolomitised. No quartz.	
			c0·4		
PORTLAND SAND FORMATION	Equivalent to CAST BEDS and BLACK DOLOMITE BEDS	A'' -Rh	c1·45	Lime mud with 60-70% *Rhaxella* casts. Silicification horizons.	Ammonites *Rhizocorallium* bioturbation.
			c0·25	Rhomb mosaic dolomite. Q<1.	
		s B+ A''	1·7	Partial silicification and decalcified shell bed. Dolomite. Partial dolomitisation of lime mud. Residual nodules of shelly micrite in dolomite matrix.	Serpulids, *Trigonia*, *Camptonectes*.
		B	1·0	Rhomb mosaic dolomite, probably argillaceous. Originally lime mud.	Scattered tiny moulds.
		C	0·55	Argillaceous dolomite. Partly dedolomitised.	Exogyra
	EXOGYRA BEDS		c 0·9	Quartoze shelly biomicrite. Q. c10% (vf-f). *Exogyra* shells in lime mud matrix. Frags of calc and arag bivs, gastropods and serpulids.	*Exogyra*, ammonites.

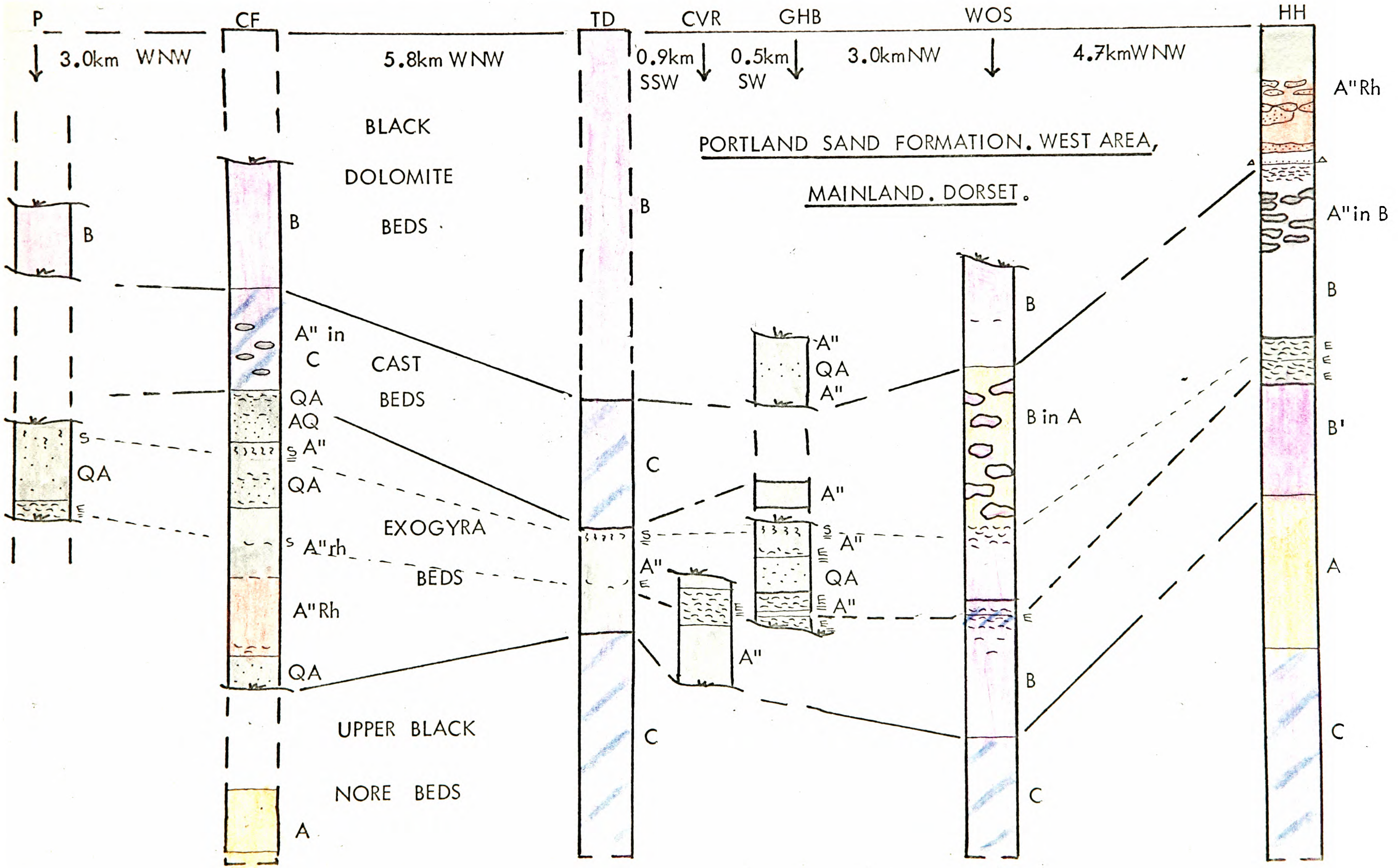

P
CF
TD
CVR
GHB
WOS
HH
3.0km WNW
5.8km WNW
0.9km SSW
0.5km SW
3.0km NW
4.7km WNW
PORTLAND SAND FORMATION. WEST AREA,
MAINLAND. DORSET.
BLACK
DOLOMITE
BEDS
CAST
BEDS
EXOGYRA
BEDS
UPPER BLACK
NORE BEDS
A" in C
QA
AQ
A"
QA
A"Rh
QA
A"
QA
A"
A"
QA
A"
A"
B
B in A
A"Rh
A"in B
B'
A
C

FIG 28

(c) Osmington District: Approximately 12m of Portland Sand Formation is exposed in an overgrown section (SY 716823) by a track from Osmington to Eweleaze Barn, 4.7km WNW of the section at Holworth House. The Exogyra Beds are 2.7km thick and composed of grey-brown dolomite (Facies B) (Fig. 28). The basal 0.3m is a hard dolomite with mould of indeterminate bivalves and 1% quartz sand. This is overlain by 2.0m of soft rubbly dolomite (5% quartz) with Exogyra, Falcimytilus, Pleuromya, Laevitrigonia and Glaucolithites in the upper half but only scattered shell fragments and <1% quartz in the lower half. The top 0.4m is a prominent bed, the original sediment of which consisted of shell sand and 1% v.f. quartz in a lime mud matrix. The rock now consists of dolomitic mosaic and rhombohedra with original calcitic shell fragments still preserved. The lower half contains Exogyra nana.

(d) Coombe Valley Outlier:

Plaisters Lane (SY 698844): A cutting on the north side of the lane to Sutton Poyntz, between Green Hill and West Hill, exposes 5.5-6m of Portland Sand Formation (Fig. 28 GHB) dipping to the NW at 45-60°. Less than 100m to the north-east of this, the Jurassic strata are faulted against Middle Chalk (Fig. 22) which is exposed in a road quarry 250m to the east.

The basal 0.7m of section is a limestone consisting almost entirely of Exogyra nana, divisible into two beds by a shell-free layer 0.15m thick and 0.35m down from the top. The Exogyra-rich rock contains an intergranular matrix of compacted pelletal lime mud with ≤1% quartz. The Exogyra are often partially silicified. The shell-free layer contains 1-2% v.f. - f. quartz sand scattered in a matrix of microsparite with micrite pellets (c. 500μ) and composite pelletal patches. Also present are micrite-rimmed fragments of Exogyra up to 4mm across, sparite-filled moulds of fragmented aragonitic bivalves and occasional echinoid spines. This represents a temporary cessation of Exogyra accumulation, perhaps due to a lime mud settling after a high energy event.

Above is 0.6m of limestone with only shell fragments in a matrix originally composed of pellets, lime mud and v.f. quartz

sand which increases from 5% in the lower part to 30% in the upper. This is overlain by 0.55m of hard limestone rich in Exogyra and Glomerula, most of which are concentrated in the lower 0.25m. The original sediment also contained medium sand-grade fragments of other bivalves, pellets and 1.5% v.f.-f. quartz sand. Above is 0.15m of rubbly limestone with Exogyra, 10% v.f.-f. quartz and rounded medium shell sand. Overlying this is 2.5m of serpulitic and Exogyra-rich quartzose limestone (A") with scattered Glomerula, 5% v.f.-f. quartz sand and pellets, in a micrite matrix.

The upper part of the exposure is separated by an overgrown gap estimated to conceal 1.5m of section. Above this is 0.15m of quartzose limestone (A"), the original sediment of which was lime mud with pellets and only 1% v.f.-f. quartz sand. The top of the section consists of 1.0m of Facies A" containing 5-10% poorly sorted quartz sand (50-500μ) and pellets (1-2mm) in a micrite matrix. Calcitic and originally aragonitic bivalve fragments (up to 5mm) are common and Glomerula occurs.

Coombe Valley Road (SY 694842): A small exposure exists 200m south-west of Green Hill on the west side of the road between Chalbury hill fort and Tout Downs. The section shows approximately 2.0m of quartzose limestone (A") with a concentration of Exogyra in the upper part. This seems to correlate well with the section in Plaisters Lane 450m to the NE. At the base of the section is 0.2m of hard micrite with 1% quartz sand, overlain by 0.85m of micrite with shell fragments, 5-10% quartz sand and occasional echinoid spines. Above is 0.4m of rock composed almost entirely of Exogyra nana with interstitial micrite and ≤1% Quartz. Occasional tiny gastropods (1-2mm) and Rhaxella spicules occur. The topmost 0.4m is a hard limestone composed of medium shell sand and scattered Exogyra, 5-10% v.f.-f. quartz sand and interstitial lime mud.

Tout Downs Gas Main (SY 690833): This temporarily exposed the Exogyra Beds on the south side of the hill overlooking Littlemoor Road. The Beds were seen to be 2.0m thick and overlain by 2.5-3m of soft yellow dolomitic clay (Facies C). Below, the typical

sediment of the Upper Black Nore Beds were exposed. At the junction with the Upper Black Nore Beds there is a fossiliferous glauconitic quartzitic limestone containing Pleuromya, trigoniids and large and small ammonites. This is overlain by 1.5m of micrite with <1% Quartz, grains of shell sand and occasional Rhaxella spicules. The top of this is marked by a thin soft horizontal seam which is overlain by 0.3m of micrite with scattered Exogyra and occasional ammonites (Glaucolithites?). The upper 0.2m is rich in Glomerula, with shell fragments and 5-10% quartz in a micrite matrix.

(e) Corton Hill District: In the cutting to Corton Farm (SY 636855) the Exogyra Beds are 5.7m thick and composed of quartzose limestones (Facies A", QA and AQ) with a variable amount of sand and Rhaxella spicules. Details are given in Fig. . Exogyra is not noticeably concentrated at any particular level but are scattered throughout almost all the section. There is a concentration of Glomerula from 1.0-1.5m from the top of the Beds.

The basal 0.6m of the limestone (Facies QA) contains 20% Quartz sand and is overlain by 1.8m of limestone rich in Rhaxella spicules (10-60%) (A"Rh). Shell sand comprises 20-30% and the lime mud matrix contains 0-5% quartz sand. The upper 3.3m of the section contains a diverse bivalve fauna, as well as serpulids, ammonites, echinoid spines and Rhaxella spicules. The original sediment was lime mud with 5-10% v.f.-f. quartz sand, shell sand and pellets.

The individual beds are usually demarcated by pressure-solution horizons which are common in the Lower and Upper Cherty Beds of the Portland Limestone Formation. No chert is present in spite of the local concentration of calcite casts of siliceous sponge spicules.

(f) Portesham: At the far west end of the area the Exogyra Beds are exposed as isolated crags round the closure of the Upwey Syncline, overlooking the village of Portesham. Approximately 2m of hard sandy limestone is exposed with common Myophorella (open but articulated), Camptonectes and Glomerula. The lowest

FIG 29

SECTION OF PORTLAND SAND FORMATION

Road cutting to Corton Farm. W.Mainland Area.

(SY 636855)

Facies	METRES	SEDIMENT	FOSSILS
Black Dolomite Beds — B	1.8	Dolomite mosaic; grains and sub-rhombs 10-20μ. Some thin calcite veins. Originally a bioturbated lime-mud. Probably partly dedolomitised. Q<1%VF.	Only moulds of ammonites and *Rhizocorallium*?
Cast Beds — C+ A''	c2.	Poorly exposed. Clay with fossiliferous micrite nodules. Clay probably dolomitic with some V.F. quartz sand. Q<1%VF. (nodule).	Bivalves common, especially in the nodules. *Eocallista, Corbula, Exogyra, Thracia, Pleuromya, Musculus, Protocardia, Isocyprina, Laevitrigonia, Myophorella, Mactromya, Ampullospira,* ammonites.
BEDS — QA	0.3	Qc25%VF-F} Matrix of lime mud with few shell fragments and micrite pellets	Shell bed at top with fossils as above plus *Camptonectes*.
AQ	0.7	Q30-40%F	Shell fragments at base.
S A''	0.6	Qc5%VF } Fine shell and pellet sand in micrite matrix.	*Glomerula* abundant plus occ *Serpula Exogyra, Liostrea,* ammonites. Shell fragments at base.
QA	0.7	Qc30%VF}	Shell sand of bivalve and echinoderm fragments. Shell layer at top and bottom.
rh S	1.0	Lime mud with some pellets and *Rhaxella* casts 1-5% Pressure solution concentrate at base. Qc1VF.	*Rhaxella* spicules. Scattered bivalves. *Exogyra, Isognomon.* Serpulids.
EXOGYRA rh A'	0.85-9.0	Qc5%VF Lime mud with 30% shell sand & 20% casts of *Rhaxella.*	Shell sand of fragments of *Exogyra* and echinoderms, and micrite pellets. *Rhaxella.* Scattered bivalves.
Rh		Q=0 Shell sand c30%, and *Rhaxella* casts c60%.	
	15-20	Qc5VF Medium shell sand.	
Rh	0.6	Lime mud, c10% *Rhaxella* casts. Some shell sand. Q<1.	*Exogyra* fragments and *Isognomon.*
	0.15	Q1-5%VF. Glauc<1.	
wQA	0.6	Lime mud. Some shell sand and *Rhaxella.* Qc20%VF. Gl<1.	
UPPER BLACK NORE BEDS	c2	No exposure.	No fossils found.
A	1-1½	Quartz sand c40% and Glauconite<1%. Matrix of dolomite and clay. Originally a quartzose argillaceous lime mud.	

0.5m contains numerous Exogyra nana.

(iii) Cast Beds and Black Dolomite Beds

(a) Ringstead Bay Outcrops: These Beds are exposed below both Cliff House and Holworth House and are described as a single section (Fig. 27). They are 5-9m thick but cannot be divided into Cast Beds and Black Dolomite Beds, being mostly dolomite (Facies B) in the lower part and limestone (A") in the upper.

Above the Exogyra Beds is 0.55m of partially dolomitised argillaceous lime mud with scattered Exogyra. Nodules of soft white micrite occur in a matrix of argillaceous dolomite (Facies C), the upper part of which has a fairly high clay content. Above is 1.0m of dolomite (Facies B) with a v.f. quartz sand content of <1% and scattered indeterminable micrite bivalve moulds. This is the result of dolomitisation of Facies A". Overlying this is 1.1m of rubbly partially dolomitised limestone (Facies A", Quartz ≤1%). In the lower part the rock consists of white micrite nodules in a dolomite matrix and in the upper part, of large brown dolomite patches in a micrite matrix. (Plate 21). The micrite contains a fauna of bivalves (Isognomon, Myophorella, Exogyra) and common ammonites (Glaucolithites), as well as shell fragments, which are represented in the dolomite only as empty moulds. Above is a shell bed 0.2m thick containing calcitic shelled bivalves and empty moulds of aragonitic shelled forms. Camptonectes, Laevitrigonia and Glomerula are common. This is overlain by 0.4m of partially silicified shelly dolomite.

A marked bedding plane divides this bed from 0.25m of dolomite above (Quartz <1%). This has the white "blebs" seen in the Black Dolomite Beds of the Isle of Purbeck (and Isle of Portland). The upper part is bioturbated, probably by the Rhizocorallium animal. This is overlain by 1.45m of cherty micrite with up to 70% calcite casts of Rhaxella spicules (Quartz ≤1%). The chert takes the form of large diffuse, light grey silicified nodules, unlike the distinct black cherts of the Portland Limestone Formation above. Above is 0.95m of what Arkell (1935) describes as "Cementstone and marly clay" but which has the field appearance of

being a fairly coarse sandstone of varying hardness. However, in this section it is seen to consist of calcite crystals 100-400μ across which are the result of dedolomitisation.

(b) Osmington District: The section by a track to Eweleaze Barn (SY 716823) exposes 6.5m of beds above the top of the Exogyra Bed. These are in part similar to those described at Holworth House (Fig. 28). The basal 1.0m is quartzose dolomite (B') above which is a bed 0.5m thick of poorly preserved bivalves and ammonites in a matrix of argillaceous dolomite (Facies C). The overlying 3.0m is soft white micrite (A") with light brown dolomitised patches. The top 2.0m is dolomite (B) with ≤1% quartz and a fine mosaic. Small bivalve moulds have been filled by high Fe-calcite.

Eastwards, between this section and the Cretaceous overstep, the dolomite forms a small scarp and can be traced as far as Pontins Holiday Camp (SY 720822). Small exposures occur and Glaucolithites is common together with moulds of poorly preserved small bivalves. This scarp continues westwards and northwards to White Horse Chalet on the A353 (SY 713831).

(c) Coombe Valley Outlier:
Tout Downs gas main: This exposed 2.5m of soft yellow argillaceous dolomite (Facies C), the Cast Beds, overlain by an estimated 6-8m of slipped and cambered fine grained dolomite with <1% quartz (Facies B), the Black Dolomite Beds.

(d) Corton Hill District: In the cutting to Corton Farm the Cast Beds are overgrown but are estimated to be 2m thick. Arkell (1935) described "Blue-grey marls and thin bands of nodular sandy cementstone"; nodules can be dug out of the grass and are micrite with <1% v.f. quartz. The "marls" between are probably argillaceous dolomite (C). Above is 1.8m of dolomite. This is a hard rock with <1% v.f. quartz and with very weathered dedolomitisation nodules, as seen in the other Dorset Areas. The total thickness of the Black Dolomite Beds ("dark grey sandstone" of Arkell) is not known.

By the track to Friar Waddon Dairy House (SY 645854) there is a degraded cutting, below an overgrown quarry in the Portland Limestone Formation, which exposes the Black Dolomite Beds, Cast Beds and the top of the Exogyra Beds. The Cast Beds are approximately 2.5m thick and contain fossiliferous nodules of Facies A" (the fauna is as at Corton, Fig. 29), in a matrix of argillaceous dolomite. Above, the Black Dolomite Beds are approximately 5m thick, composed of dolomite with <1% quartz.

(e) Portesham: Isolated exposures of Black Dolomite Beds are seen round the closure of the Upwey Syncline and the facies appears identical with that at Corton. Thus these Beds are persistent throughout the extent of the outcrop of the Portland Group in Dorset.

4. The Portland Sand Formation on the Isle of Portland (West Area, Dorset)

A. Introduction

This triangular peninsula is a wedge of Upper Jurassic strata which represents but a remnant of the gently dipping south limb of the Weymouth-Purbeck Anticline and the north-west closure of the Shambles Syncline (Fig. 30) (Donovan and Stride 1961). Arkell has described Portland as"a sample of the great tract of country which formerly lay beyond the present coastline of Dorset" (1933, p.492).

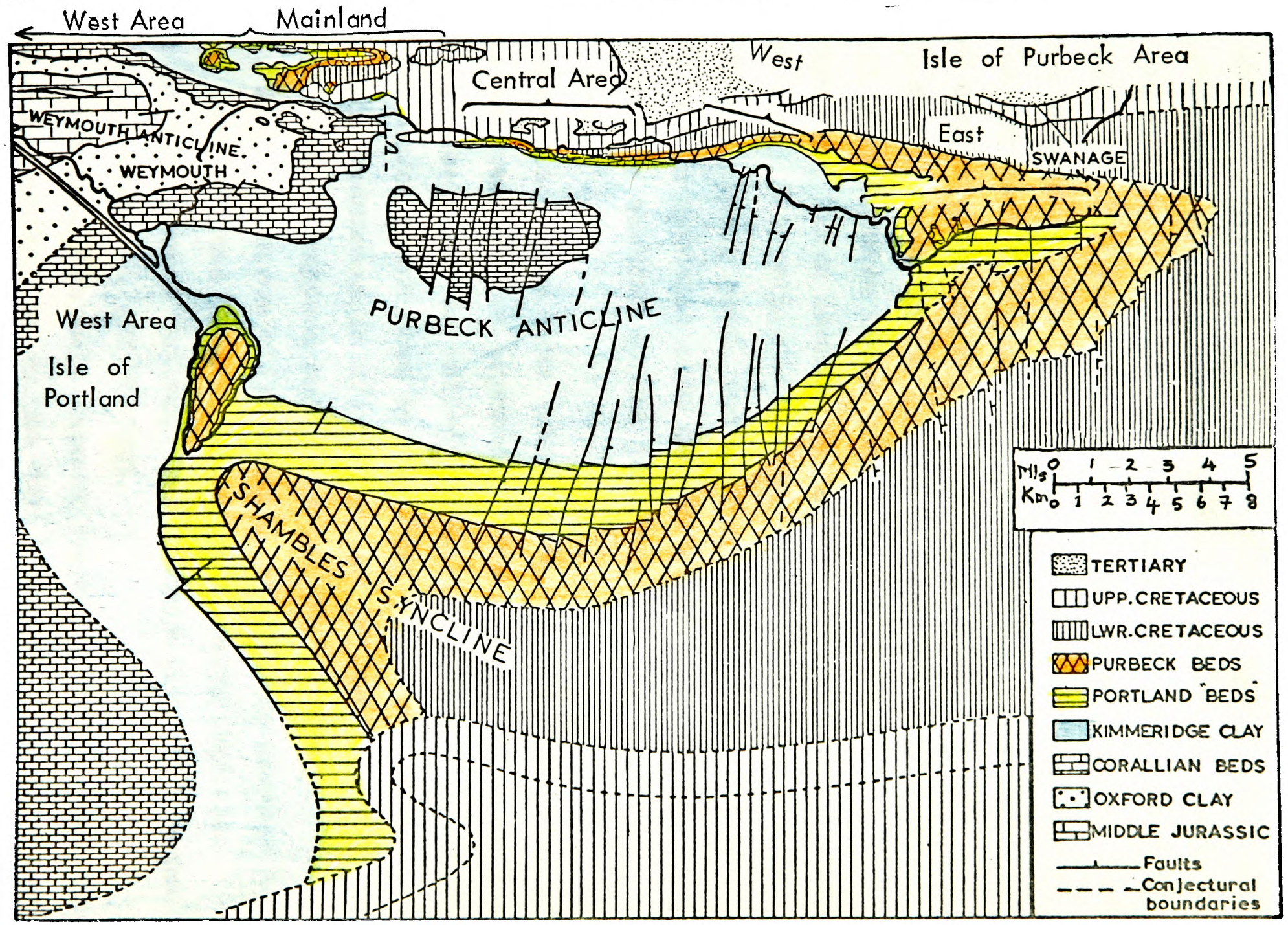
The Kimmeridge Clay, Sandy Upper Kimmeridge Beds and Portland Sand Formation dip at an angle of 1½-2° to the south and south-east and form an outcrop encircling all but the southern third of the island. The outcrop continues offshore eastwards to the Isle of Purbeck (Fig. 30), and southward for about 20km before disappearing below the Upper Cretaceous.

About 40km south of the Isle of Purbeck (longitude 2°W) the Jurassic strata reappear on the bed of the English Channel and Kimmeridge Clay, Portland Sand and (?) Middle Purbeck Beds have been recognised, around latitude 50°N by Larsonneur and Rioult (1969) (Fig. ( ).

Although the type-locality for the "Portland Sand" in Dorset is Emmetts Hill (Isle of Purbeck) (Fitton 1836), the beds have always been well displayed on the Isle of Portland. Arkell (1933) named the succession as follows:-

Portland Clay	
West Weare Sandstones	
Exogyra Bed	Portland Sands
Upper Black Nore Beds	
Black Nore Sandstone	
Lower Black Nore Beds	Kimmeridge Clay

The Portland Clay with the Basal Shell Bed of the "Portland Stone" is equated with the Lower Cherty Beds and thus promoted to the upper division of the Portland Group (See Chapter 4).



Geological map of the sea floor south of east Dorset (redrawn from Donovan and Stride 1961)

FIG 30.

The "West Weare Sandstones", when examined in the field, prove to be the Black Dolomite Beds and Cast Beds. From the "Exogyra Bed" down, the succession is as elsewhere. Arkell took the base of the Black Nore Sandstone as the junction with the Kimmeridge Clay purely for its resemblance to the "Massive Bed" of the Isle of Purbeck. However, there is no reason to suggest that this is a justifiable lithostratigraphical correlation and there seems to be biostratigraphical evidence against it (House 1958, Cope in Torrens 1969). It is considered safest here to say merely that, as elsewhere in Dorset, the beds below the Exogyra Beds are of a sandy facies and pass down into the Upper Sandy Kimmeridge Beds. It is hoped that studies of the ammonites by Cope (Swansea University) and the microfauna by Lloyd (University College, London) will soon resolve these correlation problems.

The most well known section is in the cliffs of West Weare (SY 682720) (Fig. 31) (Plate 22) on the west side of Portland, but there is an equally good, and more accessible section at Grove Cliff on the opposite side of the island (SY704721). An inferior overgrown section exists in the north, below Verne Prison (SY 692729).

The Upper Black Nore Beds (which here include Arkell's "Black Nore Sandstone") are exposed at the type locality of West Weare Cliffs, (south end is called Blacknor). These beds pass down into the Lower Black Nore Beds in the cliff and into Kimmeridge Clay mudstones in slipped masses at beach level. The thickness of "sands" exposed below the top of the Exogyra Beds is at least 25m. At Grove Cliff several metres are exposed below the Exogyra Beds but the base is obscured by talus and the embankment of the disused railway. Kimmeridge Clay is exposed on the shore at Littlebeach (SY 705722).

The Exogyra Beds are well exposed at Grove Cliff, West Weare and, to a lesser extent, below the Verne Prison. The Cast Beds are, as usual, soft and thus less well exposed than the other beds, but they can be seen at Grove Cliff and West Weare. The Black Dolomite Beds are visible in the north below Verne Prison, along the east coast at Grove Cliff and as far south-east as

Rufus Castle (Church Ope Cove) (SY 697710). On the west coast they are exposed at West Weare, Mutton Cove (SY 679712) and as far south-west as Wallsend Cove (SY 678698) where they are very well displayed in a wave-washed section rich in ammonites and dedolomitisation nodules.

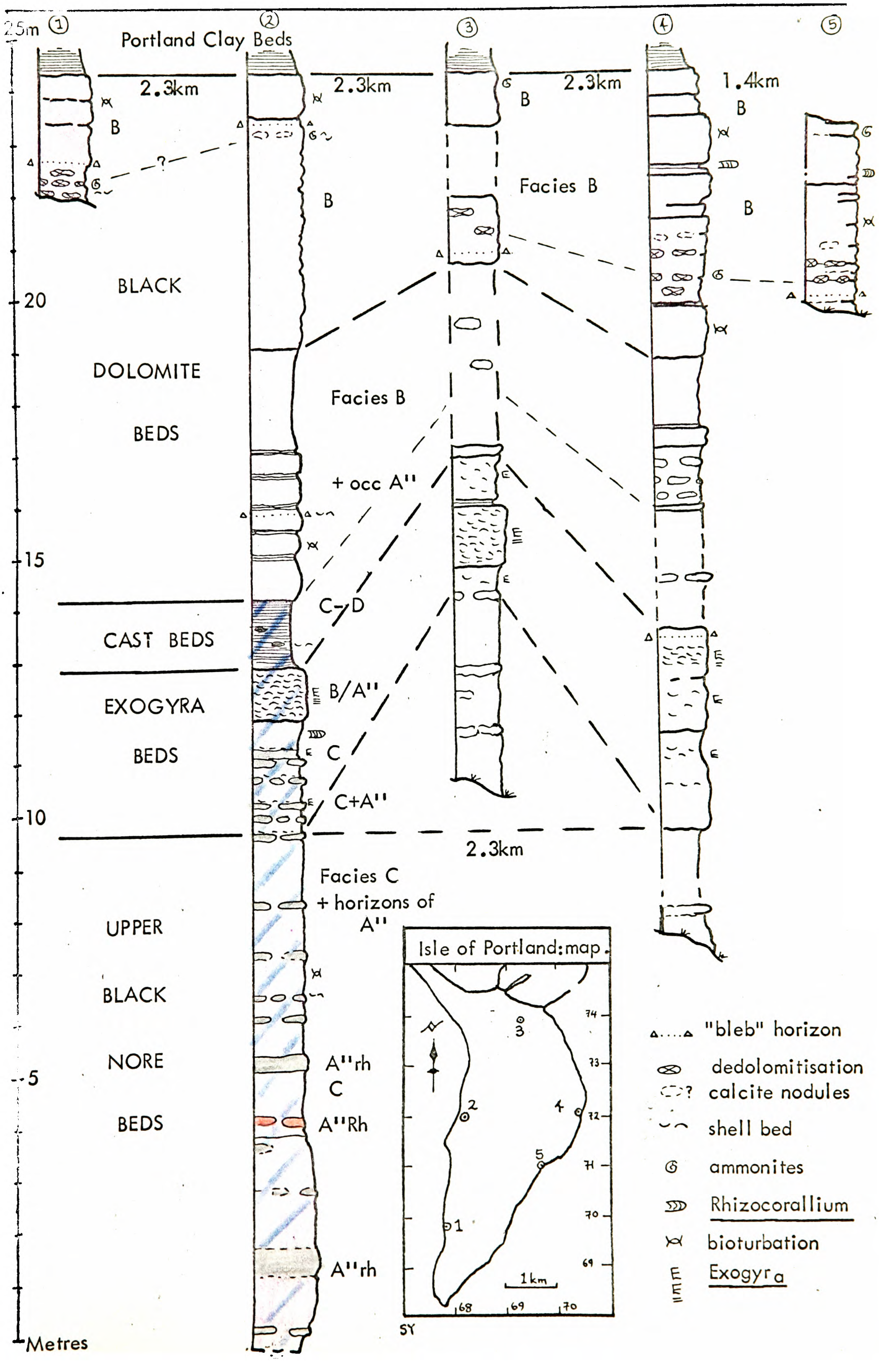
B. Description of Beds

(i) Upper Black Nore Beds: The type locality for these Beds defined by Arkell (1933) is at the wide cliff section on the west coast of the Isle of Portland between Blacknor and Tar Rocks (SY 682720) (Fig. 31) (Plate 22). His description (1933, p.497) of the section reads: "The Upper Black Nore Beds consists of black sands with lines of light grey nodules, 35ft. thick (10.6m). ... They are separated from the Lower Black Nore Beds by a 6ft. band (1.8m) of hard, black, argillaceous sandstone with intensely hard concretions. The Lower Black Nore Beds consist of blue-black sandy clays, extending as far as the foot of the visible section, 40ft. (12m) below the Black Nore Sandstone. ... It seems likely that the sandy clays constituting the Lower Black Nore Beds will one day prove to be the Hounstout Marl, regarded here as belonging to the Kimeridge Clay." However, Arkell never lived to see that day, which has yet to come. A glimmer of the impending dawn has been revealed by Cope (in Torrens 1969) who remarks: "At the base of the Portland Sand, Progalbanites has been recorded from the Lower Black Nore Beds." This ammonite is the zone fossil (P. albani) of the Lower part of the Portland Sand Formation (Emmit Hill Beds of the Isle of Purbeck) and is considered not to range down into the top of the Sandy Upper Kimmeridge Beds (Hounstout Marl of the Isle of Purbeck. "Zone of Epipallasiceras sp." Cope in Torrens 1969). Thus, as the Isle of Purbeck sequence has been used as the biostratigraphical type-section, the Lower Black Nore Beds must be included, in part at least, in the Portland Sand Formation. All this, as Cope says,: " ... suggests that more work is needed before accepting Arkell's correlation ... as exact."

In this study the section on the west coast of Portland was

PORTLAND SAND FORMATION. WEST AREA, DORSET.

ISLE OF PORTLAND. FIG 31



not measured below the base of Arkell's "Black Nore Sandstone" but it was noted that the exposed sequence continued below in a similar facies to the Upper Black Nore Beds for at least another 13m. The thickness from the base of the Exogyra Bed to the base of Arkell's "Black Nore Sandstone" is 9.5m. The section consists of alternations of light grey nodules of limestone (A") and thicker beds of dark grey argillaceous dolomite (C) similar to the alternations in the Isle of Purbeck of limestone (A") and Facies A. The quartz sand content rarely exceeds 10% and often the thin A" horizons contain <1%. Some of the latter have up to 5% Rhaxella spicules. (Fig. 31).

It is not easy to define the junction between the Upper Black Nore Beds and the Exogyra Beds but as the 2.4m below the maximum concentration of Exogyra also contains this fossil, in a sequence like that in the Central Area (Fig. 18), it is included in the Exogyra Beds rather than the Upper Black Nore Beds.

At Grove Cliff, there is approximately 2.5m of beds below the Exogyra Beds which seem identical to those displayed on the west coast. House (1958) records "Rhychonella portlandica" from the lower part of the Upper Black Nore Beds, "above the Black Nore Sandstone".

(ii) The Exogyra Beds: These are 3.3m thick on the west coast, 2.4m in the north and 3.9m at Grove Cliff on the east side. The measurments may not be particularly accurate but Exogyra are distributed through these thicknesses as indicated in Fig. 31. Details of biofabric are not very clear but wave-washed fallen blocks on the east coast show that the valves are very concentrated and seem to be not in life position (Plate 23). The maximum concentration shown in the section on the west coast is similar to that in the sections in the West Mainland Area, particularly at Holworth House and in the Coombe Valley district. This is interpreted as a result of a slower rate of subsidence in the region of Portland and the Mainland due north and north-east, than in the Isle of Purbeck to the east.

The lower part of the Exogyra Beds consists of bioturbated argillaceous dolomite (Facies C) (<5% quartz sand) with thin

nodule horizons of limestone (Facies A", 5-10% quartz). The upper, concentrated, part consists of partially silicified whole and fragmented Exogyra in a partially dolomitised lime mud matrix. (Plate 7).

There is also an exposure of Exogyra Beds at Mutton Cove with at least 5m of section below, from which Glaucolithites was collected.

(iii) Cast Beds: As has been seen for the Mainland part of the West Area, the separation of Cast and Black Dolomite Beds is not always easy, especially in the eastern outcrop (Osmington to Holworth House). On the Isle of Portland the beds immediately above the Exogyra Beds are continuously exposed only on the west coast and there the assigned thickness is 1.35m (Fig. 31). In the north the section is too overgrown to see the base of the Black Dolomite Beds and on the east coast (Grove Cliff) the thickness of 2.4m is only an estimate. The sediment is argillaceous dolomite or dolomitic clay (C or D) with occasional fossiliferous nodules (Thracia).

(iv) Black Dolomite Beds: At the West Weare section Arkell (1933) describes "30ft. (9m) of brown and grey marly sandstones and sandy cementstones. ... Towards the north end of the island ... these sandstones thicken considerably. It is convenient to distinguish them by the name West Weare Sandstones." On the contrary, these beds thin to the north (Fig. 31) and they are dolomites with <1% v.f. quartz sand. They contain the black calcite dedolomitisation nodules which Arkell (1935) recognised in his "Black Sandstones" of the Isle of Purbeck. These had been noted many years before by Woodward in the section below Rufus Castle (in Strahan 1898): "Hardened calcareous sand, blue and brown, much honey-combed, with crystals of calc-spar; Ammonites biplex" (Glaucolithites).

Thus, these beds are identical with the Black Dolomite Beds in the Isle of Purbeck, Central Area (Dungy Head) and at Corton in the West Mainland (Figs.18,29) and the term "West Weare Sandstones is not only petrographically erroneous but also lithostratigraphi-

cally redundant.

West Coast: In the large section between Blacknor and Tar rocks the Black Dolomite Beds are 10.3m thick and consist of a lower 5.0m of soft-weathering dolomite (Facies B, 1-5% v.f. quartz) separated by thin horizons of argillaceous dolomite (C) and with remnant nodules of limestone (A", c.1% quartz) containing Pleuromya with associated "white blebs" as described in the Isle of Purbeck. The upper 5.3m is the typical harder dolomite (B) with <1% Quartz and up to 5% clay. The details are not easily examined with safety at this locality (Plate 22) but there is another "white bleb" horizon near the top, possibly underlain by dedolomitisation nodules. There is, at least, some poikilitic calcite cementation fabric to the dolomite at this horizon.

At Wallsend Cove, there is a good fresh wave-washed section in the topmost 2.5m (Fig. 31) and large black calcite dedolomitisation nodules are common as is Glaucolithites and Pleuromya. These are associated with the "white bleb" material, further suggesting an association with aragonitic skeleton as noted in the Isle of Purbeck.

East Coast: The section below Grove Cliff is similar to that on the west side of the island, 2.4km away. The lower part contains thinner harder beds and thicker softer beds than in the west (Fig. 31), but the overall thickness is approximately 8.6m, and the upper part is 5.6m thick. The latter contains dedolomitisation nodules, Glaucolithites, Rhizocorallium and is more massive bedded than below.

The section at Church Ope Cove (below Rufus Castle) shows about 3.5m of the upper part of the succession and again has nodules, "blebs" and common ammonites. (Fig. 31).

North Coast: This overgrown section below Verne Prison is 1.9km north of the line joining the other two major sections. It also contains black calcite nodules, "bleb" horizons and common large Glaucolithites (up to 0.6m in diameter). The total thickness of the Black Dolomite and Cast Bed is estimated to be 7.5m and the upper part of the Black Dolomite Beds is 3.7m thick (Fig. 31).

5. Fauna recorded from the Portland Sand Formation

Black Dolomite Beds

Common: Glaucolithites gorei Salfeld

Rare: "Trigonia" (Myophorella?) portlandiensis Cox

Pleurotomaria sp.

Cast Beds

Common:- (limestones)

Thracia depressa Sowerby

Eocallista implicata de Loriol

Eocallista pulchella de Loriol

Pleuromya tellina Agassiz

Musculus autissiodorensis Cotteau

"Arca" foetida Cox

Protocardia sp.

Isocyprina sp.

Less common: limestones)

Exogyra nana Sowerby

Nucula lotioli Cox

Plectomya rugosa Roemer

Sowerbya longior Blake

Isocyprina sp.

Laevitrigona sp.

Myophorella sp.

Mactromya sp.

Corbula sp.

Ampullospira sp.

Glaucolithites sp. and pavlovids

Exogyra Beds (moderate preservation potential)

Shell beds:-

Common: Exogyra nana Sowerby

Less common: Oxytoma octavia d'Orbigny

Ostrea bohoniae Sauvage

Exogyra thurmanni Etallon

Camptonectes lamellosus Sowerby

Astarte kitchini Cox

Plicatula boisdini de Loriol

Corbula dammariensis Buvignier

Rhynchonella subvariabilis Davidson

Rhynchonella portlandica Blake

"Terebratula" bononiensis Sauvage & Rigeaux
(=T.ovoides Sowerby?, = Rouillieria Makridin of Ager 1971?)

Glaucolithites sp. and Pavlovids

Thin Limestones:-

Common: Pleuromya tellina Agassiz

Thracia depressa Sowerby

Less common: Musculus autissiodorensis Cotteau

Anisocardia cf. autissiodorensis Cotteau

Lucina arenaria Cox

Buchia mosquensis Buch

Thick Limestones:-
(West Area)

Exogyra nana Sowerby

Ostrea sp.

Isognomon sp.

Glomerula gordialis Schlotheim

Rhaxella spicules

Upper Black Nore Beds (low preservation potential)

All rare and mostly only in the more calcareous horizons.

Thracia depressa Sowerby

Pleuromya tellina Agassiz

Pinna constantini de Loriol

Oxytoma octavia d'Orbigny

Buchia mosquensis Buch

Ostrea bononiae Sauvage

Exogyra nana Sowerby

"Trigonia" cf thurmanni Contejean

Laevitrigonia gibbosa Sowerby

Camptonectes lamellosus Sowerby

Musculus autissiodoriensis Cotteau

Rhynchonella portlandica Blake

Discina latissima Sowerby

Progalbanites albani Arkell

Epivirgatites sp

Pavlovids

Portland Sand Formation	Upper Black Nore Beds Exogyra Beds Cast Beds	)	Undifferentiated. Horizon unknown

Abundance not known (presumably not common):-

"Trigonia" pellati Munier-Chalmas

"Trigonia" cf cymba Contejean

"Trigonia" (Myophorella?) aylesburiensis Cox

Camptonectes nudus Buvignier

Camptonectes morini de Loriol

Plagiostoma boloniensis de Loriol

Anomia suprajurensis Buvignier

Eocallista brongniarti Roemer

6. Synthesis

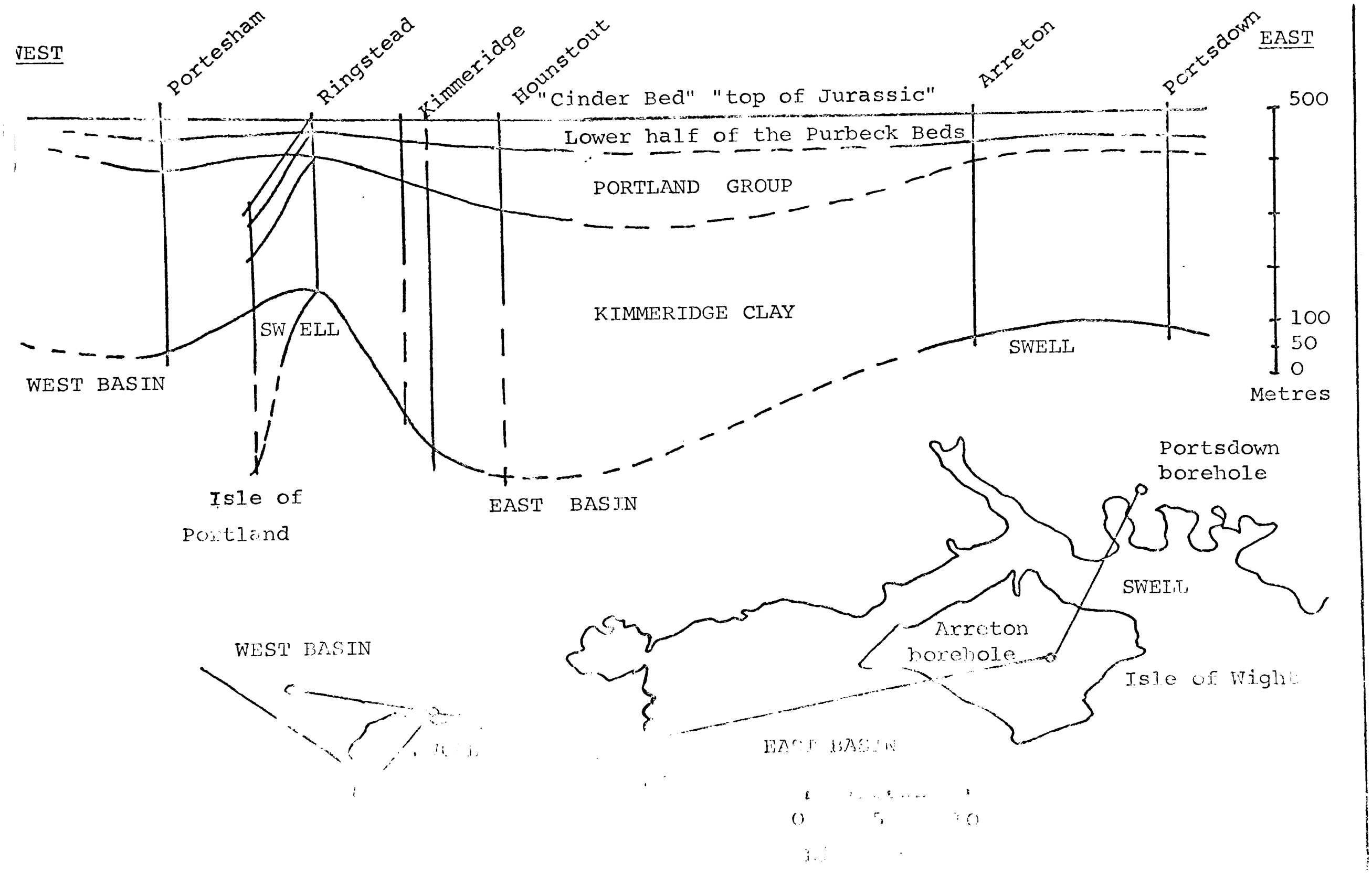
A. Introduction

Compared with the rest of Southern England, the Dorset and Weald Areas were relatively rapidly subsiding basins during deposition of the Kimmeridge Clay and onwards to the end of the Jurassic. The Dorset Basin is defined on the elementary principle that the thickest successions accumulated in areas of maximum subsidence and thin successions formed, or nondeposition took place, on "swells" where subsidence was minimal. The total Jurassic strata thin westwards from Dorset to Devon , part of which at times of regression might have been land (Arkell 1933).

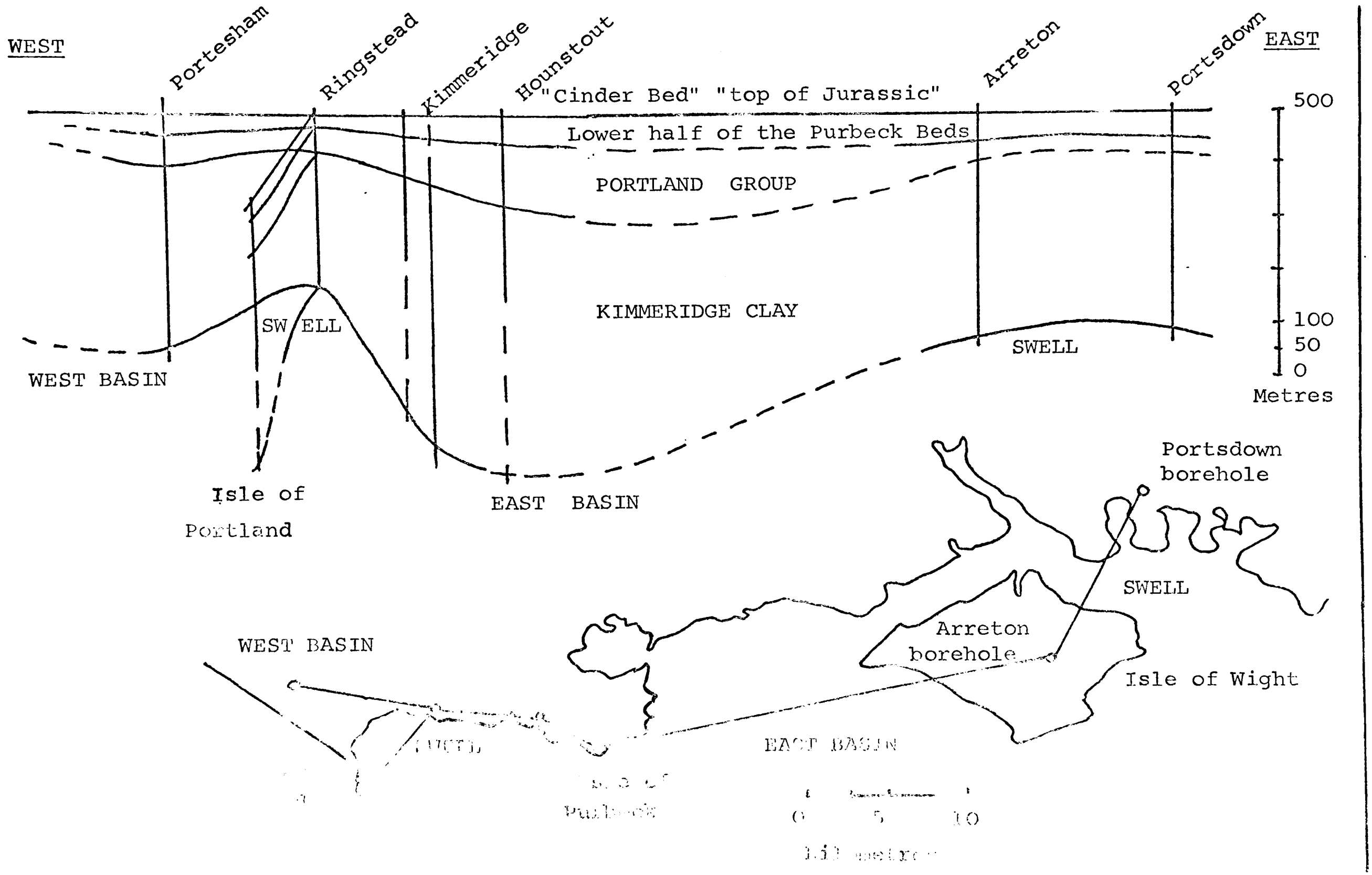
The Kimmeridge Clay is a thick deposit reaching nearly 500m in the Isle of Purbeck (Arkell 1947a) and which is known to exist in the Bristol Channel (Lloyd 1963), the English Channel (Larsonneur & Rioult 1969), Northern France, from south England to Yorkshire and in East and West Scotland (Arkell 1933). Littoral, coarse-grained cross-stratified sands occur in the Upper Kimmeridge Beds in the South Midlands and the Bas Boulonnais whereas quiet water deeper sea deposits formed in Dorset.

Although the Dorset Area was a major basin in Kimmeridge Clay times, the rate of accumulation of sediment varied over surprisingly short distance (Fig.32). The beds thicken from west to east and are probably at a maximum between the Isle of Purbeck and the Isle of Wight. Between the basin margin in the west and the Isle of Purbeck there is a swell over which the beds thin. At Ringstead Bay the total Kimmeridge Clay is half the thickness at Kimmeridge Bay, about 10km to the east (Fig 32).

This area of relatively slower subsidence persisted into Portland Group times and these beds are also halved in thickness within the same 10km (Fig.32). This is also true for the lower half of the Purbeck Beds and by using the data of Howitt (1964) it is seen that the thickness is reduced by two-thirds over this distance (Fig.32). Westwards from the swell, the Kimmeridge Clay, Portland Group and lower half of Purbeck Beds thicken but not so drastically, presumably because the basin margin was in that direction. The Dorset Basin can be discussed, therefore, in terms of a major East Basin and a minor West Basin.



THE POSITION OF THE SWELLS AND BASINS IN SO
DORSET AND WEST HAMPSHIRE DURING THE UPPER JURAS
FIG 32



THE POSITION OF THE SWELLS AND BASINS IN SOUTH DORSET AND WEST HAMPSHIRE DURING THE UPPER JURASSIC

FIG 32

As far as it is known the swell was not a very elongated structure (or "Axis") as luckily the Isle of Portland adds a third dimension to the picture and shows that the strata also thicken to the south. What happens to the north is unlikely ever to be discovered because a borehole through the Upper Cretaceous cover at Bere Regis, c.15km north of the swell, showed that the youngest Jurassic rocks are absent due to pre-Albian folding and erosion (Terris & Bullerwell 1965).

Before interpreting the deposits and constructing an environmental model, the problem of time correlation of the beds has to be discussed. The ammonites of the Sandy Upper Kimmeridge Clay and Portland Group are not sufficiently well-known for a refined correlation to be developed within the Basin. They show no more than that the highest beds over the area contain different ammonites from the lower ones, but this at least rules out the possibility of any gross diachronism.

The Beds not only thin over the swell area and towards the western margin but the lithofacies also changes, indicating deposition in shallower water. This is more noticeable for the shallow facies of the Portland Limestone Formation when the swell area was the region of slowest accumulation of limestones but of thickest development of oolites. The Basin was thus not only one of varying subsidence rate but of varying water depth.

With any model of a transgression or regression, beds of the same facies are necessarily diachronous in the direction of depositional dip. This must also apply to a swell area where the facies form encircling belts. The Exogyra Beds, for example, vary considerably in thickness and sediment-type from west to east Dorset but it is felt that the deposits within each major group of Beds were laid down during essentially the same period of time and major bedding planes approximate to time planes. The total distance from east to west outcrops is only 33km and from NE to SW only 15km. Over these distances correlation by "events" is possible. This means that a short period of deepening of the water during an overall shallowing is reflected in the sediments whether on the swell or in the more rapidly subsiding areas.

Widespread deposits of nearly the same facies throughout, varying only in thickness, are thought more likely to have been formed in deeper water than those which rapidly change laterally due to the influence of the swell.

B. The Kimmeridge Clay

Although not the object of study in this thesis, the Kimmeridge Clay is briefly discussed in order to put the Portland Group into context.

The transition from Kimmeridge Clay through Sandy Upper Kimmeridge Beds to Portland Group and Purbeck Beds is probably the result of a world-wide overall regression due to eustatic fall in sea-level (Hallam 1969). In marginal regions deposition slowed or ceased in Upper Kimmeridge Clay times and several breaks are recorded from North France to Greenland and Russia (Arkell 1957). The appearance of silt and sand-grade quartz in clays above the laminated bituminous mudstones and subordinate thin dolomites of the Kimmeridge Clay is a basinal reflection of this regression. The Kimmeridge Clay mudstones were probably laid down in relatively deep (a few 100m) quiet water which was sometimes anaerobic and was comparatively far from land. Such conditions of deposition are similar to those postulated by Hallam for parts of the Lias of Europe (1967).

Within the uppermost part of the Kimmeridge Clay mudstones there is a line of calcareous nodules known as the rotunda-nodule bed, c.30m below the Sandy Upper Kimmeridge Beds in the East Basin. At Ringstead Bay, on the swell, this is obviously a condensed deposit containing phosphatised casts of ammonites and bivalves (Arkell 1947a). It represents a break in deposition when sediment failed to accumulate on the swell. In the marginal areas of the South Midlands and Bas Boulonnais the break apparently encompasses c.80m of sediment deposited in the East Basin of Dorset. Above the rotunda-nodule bed in the Isle of Purbeck there are 31m of mudstones with occasional limestone nodules, before coarser grained sediments appear.

C. The Sandy Upper Kimmeridge Beds and Upper Black Nore Beds (Fig. 33)

Including the Upper Black Nore Beds and Exogyra Beds, the maximum total thickness in the East Basin is c.48m. These thin westwards to c.17m at Ringstead Bay and thicken again to c.28m in the West Basin. The thickness on the Isle of Portland is not known but is estimated to be c.25m. The Sandy Upper Kimmeridge Beds were not examined in detail except in the far west, but appear to be the same facies as the overlying Upper Black Nore Beds.

The dominant "background" sediment in the East Basin is a mixture of clay, calcite, dolomite and 10-40% v.f. quartz sand. On the swell at Ringstead Bay and on its flank at Portland the proportion of sand is usually much less, the sediment being mainly a mixture of clay and dolomite. In the far west part of the West Basin the beds are glauconitic and contain an appreciable proportion of fine to coarse quartz sand as well as clay and dolomite (Fig. 26).

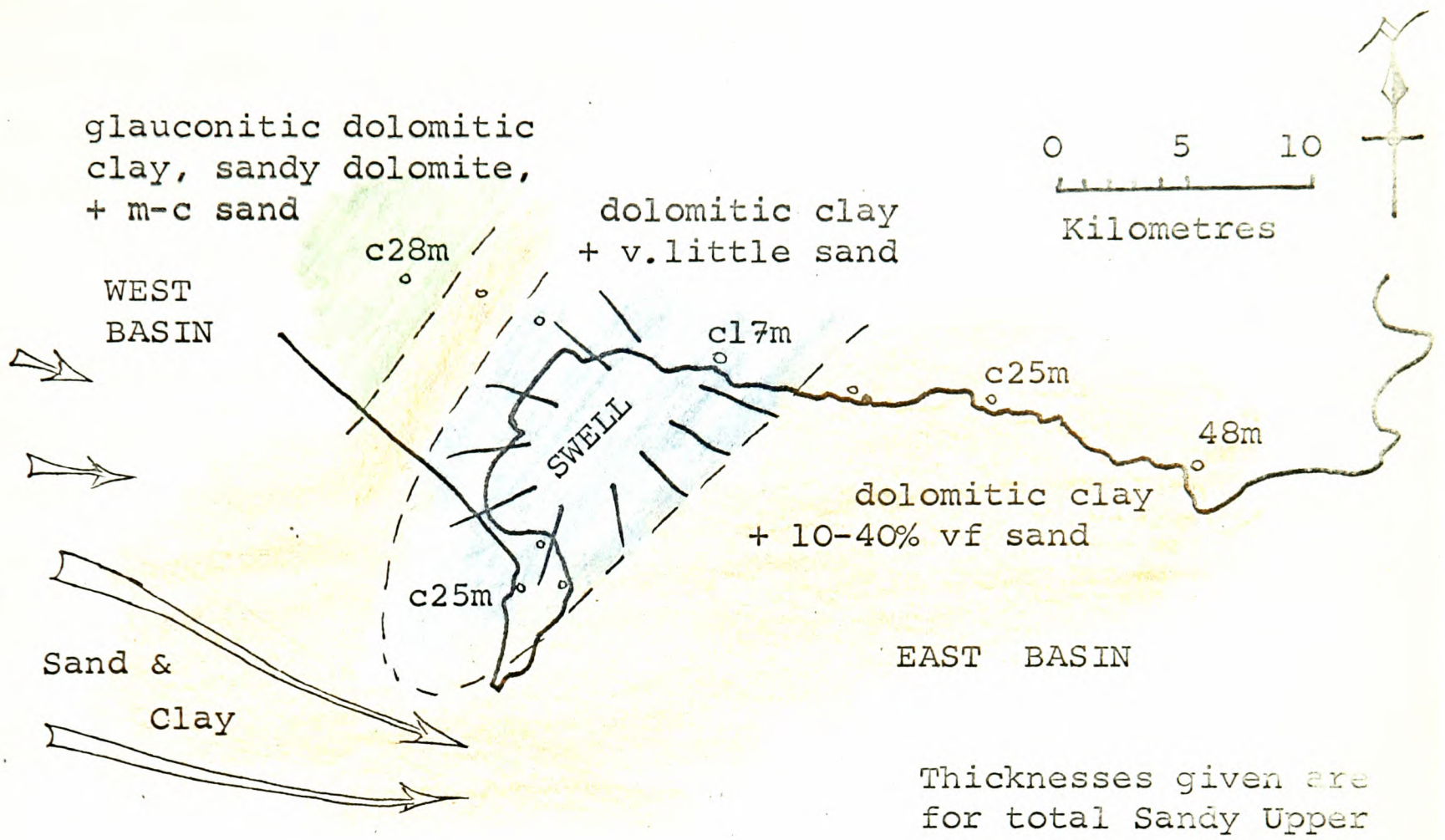
D. The Exogyra Beds

The maximum thickness of these beds is in the East Basin where they thin westwards from 7.3m at St. Alban's Head to 6.7m at Gad Cliff. Over the swell from the Central Area to Ringstead they thin from c.5m to only 3m and on Portland they are 3-4m thick, showing that the swell extended at this time to the south. In the West Basin the Exogyra Beds thicken to 5.7m. The distribution of the various types of sediment is shown in Fig. 34 .

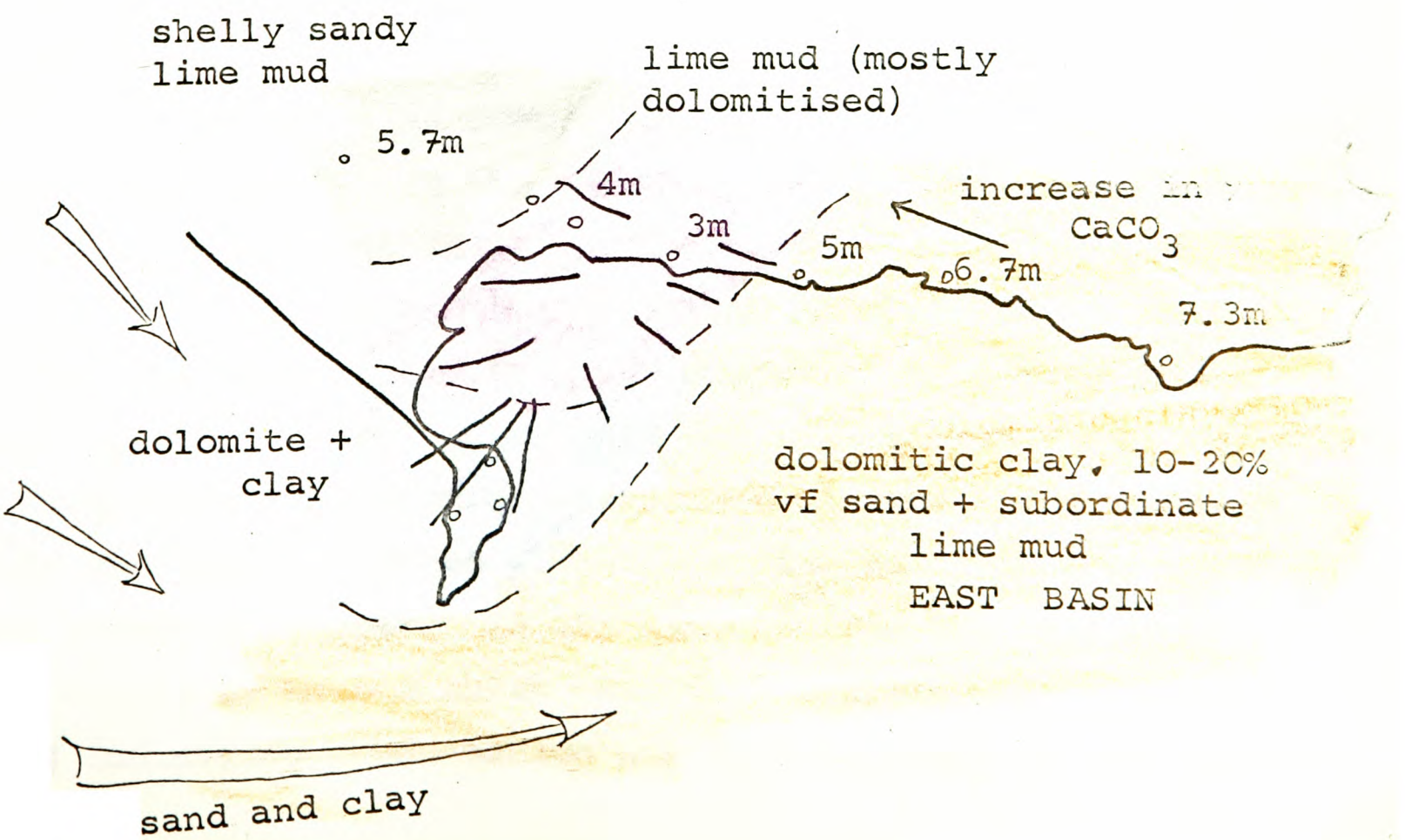
The main, poorly-fossiliferous, "background" sediment in the East Basin is a mixture of clay, dolomite and v.f. quartz sand but there are also minor horizons of relatively pure fine-grained limestones with occasional infaunal bivalves. Exogyra shell beds occur at the base of these limestones and they appear to have been deposited in quiet relatively deep water without being disturbed by currents or waves.

In the Central Area the proportion of limestone increases and over the swell at Ringstead terrigenous material was excluded altogether. The beds were deposited as pure limestones but are

(1) GENERALISED FACIES DISTRIBUTION DURING THE UPPER PART OF THE SANDY UPPER KIMMERIDGE BEDS AND UPPER BLACK NORE BEDS



(2) GENERALISED FACIES DISTRIBUTION DURING THE DEPOSITION OF THE EXOGYRA BEDS FIG 34



now composed mostly of dolomite (Fig.24). Exogyra were concentrated by slow deposition and the shell beds show signs of current disturbance, indicative of the shallower water. The swell's influence at this time extended to Portland where the beds are composed of argillaceous dolomite and the matrix of the concentrated shells has been dolomitised (Plate 7). Here the shell-beds also appear current disturbed (Plate 23).

In the West Basin the Exogyra Beds are composed of micrite and a slightly more diverse fauna appears. Serpulids, trigoniids and sponge spicules are common at certain horizons and v.f. quartz sand becomes noticeable, reaching 40% at some levels in the far western exposures (Fig. 29). The facies in this area is similar to parts of the Portland Limestone Formation which was deposited in shallow water away from the influx of terrigenous material.

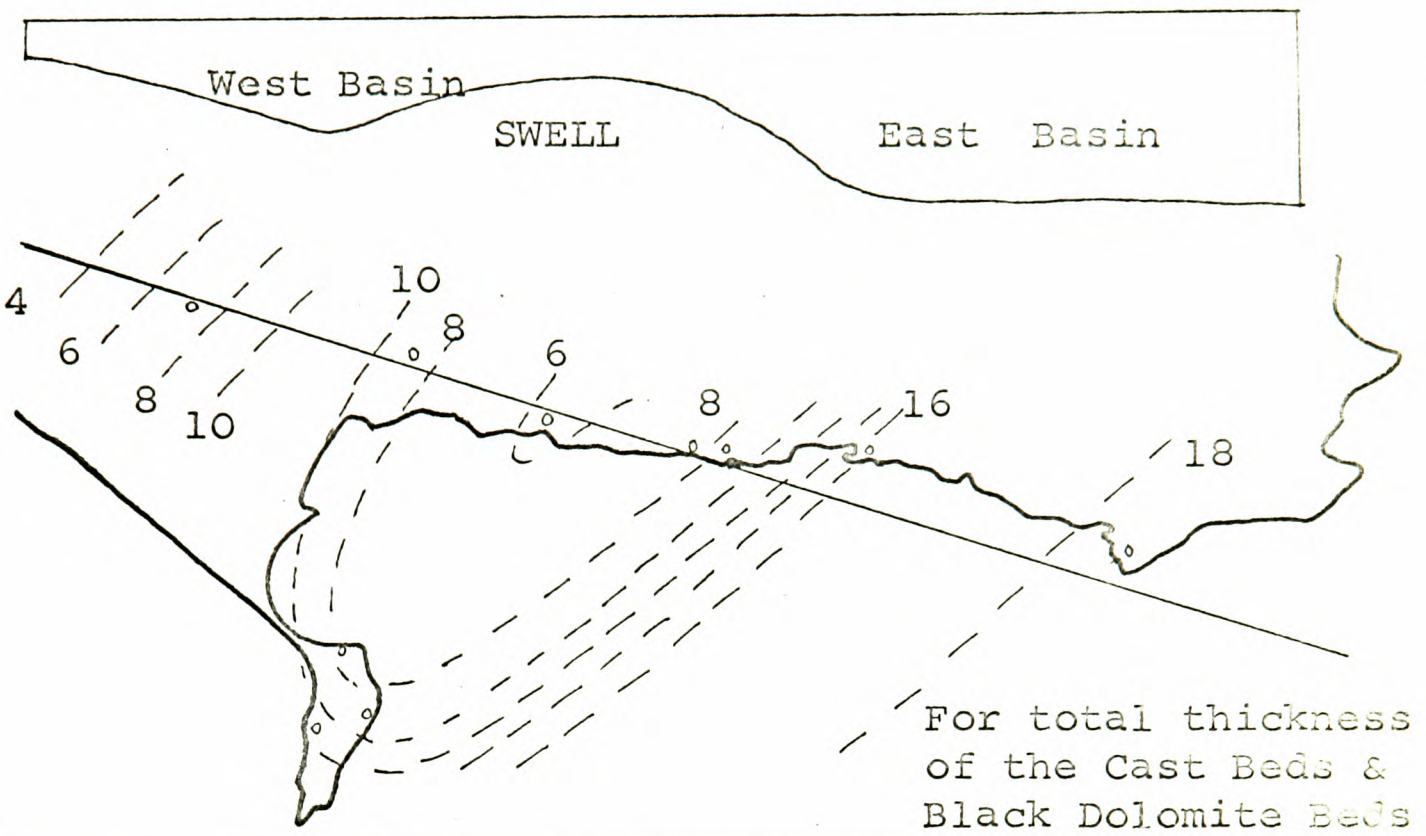
E. The Cast Beds and Black Dolomite Beds

These two groups of beds are remarkably widespread and uniform in facies although they vary in thickness (Fig. 35). This indicates that they were deposited in deeper water than were the Exogyra Beds and marks the second phase of sedimentation. After an initial transgression the sea progressively shallowed and carbonate sediments were laid down, culminating in deposition of the lower strata of the Portland Limestone Formation.

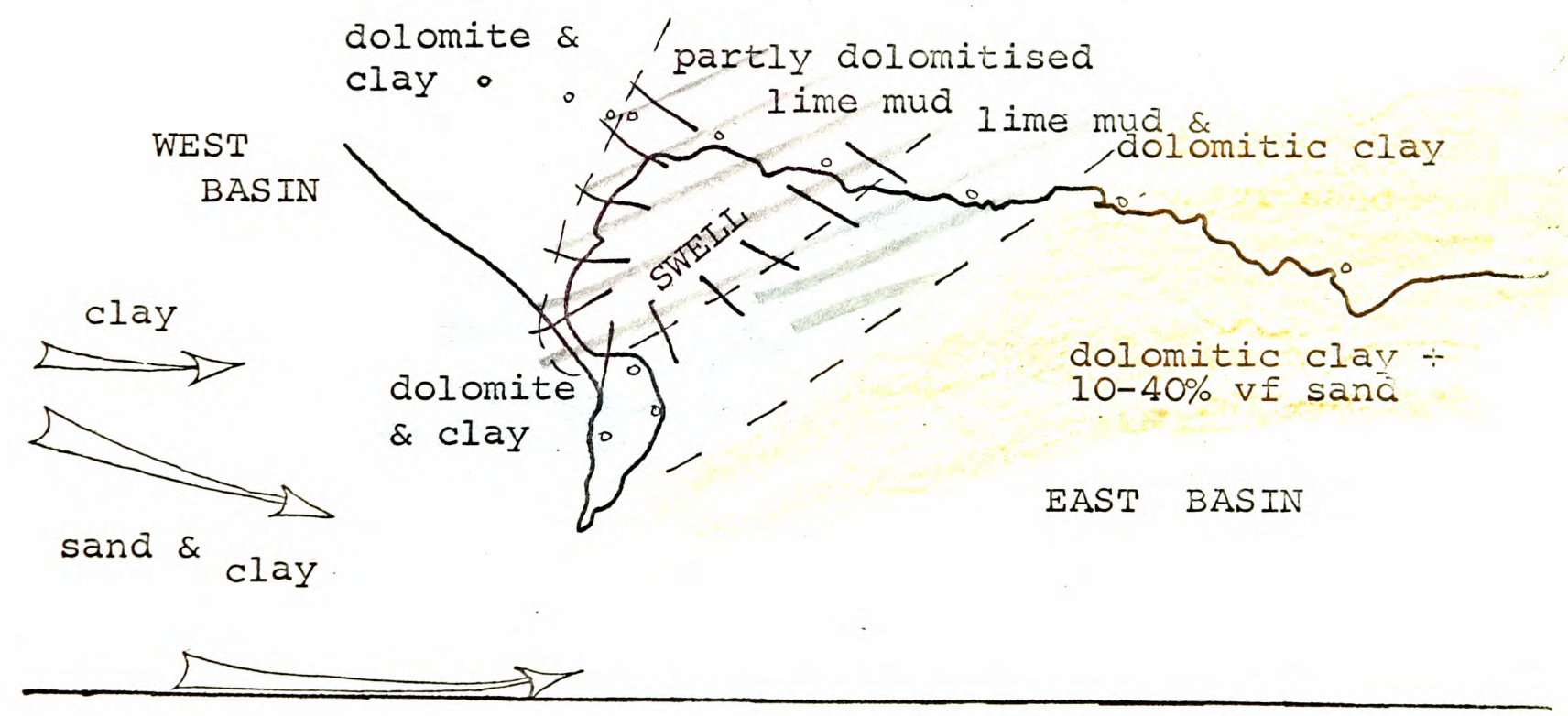
In the East Basin the Cast Beds plus Black Dolomite Beds thin westwards from 18.5m to 16.1m; near the swell in the Central Area they thin westwards from 9.5-6.15m and at Ringstead Bay they are only 5.9m thick. In the West Basin they thicken to 9.5m and thin again to at least 7m in the far west. On the Isle of Portland they thicken southwards from 7.5 to 11.5m.

The Cast Beds of the East Basin consist of 4-6.5m of a mixture of clay, dolomite, calcite and v.f. quartz sand, alternating with thin nodular beds of fossiliferous micrite. The proportion of clay and sand increases slightly to the west, in the direction of the source of supply. In the Central Area the Cast Beds are only a couple of metres thick but still contain many limestone nodules indicating condensation due to a decrease in the amount

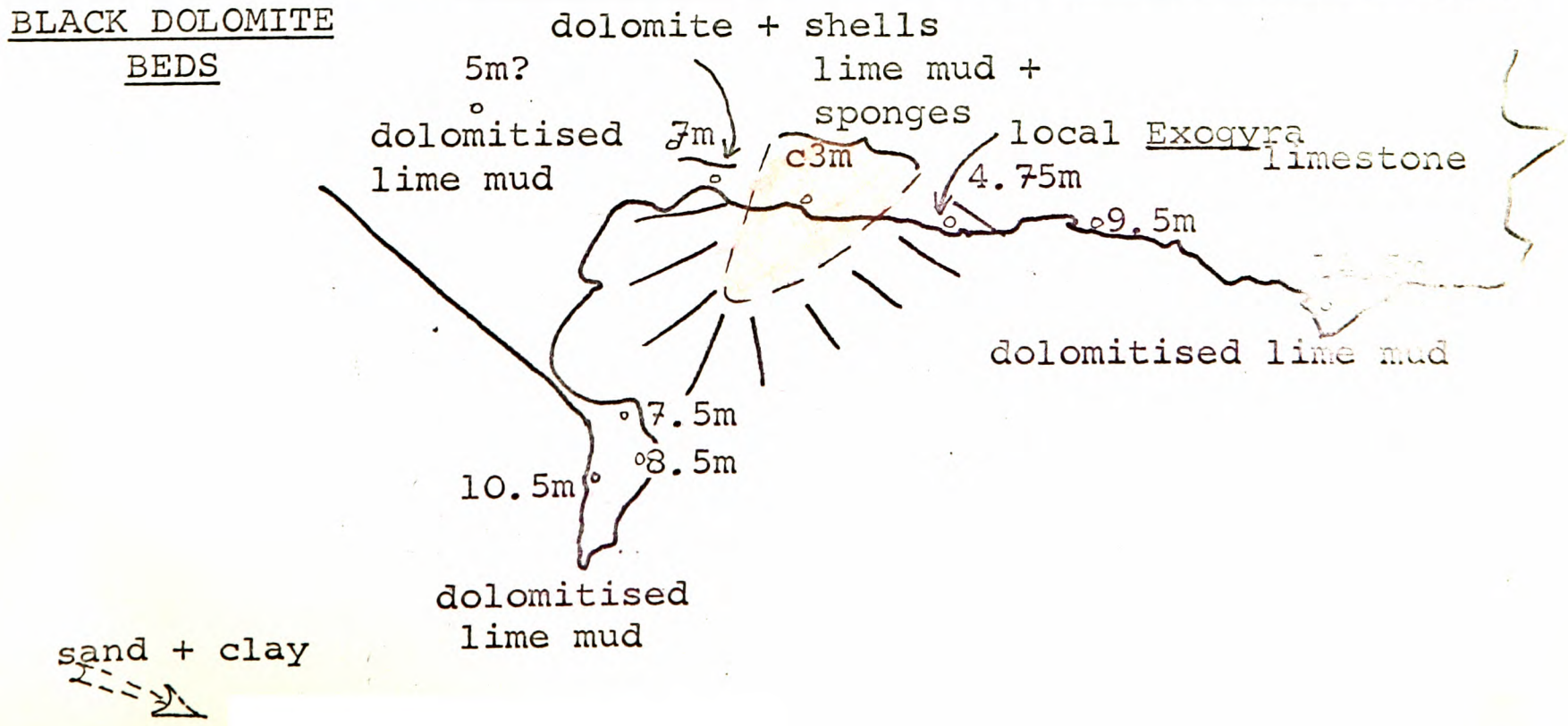
ISOPACHYTE MAP & GENERAL FACIES DISTRIBUTION DURING DEPOSITION OF THE CAST BEDS AND BLACK DOLOMITE BEDS FIG 35



CAST BEDS



BLACK DOLOMITE BEDS



of terrigenous material and to slow subsidence.

The Black Dolomite Beds of the East and Central Area are devoid of body fossils apart from ammonites and are identical in facies except for the unique Exogyra development at Stair Hole (Fig.20). They are virtually free of clay and quartz and mark the general end of terrigenous deposition in the Portland Group of Dorset.

Where thinnest, at Ringstead, the Cast Beds and Black Dolomite Beds are indivisible (Fig.27) indicating shallowing on the swell to such an extent that clay deposition was eliminated. The original lime mud of the Black Dolomite Beds is only partly dolomitised and the upper part is a limestone rich in Rhaxella sponge-spicules - a facies common in the Portland Limestone Formation above. The Cast Beds and Black Dolomite Beds are distinguishable again in the West Basin and on Portland (Fig.31). The facies of the Black Dolomite Beds at the far western exposure is identical to that in the far east of Dorset, which indicates that the water depth was greater than that over the swell at the same time.

These beds are the highest strata of the Portland Sand Formation and are succeeded in the East Basin by sponge-spicule rich micrite of the Portland Limestone Formation. In the West Basin and on the Isle of Portland the Black Dolomite Beds pass up into a clay which is thought to be equivalent to the limestones further east. This is the only terrigenous sediment after the Cast Beds and is significantly confined to the West Area. The clay is very thin at Ringstead and the swell must have been an effective barrier preventing it from being deposited further east.

7. Interpretation

A. Introduction

The basic model proposed for the deposition of the whole Portland Group in Dorset is a shallow marine carbonate shelf, marginal to the land, which sloped into deeper offshore water where terrigenous sediment accumulated, brought in by rivers draining land in the west. This model will be discussed in

more detail in the course of the interpretations.

The westerly source is suggested by the increase in the influence of land-derived sediment in that direction and by studies of the heavy mineral suites by Neaverson (1925) and Latter (1926). The Portland Sand Formation contains a characteristic assemblage of abundant fresh garnet, tourmaline, zircon, rutile, kyanite and ilmenite with common magnetite, staurolite, epidote, muscovite and sphene. This assemblage is most complete in the west and kyanite and staurolite are almost completely absent in the east. Both authors suggest derivation of this essentially metamorphic suite from the Armorican land areas of Brittany and S.W. England. However, it appears that the Devon and Cornwall crystalline rocks were still covered by Triassic strata and were not unroofed until Wealden times (Groves 1931 & Arkell 1933).

The heavy mineral assemblage from the Upper Lias sands are similar to those of the Portland Sand Formation and are markedly different from those from the Trias of South-west England. (Boswell 1924). Boswell concluded that the sands of the Lower Jurassic in Dorset were derived from the south and south-west, notably from rocks like those of West Brittany. It is probable therefore, that this was also the source area for the Upper Jurassic sands of Dorset. It is equally probable that the source included a now submerged land mass in the Western Approaches of the English Channel, as invoked by Allen (1969) for the Wealden of southern England and by Hallam (1971) for late Jurassic times.

The rivers brought in sand and clay whilst fine grained calcium carbonate drifted in to the Basin from off the shelf to the north-west. The fine-grained clastics and carbonate settled in quiet relatively deep water as fine laminations.

B. The Dolomite Problem

The presence of fine-grained euhedral and mosaic dolomite in beds which on general consideration are thought to have been laid down in relatively deep water poses a problem. Modern opinion favours dolomite formation in supratidal environments,

mainly because it is now known to occur there whereas records from the sea depths are unsatisfactory (Correns 1939). No supratidal features are present in the Portland Sand Formation and the position of the dolomitic sediments in the overall sequence together with the presence of marine bivalves, ammonites and rare brachiopods indicates a deeper water environment.

Teodorovich (1945) and Fairbridge (1957) have reviewed the problem and conclude that dolomitisation takes place by metasomatic replacement of calcium carbonate due to an increase in the magnesium-ion content of the water in contact with the sea bed. The Mg/Ca ratic is increased when pH is increased by lowering the proportion of dissolved carbon dioxide. In anaerobic environments, bacterial action can raise the pH by breaking down bicarbonates and by releasing ammonia compounds; the H_2S content of the sediment is high and the presence of bituminous hydrocarbons seems to promote dolomitisation. Calcite with up to 30% magnesium carbonate in solid solution is fixed on a large-scale by organisms in warm shallow-water marine environments and fine-grained high-Mg calcite breaks down to low-Mg calcite releasing magnesium carbonate. Warm water promotes this reaction and decreases the solubility of carbon dioxide, which in turn raises the pH.

An increase of pH to 9 or 10 precipitates magnesium and calcium carbonate together and, in theory, this unstable association would dissociate and the excess Mg-ions would tend to recombine as dolomite even without added temperature or pressure. A moderately deep water decay environment with high alkalinity, receiving organic calcium carbonate suspended in warm water would thus appear to be a favourable situation for penecontemporaneous dolomitisation.

Adams & Rhodes (1960) propose a model in which the Permian dolomite in the Midland Basin of Texas formed by a process of "seepage refluxion". They envisage evaporation of warm shallow water on a gently sloping shelf restricted by some form of barrier. Slightly concentrated warm sea water flowed down a slope into deeper, basinal water in which silts and shales were deposited. Warm heavy brines sunk to the lowest closed depressions and were covered by a blanket of lighter water. The postulated

pH was greater than 9 and redox potentials were nearly neutral; CO_2, Ca-ions and O_2 were abnormally low and the concentration of Mg was high. The pores in the aragonite and high-Mg calcite lime muds were capillary sized and fine grained dolomite occupies the zones in which lithographic limestones usually formed on the Permian open shelves.

Schmalz (1969) elaborated this idea of Adams & Rhodes and proposed a general genetic model of deep water evaporite deposition. Four necessary conditions are:- a suitable climate for evaporation on the shelf; an enclosed or semi-restricted basin in which brines can be accomodated; intermittent or continuous supply of sea water must enter; the basin must subside. He concludes that the depth of the sill is not critical except that it should be substantially less than the basin, although the importance of sill depth decreases as the area of the basin increases.

In the formative stage, calcium carbonate is precipitated when evaporation starts and is exhausted before much calcium sulphate is deposited. At this stage the sea is well oxygenated throughout with a normal marine nectonic and benthic fauna. As evaporation continues and heavier brine displaces that from the basin floor a euxinic phase starts and the bottom water stagnates, oxygen is depleted and a decay environment sets in. Nectonic fauna still inhabit the surface water but the benthos is anaerobic and reducing conditions occur, possibly with free H_2S. (This is opposite to the Black Sea situation where a freshwater wedge, due to evaporation being less than the run off and precipitation, prevents ventilation of the deep parts.)

With Schmalz's model, if evaporation continues, the marginal surface water gets concentrated and gypsum is precipitated but is re-dissolved before reaching the basin floor; fauna is absent or sparse at all levels. The basin will be occupied for long periods of time by brines depleted in calcium ions relative to magnesium ions and this results in dolomitisation of precipitated primary carbonate minerals.

The model of reflux dolomitisation is attractive when the

Portland Group and Lower Purbeck Beds are considered together. The basal Purbeck Beds are rich in calcium sulphate minerals which appear to be very shallow and supratidal in origin (West 1964 Shearman 1966), but they are anomalous when compared with recent sabhka deposits in that dolomite is absent. Precipitation of $CaSO_4$ would increase the Mg/Ca ratio without altering the proportion of carbonate ions and warm magnesium-rich sea water could have flowed off the shallow carbonate shelf, on which the facies of the Portland Limestone Formation were deposited, into the deeper basinal waters in which the sediments of the Portland Sand Formation were laid down. The swells (Dorset and Portsdown) could have acted as barriers to circulation of water but probably the depth alone was enough.

The carbonate shelf was sufficiently shallow for aeration of the water and for a moderately diverse molluscan fauna to flourish, but the scarcity or absence of stenohaline organisms such as corals, brachiopods, crinoids, echinoderms and belemnites on the shelf is a reflection of the slightly abnormal composition of the sea.

It is postulated, therefore, that during Portland Group times in Dorset there was a "critical level" in the sea below which oxygen was low, the pH of the water in the bottom sediment was high, conditions were stagnant and dolomitisation of $CaCO_3$ took place within the sea bed. Above this level normal calcium carbonate deposition took place. The"critical level" probably fluctuated considerably due to the interaction of the influence of the swell on local water depth and the overall changes in sea-level through time. For want of a more satisfactory model, the following interpretations are given with presence of a critical level in mind. (The dedolomitisation nodules and the rare occurrence of celestite is discussed in the appendix.) See Fig 36.

C. Environmental History

The overall change from the Kimmeridge Clay to the Purbeck Beds is a regressive sequence but minor deepening of the sea occurred and sedimentation occurred in a series of shallowing

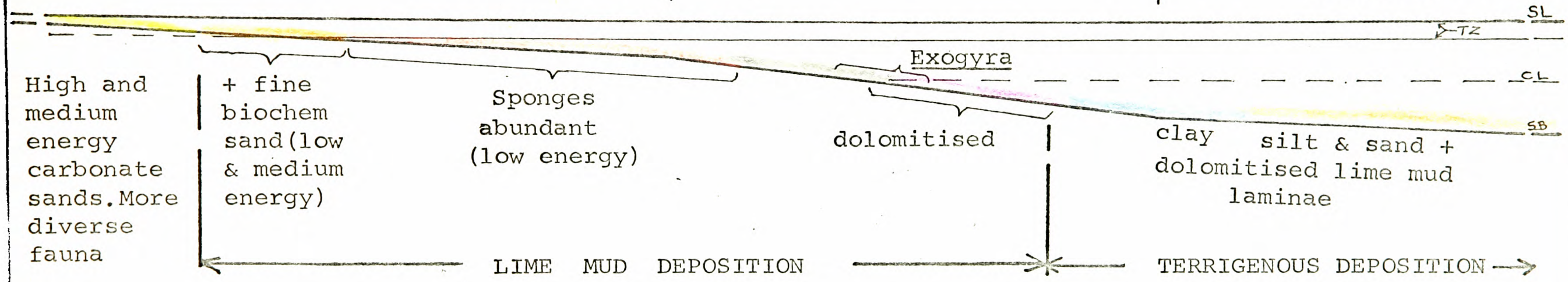
PORTLAND SAND FORMATION

Portland Limestone Formation

Shallow water Carbonate Shelf (generally well oxygenated)

Deeper Shelf and Slope (transitional zone)

Relatively Deep Basin (generally anaerobic sea bed)



High and medium energy carbonate sands. More diverse fauna

+ fine biochem sand (low & medium energy)

Sponges abundant (low energy)

dolomitised

clay silt & sand + dolomitised lime mud laminae

LIME MUD DEPOSITION

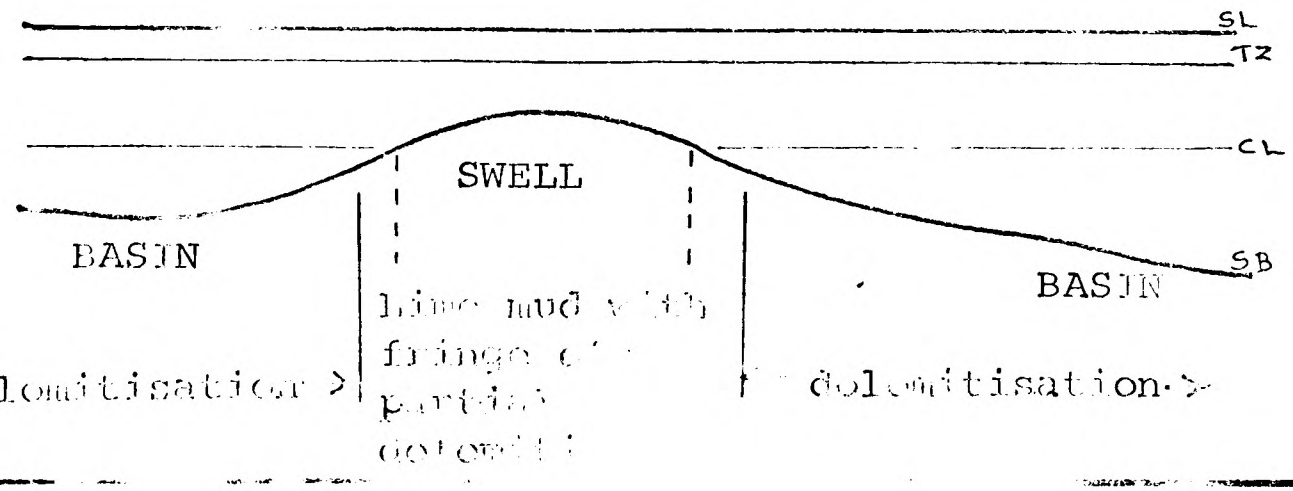
TERRIGENOUS DEPOSITION

SL= Sea level

TZ= Turbulent zone

CL= Critical level

SB= Sea bed



Exaggerated figure to show the influence of the swell on depth of water and hence on dolomitisation

GENERALISED MODEL FOR ENVIRONMENTS OF DEPOSITION OF THE PORTLAND GROUP IN DORSET (vertical scale exaggerated) FIG 35

phases, such as that culminating in the deposition of the Exogyra Beds. Minor changes in sea level took place during these phases producing cyclic deposition, best seen in the Exogyra Beds.

When sea level is lowered the stream power of rivers entering the sea is diminished and less terrigenous material is transported far from the land. This may explain the change from clastic deposition to carbonate deposition during the second phase when the Cast Beds and Black Dolomite Beds were laid down.

By following the facies distribution through time (Figs 33, 34, 35), the effect of changes of sea level and the presence of the swell can be seen. When the Upper Black Nore Beds were accumulating, water was deep and both basins received clay and sand, but the swell only clay. The whole Dorset Basin was below the critical level and dolomite formation ensued. In the west, coarse-grained sand was deposited and subsidence was sufficiently slow for glauconite to form, probably in shallower water than over the swell.

The sea level fell during the deposition of the Exogyra Beds and the influence of fine-grained shelf carbonate increased. Sand and clay deposition was pushed further south and east and on the swell margin at Portland only dolomitic clay accumulated. On the swell proper, virtually pure lime mud was laid down and dolomitised. In the West Basin, lime mud was deposited on the outer part of the carbonate shelf with a fauna indicating shallowing above the critical level. In the East Basin minor changes in sea-level were responsible for the presence of alternations of thin limestones, Exogyra beds and "background" sediment. Using the model invoked these must be shallowing cycles with the Exogyra-rich beds forming at the critical level and limestones just above. On the swell the proportion of calcium carbonate increased and deposition was slower, resulting in cycles becoming less distinct. In the West Basin the beds are totally limestone and any fluctuations in water depth are not obvious, except perhaps as variations in the amount of shell sand, pellets and quartz sand in the micrite matrix.

After the maximum concentration of Exogyra the water deepened and the Cast Beds were deposited below the critical

level except on the crest of the swell where the lime mud was only partially dolomitised. Sand bypassed the East Basin and swell showing that although the sea was deeper at this time, it was not as deep as during deposition of the Upper Black Nore Beds (Compare Figs 33,35).

As the overall regression continued, sand and clay failed to reach the Basins and dolomitised lime mud accumulated over the whole area except on the crest of the swell where the water was shallow enough to be above the critical level and for lime mud to accumulate and sponges to thrive. Marginally to this some bivalves managed to live, notably Exogyra locally in the Central Area. Dedolomitisation has taken place at certain levels in the Black Dolomite Beds and at Dungy Head celestite occurs (see appendix).

CHAPTER 4

THE PORTLAND LIMESTONE FORMATION OF DORSET

"It is very desirable that the examination of the Portland quarries should be repeated from time to time: for as the valuable stone lies deep in the series, and it is necessary, for the purpose of obtaining it, to remove the whole of the incumbent matter, the features described in this paper are constantly undergoing a process of destruction; while, on the other hand, new facts are continually brought into view, which are lost if not observed at the moment. The greater part of the phaenomena described by my predecessors had thus disappeared when I visited the island, and a few hours might removed the fossils which I observed in the bed below the Cap. Geologists may assure themselves that the trouble of a journey to Portland will be most amply rewarded; since few places, it is probable, in the world, exhibit with such distinctness and in so small a space, phaenomena of more extraordinary interest, or of greater importance to theory."

Fitton 1836

1. General Introduction

The succession of limestones which lie above the dominantly terrigenous deposits of the Portland Sand Formation have long been known for their use as building stones. The highest beds, or "Freestones", in the Isles of Purbeck and Portland were highly prized for their strength and their resistance to weathering as demonstrated by their use in several of London's monumental buildings including St. Paul's Cathedral, the British Museum, King's College and Waterloo Bridge. More recently, the stone has been used for facing prefabricated concrete constructions and certain of the beds on Portland, previously rejected, are now used for decorative purposes. These polished slabs often display the structure of the limestone to perfection (Plate 6|) and such new buildings as part of Christchurch College, Oxford, afford excellent "exposures" of, for example, algal-oyster-bryozoan patch reefs.

The underlying cherty limestones were not exploited, except for the convict-built Portland Harbour breakwaters, but recently worked-out quarries in the Freestones on Portland have been excavated deep into these beds and the chert and limestone is crushed for roadstone and for making aggregate building blocks.

This fundamental division of the "Portland Stone" into "Freestone Series" and "Cherty Series" was not really considered in further detail until the summer of 1933 when Arkell spent three weeks examining the mainland outcrops. The results were published in 1935 and reprinted in 1947 (Arkell 1947a). The succession on Portland was studied by Gray (1861) and his details have not been improved on, in fact Arkell's account of Portland is dismal (Arkell 1947a, pages 121-2). House (1969) published a few sections of the "Cherty Series" on Portland but these are not discussed in any detail.

Arkell (1935) used the quarrymen's colloquial names for the divisions of the Freestones throughout Dorset and gave bed letters to the cherty limestones on the mainland. His figures are reproduced here for comparison with the detailed sections measured in the course of this study; his figure for the Isle of Purbeck is given

here as Fig. 44a.

The "Portland Stone" has been renamed as the Portland Limestone Formation and is defined in the western outcrops in a slightly different way to that of previous accounts. The "Freestone Series" is renamed the Freestone Beds and the "Cherty Series" is divided into the Lower Cherty Beds and the Upper Cherty Beds, using the top of Arkell's bed J' as the junction (Fig. 82). Arkell's bed letters are not used here because often they embrace large thicknesses of rock, also they are not always identifiable especially when traced from the Isle of Purbeck westwards. No system of numbering the beds is used here partly because this complicates nomenclature considerably but mainly because bedding planes are not always sufficiently continuous or distinct.

In order to remedy the lack of knowledge about this well-known, often visited but seldom discussed succession of limestones a total of 28 weeks of field work was spent examining every available outcrop. A total of 197 sections were measured (the great majority on the Isle of Portland) but of these only 78 are figured here although data from the others is included in detailed facies distribution maps for Portland. About 750 hand specimens were collected as well as many fossils including some of the large ammonites for which these beds are famous (the largest seen was 1.1m in diameter). Most of the rock samples were personally cut into thin sections and stained but some were only polished and a few stained acetate peels were also made.

The results of this labour are given first in a section on carbonate microfacies. These are then used to describe the successions in the same geographical divisions into East, Central and West Areas that were employed in the previous chapter. A synthesis is given at the end with interpretations.

2. Carbonate Microfacies

A. Introduction

"Carbonate rocks are so complex that it is usually necessary to make a thin section study in order to pigeon-hole a specimen properly." (Folk 1968.)

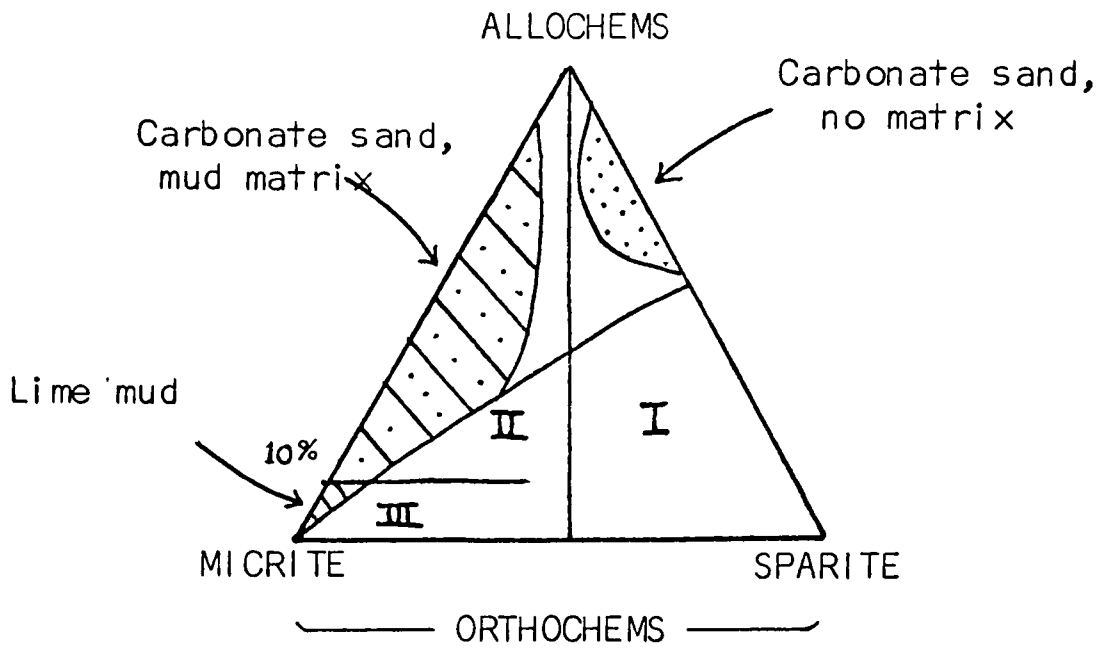
The aim of studying thin sections, polished surfaces and peels of limestones is to deduce what the original sediment was like at the time of deposition, by unravelling the effects of diagenesis, "that arch-thief of evidence, homogenising, changing, destroying, even before the grains are decently buried." (Bathurst, 1967). Several attempts have been made to classify carbonate sediments to give an indication of their mode of formation but only two classifications have received universal acceptance, namely those of Folk (1959, 1962, 1965) and Dunham (1962), See Fig. 37.

In describing a limestone Folk's terminology is restricted to the use of the "orthochems" micrite (microcrystalline calcite) and sparite (sparry calcite) for describing the interstitial matrix of the grains. These constituents are known as orthochems when they are formed within the basin of deposition or within the rock itself. However, interpretation of depositional texture requires careful interpretation of the origin of these fabrics and it is not always practical to categorise using only the Folk method. For example, the two orthochems can sometimes occur together within one thin section of a bioturbated sediment. The Dunham method was devised to indicate depositional texture but often this has to be interpreted subjectively from a study of the diagenetic textures present. Dunham's classification has the inherent implication that observed textures are original and does not allow for subsequent biogenic and diagenetic modification.

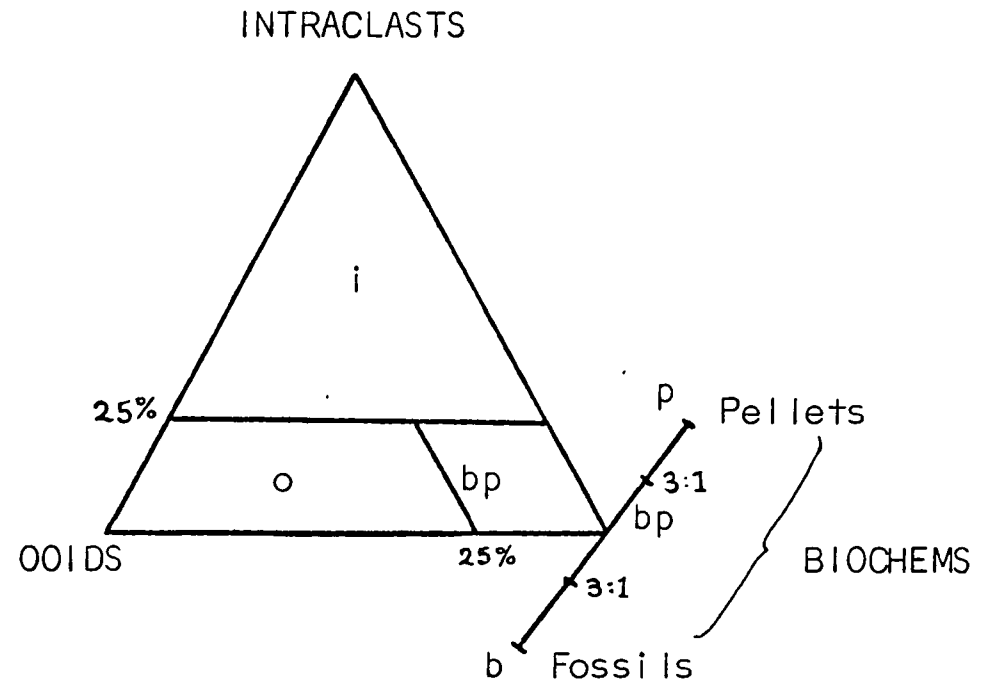
A description using only the Folk and Dunham classifications does not adequately supply the evidence with which to make interpretations. Although their schemes will be used and the shortcomings discussed in the following section on microfacies, the actual facies descriptions are of the original sediment. For example, a Folk "biomicrite", Dunham "packstone" is a muddy biochem

FIG 37

LIMESTONE CLASSIFICATIONS



BASIC TYPES OF FOLK (1962)



ALLOCHEM RATIOS (FOLK 1962)

BOUNDSTONE	Components self-bound	
GRAINSTONE	No mud	Grain Supported
PACKSTONE	Some mud	Grain Supported
WACKESTONE	> 10% allochems	Mud Supported
MUDSTONE	< 10% allochems	Mud Supported

TEXTURAL CLASSIFICATION OF DUNHAM (1962)

sand; "muddy" in this context is understood to be lime mud. It is felt that this provides a much more useful and more easily grasped idea of what the sediment was like than the terminology of Folk and Dunham alone.

Before undertaking a series of facies descriptions, based on a study of c.425 stained thin-sections, an account of the allochemical and orthochemical constituents is given. Folk divides allochems into Ooids, Intraclasts, Fossils and Pellets but here pellets are included with fossils as Biochems because often it is not possible to decide genetically whether a pelletal grain (peloid of McKee & Gutschick 1969) is part of a micritised fossil fragment or a genuine faecal pellet.

B. Components of the Facies

(i) Biochems. Fragments of the following:

(a) Molluscs

Bivalves with shells of calcite and aragonite mixed layers: The size can vary from whole, articulated valves, to very fine sand grade. The most common calcite bivalves in the Portland Limestone Formation are pectinids (foliated calcite/aragonite), isognomenids, limids (calcite foliated outer and cross-laminated inner layers) and ostreids (foliated calcite). In fine sand grade fragments all that is generally recognisable is a few lamellae or prisms of calcite. Algal and/or fungal borings are common (Plate 24), the degree of boring presumably being an indication of the length of time the fragment has been on the sea bed unburied. The process can go to completion and produce a pelletal grain of micrite (see section on micritisation, page 89).

Bivalves with aragonite shell in life: Most common in the Portland Limestone Formation are trigoniids, pleuromyoids and cardiids. The aragonite dissolved to leave a void which may remain or be filled by sparry calcite (Plate 31). Algal borings in the original shell produced a micrite envelope (Bathurst 1966) and this maintained a cavity for precipitation; however, sometimes compaction can collapse the void distorting the shape of the

original fragment and often completely flattening the envelope so that no cast can form. Casts can be found in all stages from complete preservation to complete loss of original shape. The latter case occurs mostly in the lime mud facies where lack of grain-supported allochems enables compaction to be more pronounced. Thus, there is some evidence for compaction in lime muds but the observations of Bathurst (1970) are substantiated in general; such compaction by collapse of micrite envelopes would account for a reduction of porosity by only a few percent. Such collapse in Upper Jurassic examples has already been described by Wilson (1967) and other workers have discussed this phenomenon (Bathurst 1966, Chave 1964). It is not thought that collapse and compaction have obliterated and eliminated the presence of fauna to any great extent and that the distribution of shell beds in lime mud facies is original, even in areas dominated by lime mud sedimentation (e.g. the West Mainland Area). Calcite casts of aragonitic shell fragments can be identified down to v.f. sand grade and sometimes a sediment originally composed of v.f. aragonitic shell sand with a mud matrix (packstone-wackestone) will have the appearance of a sparite-cemented rock on replacement. Unless careful microscopic observations are made false interpretations might result as to the original porosity, or ratio of sand to mud, of the sediment at time of deposition. Aragonitic shell-structure can be preserved by early stage silicification and there is abundant evidence to substantiate Wilson's conclusion (1966) that there was an early phase of "pre-aragonite solution silicification".

Gastropods: These are preserved in the same way as aragonitic bivalves, although micrite envelopes are not so obvious. Whole minute gastropods are seen in the mud facies as calcite casts, often with the chambers also secondarily filled. Fragments of gastropods are not easily recognised below about coarse sand grade.

(b) Echinoderms

Crinoids are not known in the Portland Group and fragments which are recognisably echinodermal in origin are echinoid and asterozoan-derived. For convenience these fragments will be

referred to as echinoid (with the proviso that asterozoan remains are probably included to a lesser extent.) They are recognisable down to v.f. sand grade and are often bored by algae but not so much as calcitic bivalve fragments. Syntaxial overgrowths are always found round the fragments and sometimes only careful examination reveals "ghost" echinoid structure in a patch of poikilitic calcite. Concentration of syntaxially-overgrown echinoid fragments produces a sparite-rich rock the origin of which could easily be misinterpreted if classified according to Folk. Syntaxial overgrowths absorb micrite and can alter the original texture from a fine echinoid-sandy lime mud (mud supported, Folk biomicrite) to an apparently coarsely crystalline sparite. This phenomenon is described and discussed by Bathurst (1958).

(c) Sponges

Rhaxella spicules: These are hollow chalcedonic kidney-shaped bodies ("reniform sterrasters") 60-100μ in diameter, usually recrystallised to microcystalline quartz and sometimes with a fill of lutecite (Plate 25). More commonly, and significantly, they are preserved as empty voids or as calcite casts (Plate 30). Often the cast is one crystal and several closely packed moulds may be filled by calcite in optical orientation.

Modern geodiid sponges have megasclere spicules as well as microscleres (including sterrasters) which pack an external fibrous cortex to form a stony armour. Rhaxella has similar sterrasters but associated megascleres have not been described. In the very fine-grained sponge-spicule lime mud facies of the lower part of the Upper Cherty Beds, however, very fine straight calcite casts of megascleres accompany the familiar kidney shaped microscleres. They are 1-1.5mm long and 40-50μ across and some appear to branch (trianes?). These other spicules comprise a high proportion of the sponge debris but, due to their shape, are probably far more susceptible to solution and less likely to be preserved as calcite casts except in micrite. Without this added, generally undetectable source of the silica, the sterrasters alone are an adequate source of the silica of the cherts in the sponge mud facies. With the added megasclere source there is no problem in deriving all the

silica from sponge spicules (Raisin 1903, Wilson 1966).

The sterrasters provide a biogenic source of very fine, very well sorted, allochemical silicate sand. This differs from terrigenous quartz sand in hydrodynamic properties because the spicules are hollow spheres (liquid filled?), thus having an overall lower density than quartz. Many of the "sandy limestones" of Arkell (1935, 1947a) are rich in Rhaxella, not quartz sand.

Pachastrella spicules: The spicules of this demosponge "genus" are hollow, siliceous tetraxons with rays 1-2mm long which are often seen weathering out on rock surfaces when concentrated. These spicules are also closely related to silicification and cherty horizons especially in the coarser grade carbonate facies. Calcite casts and empty voids occur in the same way as for Rhaxella but they seem less susceptible to solution of silica as both "genera" can occur together but only the latter as casts or voids.

(d) Serpulids

There are two common forms of serpulid represented; small Glomerula gordialis (diam 1-2mm) and a larger "Serpula sp." (2-4mm). Whole and fragmented tubes are abundant at certain horizons to such an extent as to be self-supporting. The shell has a characteristic calcite lamella structure and is usually distinguishable from calcite bivalve debris.

(e) Foraminifera

These are not abundant but sometimes whole calcareous forms are seen in thin sections.

(f) Ostracods

These are only common at the Portland-Purbeck transition and are not significant in the Portland Group. Whole valves are seen with brown walls and often with sparry calcite internal casts.

(g) Bryozoa

Fragments occur and are recognised by the characteristic pores. Whole bryozoa are recorded from the Basal Shell Bed

(Cox 1925) and encrusting forms bind together algae and oysters into small patch reefs in the upper part of the Portland Freestone Beds on Portland. Detrital material from the latter can vary in size from pebble to medium sand grade (Plate 60).

(h) Corals

Corals are rare in the Portland Group but specimens of Isastraea oblonga have been found in the upper part of the Cherty Beds of the Isle of Portland. The original aragonite is now represented by calcite but some are silicified. Fragments have not been recognised as allochem constituents.

(i) Algae

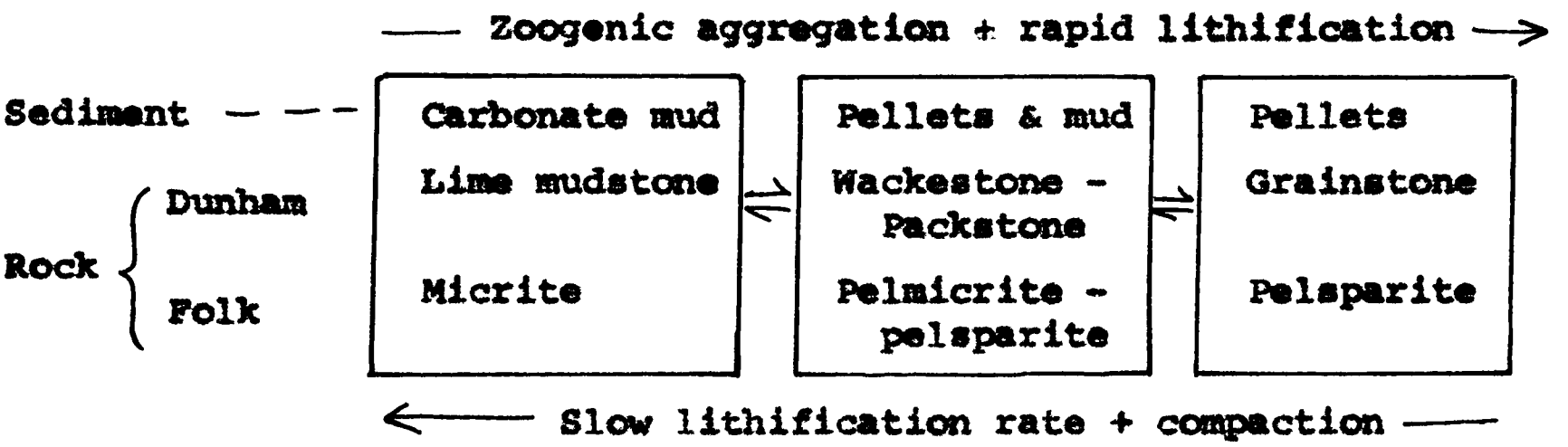
In contrast to the Purbeck Beds, Red Algae are the only rock-forming algae in the Portland Limestone Formation; these are Solenoporacean genera which occur as patch reefs in the Freestone Beds of the Isle of Portland. Detrital material from these colonies ranges from whole organisms down to medium sand grade. A common and important occurrence is as "pseudo-pisoliths" which are medium calcirudite in size (4-16mm). These are most abundant in the upper part of the Freestone Beds on Portland and to a lesser extent in the Top Grey Micrite Bed at the farthest east of the Isle of Purbeck

(j) Pellets

This group contains both true faecal pellets and micritised biochems. The former are round to oval and range from 50-250μ in diameter. Intensely micritised, well rounded, biochems such as algal or calcitic bivalve fragments are generally 100-250μ across. Faecal pellets are formed from mud by a process of zoogenic aggregation whereby filter-feeding invertebrates form "pseudofaeces" and sediment-eaters produce "true faeces". These can be detected in many cases because the pellets were still soft at the time of compaction and they have been distorted by other grains. Compaction can degrade a pellet sand into an apparently homogenous lime mud (from which it was organically derived) and its origin can only be discovered by finding pellets protected

from compaction by being inside serpulid tubes, under convex-up bivalve shells, inside gastropods or in algal mats ("umbrella effect").

Pellets that are compacted change the texture of the sediment from being grain-supported to being matrix-supported. A pelletal grain produced by micritisation is hard and could not be compacted in the same way.



From the above figure it is seen that the resulting rock depends on the time of lithification of the sediment. Some faecal pellets become hard soon after formation and grain-supported pellet sands are common in the Purbeck Beds. However, soft compacted pellets form structureless mud in most of the Portland Limestone Formation examples, and pellets can be seen only when they are sheltered from compaction. The latter examples are thought to have accumulated in low energy subtidal conditions, whereas certain Lower Purbeck examples formed in extremely shallow water which probably was agitated more often. These Purbeck pelletal sediments contain halite pseudomorphs, suggesting an intertidal to supratidal environment, perhaps more suitable for rapid hardening of faecal material.

It is salutary to note here that in interpreting Folk and/or Dunham's designations one might be tempted to assign relative energy indices to the three types. The energy involved is not of current strength but of animal activity and lithification-rate versus compaction. One could not say whether a pellet grainstone was transported to the site of deposition or whether a compacted lime mud was formed <u>in situ</u>. In the case of grain-supported pellets with a mud matrix this could form by a variety of ways;

for example, by animal activity with mud and pellets forming *in situ*, by either component being transported, and less likely, by both components being transported.

This latter discussion assumes that the pellets are faecal aggradations of lime mud. However, phytogenic degradation by algal boring produces apparently identical grains. Boring algae are seen to be very important in the destruction of calcite bivalve fragments and are responsible for the preservation of aragonite fragments as calcite casts due to the micrite envelope produced. Thus it is seen that pelletal grains can form in two different environments. They can indicate that mud was once present and this would suggest a lower energy of environment than when the sediment is pure sand. A mixture of skeletal and pellet sand could indicate either deposition in a high energy area (grain support, no mud) with the pelletal grains being transported as hardened faecal pellets or micritised skeletal grains; or deposition in a dominantly low energy environment with skeletal sand being occasionally brought in by currents, and pelletal grains being formed by animals eating mud. Faecal pellets are often naturally well sorted, so that on compaction a tightly packed sediment results. Any interstitial recrystallisation of remnant lime mud produces microsparite due to space restriction, and any pore space precipitation (in the former case) would give a similar effect. When the grain size is very fine sand it is extremely difficult to interpret how the sediment formed.

(ii) Ooids (Oolite grains, ooliths) (See discussion on terminology, Teichert 1970).

Ooids in the Portland Limestone Formation have an average grain size of 500μ in diameter (medium to coarse sand) and can have almost perfect, unaltered, concentric lamellae with uniaxial interference crosses under polarised light, or be completely micritised barely recognisable grains with pores due to boring animals, algae and secondary solution. Sometimes two ooids are stuck together by thin outer lamellae embracing both grains; this

is here considered as a composite ooid grain, as distinct from an oolitic intraclast which looks similar but is really a lump of oomicrite. Superficial ooids are common on quartz grains and skeletal fragments but the coat is nearly always micritised. Bathurst (1968) has summarised recent knowledge on the formation of ooids and concludes that the tangential orientation of oolitic aragonite is probably due to monolayer cleavage fragments, flattened in the plane containing the c-axis, attached perpendicular to the ooid face. Annual growth rate of Bahamaan ooids is about 70 unit cells but probably takes place in a few hours and the rest of the time is spent buried in a mucilage layer which binds grains at a depth of a few mm. Sorby's hypothesis (Sorby 1879) of a "snowball effect" is discounted by Bathurst on the evidence that the surface of ooids is polished indicating erosion, not deposition. Also it seems that an organic origin is not directly responsible as ooids will grow in the dark and the mucus found associated with them is not sticky. Ooid growth in the Bahamas has taken place by alternate deposition of oriented aragonite, and attack by boring algae but there is no evidence that the latter is necessary for ooid growth.

The rate of accretion of ooid lamellae is very slow, so the amount of agitation required to prevent cementation and to keep surfaces exposed to the supersaturated solution is very little. Rate of growth is suggested to be 30-180μ in 2000 years. The most important role of agitation is to maintain the high level of supersaturation at the ooid surface and not to allow diffusion rates to decrease growth rates. There does not seem to be a critical size required for agitation of ooids and they can form in water with virtually no agitation. The reason that ooids rarely get bigger than 500μ is that the rate of growth is balancedby loss of material by abrasion due to the increased impact forces of large grains.

Bathurst's important conclusion is that at the site of ooid formation grain agitation is high, but not continuous; there is a rapid loss of CO_2 and there are suitable nuclei available for precipitation.

Shearman et al (1970) studied ooids from the Trucial Coast, Persian Gulf, and found that they have layers of organic mucilage which are thought to act as adhesive surfaces and trap aragonite needles in the "snowball" way that Sorby suggested. Tangential orientation of the needles is thought to be the stable, natural attitude and repeated collision adds definition to the orientation of the needles. This does not, however, explain the fact that the Bahamian ooids are polished by abrasion, or that, although the lime mud available for "snowball accretion" is a heterogeneous mixture of aragonite, high and low magnesium calcite, the ooid is made of aragonite only. Organic mucilage may play a greater role in ooid formation in the Trucial Coast than in the Bahamas, but ooids can also grow in the dark so algal mucilage need not always play a role. (Donahue 1969). Organic mucilage and boring algae are both important in the micritisation of grains and Shearman et al conclude that loss of internal detail during diagenesis is due to destruction of organic mucilage layers by boring algae prior to replacement of the aragonite by calcite. (See section on Micritisation, page 89).

(iii) Intraclasts

As defined by Folk (1968) intraclasts "represent pieces of penecontemporaneous, usually weakly consolidated, carbonate sediment that have been torn up and redeposited by currents". They consist of any form of limestone clast but in the Portland Limestone Formation biomicrite and oomicrite fragments 250μ-5mm diameter are most common, although large eroded blocks of algal-oyster patch "reef" up to 40cms across are strictly intraclasts. The characteristic feature is erosion of the grains within the clast and thus many purely micrite clasts may be undetectable. Intraclasts can be micritised and only "ghost" remnant structures discernible. A common origin for modern intraclasts is the destruction by wave action of the margins where lime mud is accumulating and where allochems can be swept in and trapped by the mud. To produce intraclasts a certain degree of turbulence is required although it may be only in rare high energy bursts

and produced by storms over shallow water. The sea floor off the Berry Islands, Great Bahama Bank (Bathurst 1967) contains carbonate grains trapped for long periods in a subtidal mucilaginous mat and it has been suggested that microcrystalline aragonite may be precipitated in pore spaces (water is depleted in CO_2 by algal metabolism) producing the "grapestone aggregates" of Illing (1954), or "Bahamites". Erosion and abrasion of these aggregates would produce intraclasts. Erosion of the banks of tidal channels produces "armoured mud balls" which are subtidal intraclasts. (Jindrich 1969) Deductions about Portland Limestone Formation intraclasts will be made in context with facies.

(iv) Orthochems

Folk defines two fundamental orthochemical types - micrite and sparite.

Micrite is microcrystalline calcite mud, 1-4μ grain size, but can recrystallise (aggrading neomorphism) to microsparite, 8 to 20 or 25μ. It is sometimes difficult to distinguish between a micro-sparite, produced from lime mud from one produced by precipitation in small intergranular pore spaces. Micrite of grain size 1-2μ is found as mud matrix in some of the Portland Limestone facies.

The origin of lime mud has long been a bone of contention amongst carbonate researchers and there is an extensive literature upon the subject. The problem is whether the aragonite needles found in areas of modern carbonate mud accumulation are inorganic precipitates or algal material. Matthews (1966) studied the lime mud on a reef complex and in the back-reef lagoons off the British Honduras and decided that it is forming in situ in the lagoon mainly by breakdown of molluscs and foraminifera but that there is also an influx of coral and algal derived mud from the reef. In the Bahamas the mud is very different and both organic and inorganic origins have been postulated since. Drew (1914) first suggested bacterial production. Lipman (1924, 1929) said that Drew's idea would not work over such a large area; however, Lowenstam (1955) experimented and decided that bacterial breakdown of codiacean

algae provided a very important source. Lowenstam and Epstein (1957) made chemical studies (O^{16}/O^{18} ratios) but could not satisfactorily demonstrate an algal origin to the exclusion of inorganic precipitation. Cloud (1962) also used a chemical approach (on activity products) and decided that all the Bahamian Bank aragonites could theoretically be inorganic in origin. In the Persian Gulf Kinsman (1964) worked on strontium contents and decided that the mud was similar to inorganic precipitated aragonite. Clouds of aragonite needles have been observed in the Bahamas and Persian Gulf ("Whitings") but it is not conclusively known whether this is due to sudden inorganic precipitation or to disturbance of the sea floor mud by storms or fish shoals. Stockman et al (1967) estimated the annual production of aragonite mud by algae in Florida Bay and the nearshore part of the Florida Reef tract and concluded that Penicillus is the major contributor and could account for all the mud in the reef tract and for a third of that in N.E. Florida Bay, accumulated in the last 4,000-10,000 years. Other contributors include different algal species, molluscs, and corals broken by mechanical and biological means.

Having tried to keep this review as short as possible one can conclude by saying that we do not know much about modern lime mud formation and that diagenetic effects remove such clues as exist in the sediment at the time of formation. "We can only fall back on the simple truism that fine grained sediments accumulate in the less turbulent waters, and hope to glean some information from the association with other sediments of less recondite demeanour" (Bathurst 1967).

Sparite This is cement consisting of grains or crystals of non-ferroan calcite greater than 10μ, forming as a pore space precipitate and is best seen in the grain-supported medium and coarse carbonate sands of the Freestone Beds on Portland. Single sparite crystals fill Rhaxella moulds and micrite-enveloped moulds of fragments of aragonitic bivalves. Various textures have already been adequately described by Wilson (1967) and here the emphasis is more on environmental interpretations.

C. "Micritisation"

Purdy (1968) gives a useful and comprehensive discussion on "subsea diagenetic recrystallisation to cryptocrystalline calcium carbonate", (or "micritisation" of Bathurst 1966,) and the salient points are given here as being pertinent to a study of the Portland Limestone Formation.

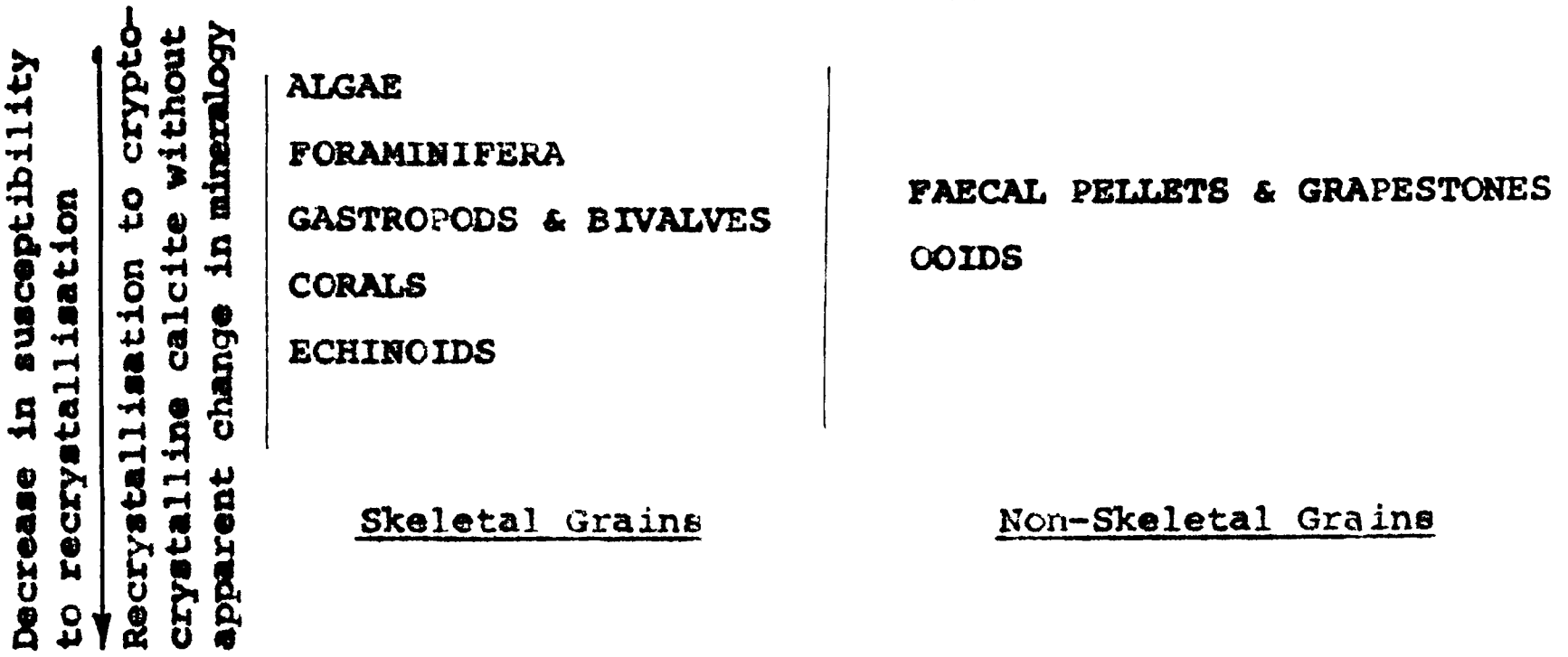
Of the allochems previously described many were originally deposited as aragonite; for example, some bivalves, gastropods, algae, corals, pellets, ooids and intraclasts, as well as much of the orthochemical lime mud. As has been briefly noted, these grains are often intensely micritised and similar modern day examples have been described from the Bahamas (Illing 1954), the Gulf of Batabono, Cuba (Daetwyler & Kidwell 1959), Campeche Bank, Mexico (Cann 1962), British Honduras (Pusey 1964), Baffin Bay, Texas (Dalrymple 1964), East Australia (Wolf 1965), Red Sea and Persian Gulf (Purdy 1968, (Shearman et al 1970).

Illing (1954) decided that micritised grains are "the fundamental unit in the formation of the vast spread of calcareous sand that covers the sea bottom on the Banks" (Bahamas). Purdy (1968) illustrates micritisation in Bahamian ooids, forams, algae, echinoid spines, intraclasts, algal mats, coral and mollusc fragments as well as in Mississippian and Eocene oolites. Further examples are here given from the Portland Limestone Formation of Dorset (Plates 32, 58).

When the carbonate of all the Bahamian allochems recrystallises there is no detectable change in mineralogy, only a change in the size and orientation of the calcium carbonate (be it aragonite, high or low Mg-calcite). There are apparent differences in susceptibility to recrystallisation in the skeletal grains and this is also true for the Upper Jurassic examples studied here. Echinoid grains are less micritised than bivalve grains, which are often so altered as to be barely recognisable and obviously contribute to the unidentifiable "pelletal" material. In the Bahamian grains the coralline algae and Halimeda are even more susceptible than bivalve fragments and it is probable that many of the micritised pelletal grains of the Portland carbonate facies

are algal in origin.

Sub-sea Diagenetic "Micritisation" Susceptibility Orders (Purdy 1968)



The recrystallisation process is rapid as C^{14} analyses by Pusey (1962) give a general order of magnitude of hundreds of years rather than thousands. The process is limited to the depositional interface and a few millimetres below, also it decreases with an increase in mud content of the sand. As to the origin of the micrite found, there is in modern examples some relationship with boring algae. This is also true for examples from the Portland Limestone Formation but the relationship is not a simple one because the algae leave tubular moulds which have to be filled. Bathurst (1966) has described and figured his ideas on the formation of "micrite envelopes" but is astute enough not to suggest that the processes he describes are necessarily the only ones or are even the most important on a general scale. Purdy (1968) compellingly suggests a relationship between micrite and organic matter, whether in the form of an organic matrix in skeletal grains, dispersed in faecal pellets or as algal inclusions in bored allochems. He suggests that this association is due to decomposition of organic matter by bacteria and/or fungi, and that certain bacterial reactions can precipitate calcium carbonate (Purdy 1963). Bacteria and/or small fungi have been found infesting boring algae in Bahamian ooids (Newell et al 1960) and it has been suggested that reaction with the grain, produced by decomposition

of organic matter, may simultaneously cause solution of host carbonate and replacement by micrite. The susceptibility order described can be explained in terms of differing organic matrices rather than chemical composition which is not reflected. The relationship to mud content of sand could be a result of decreased porespace for bacterial inhabitation and/or inhibiting diffusion rates of metabolic products and food.

The degree of micritisation is a reflection of rate of burial of the sediment, but also it is inhibited by the interstitial mud content. Thus, a slowly deposited mud-free ooid sand would be much more micritised than an equally slowly deposited oolitic lime mud. This would account for the exceptionally good preservation of ooids in the oomicrites in the topmost part of the Portland Freestone Beds in the Central and Isle of Portland Areas. The degree of micritisation, if purely algal, should be also a function of depth of the water due to light being needed for photosynthesis. No such relationship has been found by Friedman et al (1971) who conclude therefore that fungi also play a major role.

Shearman et al (1970) studied Trucial Coast ooids (Persian Gulf) and substantiate the findings of the above workers that there is an association of recrystallisation to cryptocrystalline calcite with the presence of blue-green algal borings (e.g. Entophysalis duesta in the Trucial Coast and Bahamas). The overall conclusion is that alteration is either a direct or indirect result of algal infestation. However, according to Shearman et al (1970) the alteration is not simply a matter of change in crystal fabric but also a complete redistribution of the organic mucilage. Shearman et al (1970) describe the organic matter as being a skin round ooids which acts as a surface for accretion, possibly in the way that Sorby (1879) first suggested, and that the recrystallisation involves a redistribution of this mucilage. Margolis & Rex (1971) studied Holocene Bahamian ooids with a scanning electron microscope and concluded that endolithic algae play neither an active nor passive role in their growth.

Thus, although it is still debatable whether organisms are

essential for the construction of ooid lamellae, it is generally agreed that they are responsible for their destruction. "In the face of such wholesale destruction of evidence the attitude of a geologist trying to reconstruct the depositional environments of ancient limestones must be one of profound humility." (Bathurst 1971).

D. Carbonate Micro-facies (See Fig. 38)

Facies 1. Lime mud

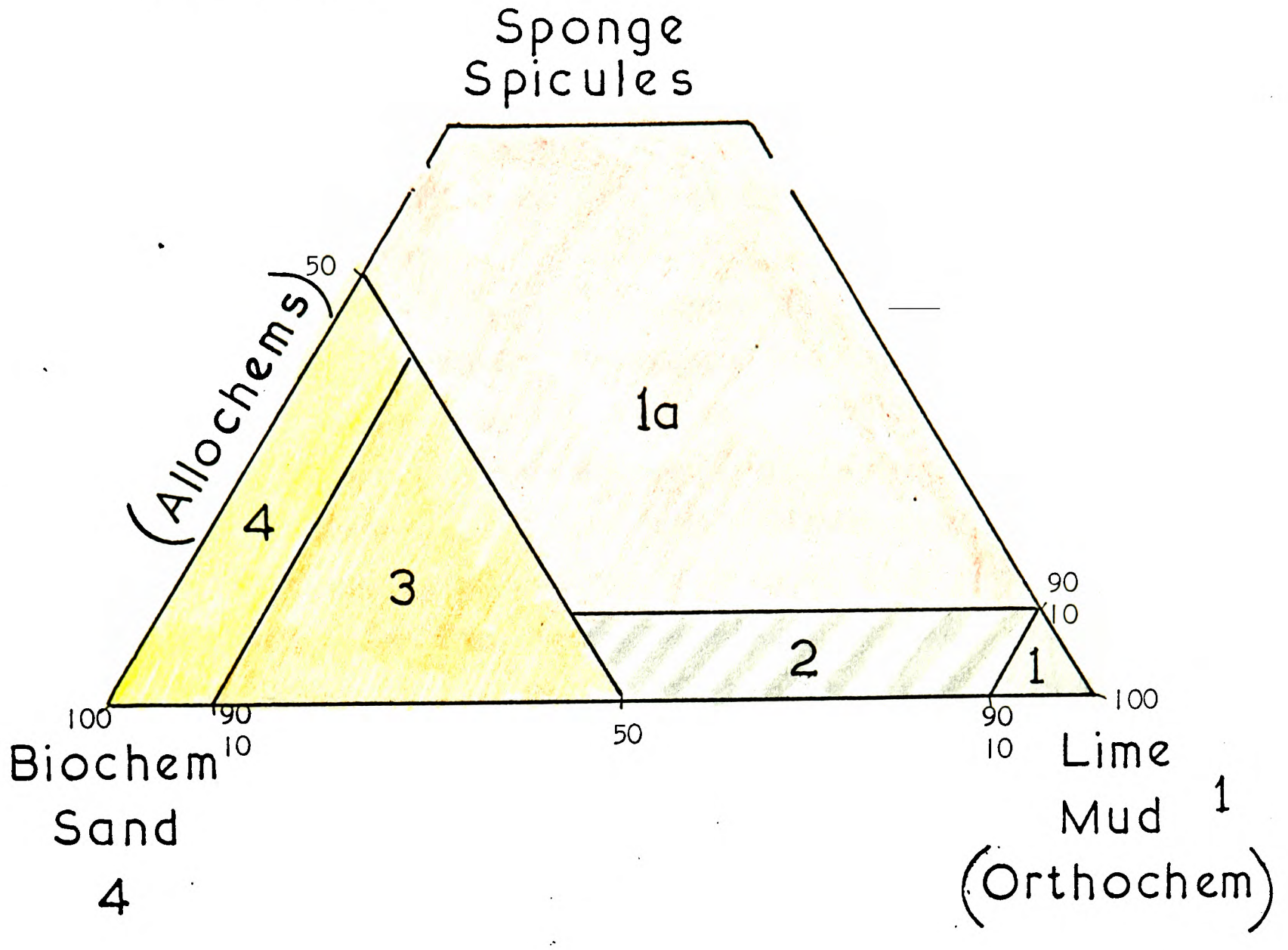
This contains less than 10% allochems, other than micropellets which are either faecal in origin or formed by aggregation of micrite (pellets are 30-100μ, mean grain size c. 50μ). The latter are detectable only when protected from compaction inside gastropod shells or by the umbrella effect of bivalve shells, and probably also by algal mats (Plate 29). When not compacted, a pelmicrite exists. Calcite casts of Rhaxella spicules comprise up to 10% but are rarely seen more than 1%; occasional silica Pachastrella spicules also occur. Quartz sand is rare and hardly ever seen within the area of one thin section. Fragments of echinoids, bivalves, gastropods, bryozoa, and algae have a mean size of 500μ, but occasional whole or broken bivalves exist; aragonitic bivalves are often preserved as collapsed micrite envelopes. Whole tiny gastropods (3-4mm) are sometimes common, as are crushed and whole ostracod valves in places (especially in the Top Grey Micrite Beds immediately below the Purbeck Beds). Laminations of micrite and pelmicrite, 0.5-2mm per lamina, occur at the transition between this facies and the basal Purbeck stromatolitic ostracod-rich limestones (Brown 1963, 1964, Pugh 1968), and were very probably algal mats.

Remarks:

Assuming that fine grained sediments generally accumulate in still water, the lime mud facies must reflect the existence of a generally low energy environment of deposition. Occasionally current depositional structures can be seen by the distribution of shell fragments, in spite of bioturbation, but this probably represents only rare occurences of high energy events. The presence of stromatolite laminations at the top of the succession and the

CARBONATE FACIES, PORTLAND LIMESTONE, FORMATION DORSET Fig 38

See also Fig 39



1 LIME MUD: Sediment contains <10% allochems. Lime Mudstone (Dunham) Transitional with facies 1a and 2.

1a SPONGE SPICULE LIME MUD: Mud-supported sediment contains >10% allochems of which >50% are sponge spicules (nearly always *Rhaxella*). Generally a Wackestone (Dunham). Transitional with facies 1 and 3.

2 SANDY (BIOCHEM) LIME MUD: Matrix 50-90% lime mud. Allochems poorly sorted, medium sand to coarse pebble grade. Packstone and Wackestone (Dunham). Transitional with facies 1 and 4.

3 MUDDY FINE BIOCHEM SAND: Well-sorted fine sand, grain-supported with mud matrix. Generally Packstone. Transitional between facies 1 and 4.

4 BIOCHEM SAND FACIES: Generally a grainstone (Dunham). See fig 39

occurrence of halite pseudomorphs in the basal Purbeck facies immediately overlying, suggests that at least the laminated part was formed in very shallow water indeed (very shallow subtidal to supratidal); the water depth at that particular time was probably less than a metre or two.

In the other beds of facies 1, especially in the West Mainland areas, the mud is interbedded with facies 1a, the latter containing >10% Rhaxella spicules.. Thus the lime mud probably accumulated laterally to the sponge mud as well as in shallower and deeper water. The dolomitised lime mud of the Portland Sand Formation is considered to be the deepest carbonate facies, offshore of the sponge mud facies. Lime mud, being deposited in quiet conditions can, therefore, occur in shallow sheltered areas and in deeper water away from the influence of coarser material derived from carbonate sand banks in shallow water. This will be dealt with more fully when the overall environmental model is discussed.

Occurrence:

Top Grey Micrite in Eastern Area and Ringstead (West Area), Cherty Micrite Beds in the West, Mainland, Areas and at certain horizons in the U. Cherty Beds and Freestone Beds on the Isle of Portland.

Facies 1a. Sponge Spicule Lime Mud (Rhaxella biomicrite, Wilson 1965) (Plate 30).

Essential allochems (>10% of sediment, >50% of allochems) are spicules of the sponge Rhaxella which comprise up to 70% of the sediment in places and often are the only allochems present. Pachastrella spicules can accompany Rhaxella and sometimes in the same proportion. The spicules are grain supported if highly concentrated (packstone). The allochemical component at the time of deposition was obviously very fine (very well sorted) biogenic silicate sand.

Accessory allochems (0-50% of total allochems) include well-sorted, fine grade biogenic carbonate sand which is the essential component of facies 3. Bivalve shells and shell beds sometimes occur but their distribution is best seen in the figures of sections.

very fine angular quartz sand comprises 1-5% of the sediment although pressure solution in places has concentrated insoluble residues and raised the quartz proportion to c.10%. The proportion of glauconite grains is generally 1-10% of the quartz content.

The orthochem component is lime mud in the form of micrite 1-2μ diameter, or sometimes aggraded to microsparite. It can have been biogenically "cycled" in the form of faecal pellets, and, if still soft, compacted to mud again.

Remarks:

Generally the sediment is mud supported although coherent pellets can be grain supported with interstitial mud (packstone). The higher the allochem proportion the less mud matrix there is, but grain support may be more apparent than real in the case of the Rhaxella spicule rich sediment because there is probably a thin mud layer between each spicule, which themselves would have had a low density, being hollow sphaeroids. The spicules are probably preserved in situ, the skeleton disintegrating very rapidly as does that of the modern Geoiid representatives. (pers. comm. R.E.H. Reid). Distribution would be only by bioturbation (Plate 50) and possibly rare current activity. The sponges on the sea floor might act as "baffles" in the same way as do modern sea-grasses in lime mud areas, trapping mud and slowing water currents, as suggested by Wilson (1968). These sponge muds are thought to be one of the lowest energy facies of all those represented in the Portland Limestone Formation. The well sorted fine biochem sand was probably swept in by occasional currents from a higher energy facies and was not formed in situ. The sediment is usually remarkably free of body fauna and the only sign of the presence of any bottom fauna other than the sponges is bioturbation. Occasionally ammonites occur but they are least common in this facies and this fact may be due to lack of a suitable food web.

Occurrence:

Purbeck East. Lower part of L. and U. Cherty Beds.

Purbeck West. Middle parts of L. Cherty beds and lower part of U. Cherty Beds.

Central Area. Lower part of L. Cherty Beds, and Middle part of

U. Cherty Beds.

West Mainland Area. Ringstead. Lower part of U. Cherty Beds.
West. Beds A, B & C of Cherty Micrite Beds.
West, Portland. Upper Cherty Beds and middle part of the Freestone Beds.

Facies 2. Sandy (biochem) Lime Mud (Plate 31)

This is a transitional facies between 1 and 4 and is characterised by having poorly sorted, coarse-grained skeletal material in a lime mud matrix. If bioturbation has not been too intense, signs of current accumulation are sometimes visible.

The allochem components are skeletal material and whole skeletons, typically of calcitic and aragonitic bivalves, echinoids, gastropods, bryozoa, algae, foraminifera, sponge spicules, ostracods and serpulids. Intraclasts occur, in places up to 1mm in diameter. Skeletal material, other than whole valves and shells of bivalves, range from medium sand to coarse pebble grade but the average is medium to coarse sand. Aragonitic bivalve fragments are particularly well preserved as micrite-enveloped casts, and echinoid and calcitic bivalve fragments often display good algal borings. Gastropods are often tiny turreted forms c. 1.5mm long with spar-fill at the apex. Whole forams have been seen (c.0.5mm) and some encrusting forms occur. A lot of the indeterminate micritised grains are probably algal in origin, but in places recognisable fragments of solenoporacean algae occur (in the Top Grey Micrite of the Eastern Area, Pbk 1, 2 - up to 2cms across. The lime mud can contain Rhaxella casts and Pachastrella as original siliceous spicules and as casts. Serpulid fragments are common.

Orthochems:

The allochems are both grain-supported with 50-90% interstitial lime mud (packstone) or purely mud-supported by micrite about 1μ size (wackestone). The micrite does not aggrade to microsparite and, where protected from compaction, the original lime mud is seen to have been pelletal (c.50μ diameter).

Remarks:

This facies is best interpreted in context but the salient feature is that it has a prolific diverse molluscan fauna in a lime mud matrix. Mostly this is found as laterally persistent thin shell-beds between facies 1 and 4 (Top Grey Micrite) and between terriginous clay or facies 1, and 1a (Basal Shell Bed; facies 1 in this context being the upper, dolomitised, part of the Portland Clay Beds on the Isle of Portland). The Top Grey Micrite probably accumulated on shallow, moderately sheltered water behind carbonate sand banks. Bioturbation has mixed the sediment but sometimes current depositional structures are visible indicating periodic high energy conditions in a generally low energy environment, based on the presence of the micrite. A lot of the shells were buried in situ but also a lot of the allochems were transported and rounded (algal fragments for example). Skeletal material was swept off the sand banks to the slightly deeper, quieter back-bank areas as well as forwards into deeper water. The Basal Shell Bed, also facies 2, is thought to have accumulated slowly, in deeper water than that just described and is a condensed multi-depositional accumulation between zones of terrigenous clay and sponge mud.

Occurrence:

Purbeck East. Shell Bed below and basal 0.5m of Top Grey Micrite. All of it at far east (Pbk 1 & 2).

Purbeck West. 0.5m below base of Top Grey Micrite.

West Mainland. Ringstead. Parts of Top Grey Micrite and Basal Shell Bed.

West and Portland. Basal Shell Bed. Some Shell Beds in upper part of the U. Cherty Beds on Portland.

Facies 3. Muddy Fine Biochem Sand

The essential allochems are well sorted fine-grained shell sand composed of fragments of calcitic and aragonitic shelled bivalves, echinoids, occasional siliceous Pachastrella spicules, and pelletal grains about 100μ, which may be micritised biochems

or genuine faecal pellets. Cherts in this facies are rich in Pachastrella spicules.

Accessory allochems are scattered Rhaxella spicules (usually as calcite casts), whole and fragmented bivalves, occasional gastropod and bryozoan fragments, and Serpulid "knots" (Glomerula gordialis and "Serpula" sp.) (Plate 39).

The orthochems are lime mud as micrite or microsparite. It is often difficult to discriminate between aggraded microsparite or fine precipitated sparite due to the small pore space available.

Remarks:

The fine skeletal sand is dominantly grain-supported (packstone) and well-sorted which suggests current deposition. There is an abundant fauna of bivalves, ammonites, serpulids and trace fossils which suggests that it was deposited in a more agitated environment than was the mud facies (1). One can only suggest a higher overall energy level than that for facies 1, but a lower level than that for the sand facies (4, 5 & 6).

Occurrence:

Purbeck East. Upper part of the L. Cherty Beds and in places, part of upper part of U. Cherty Beds.
Purbeck West. All parts of L. Cherty Beds which are not 1a, part of upper part of U. Cherty Beds.
Central. Parts of U. Cherty Beds. Top of L. Cherty Beds.
West. Ringstead. Thin bed at top of U. Cherty Beds.

Facies 4. Biochem Sand Facies (see Figs.38,39) With sub-facies a, b, & c. (Plate 32).

4a Relatively pure biochem sand

Essential allochems are medium grained bivalve and echinoid debris as well as unidentifiable micritised pellets which very probably include algal skeletal material.

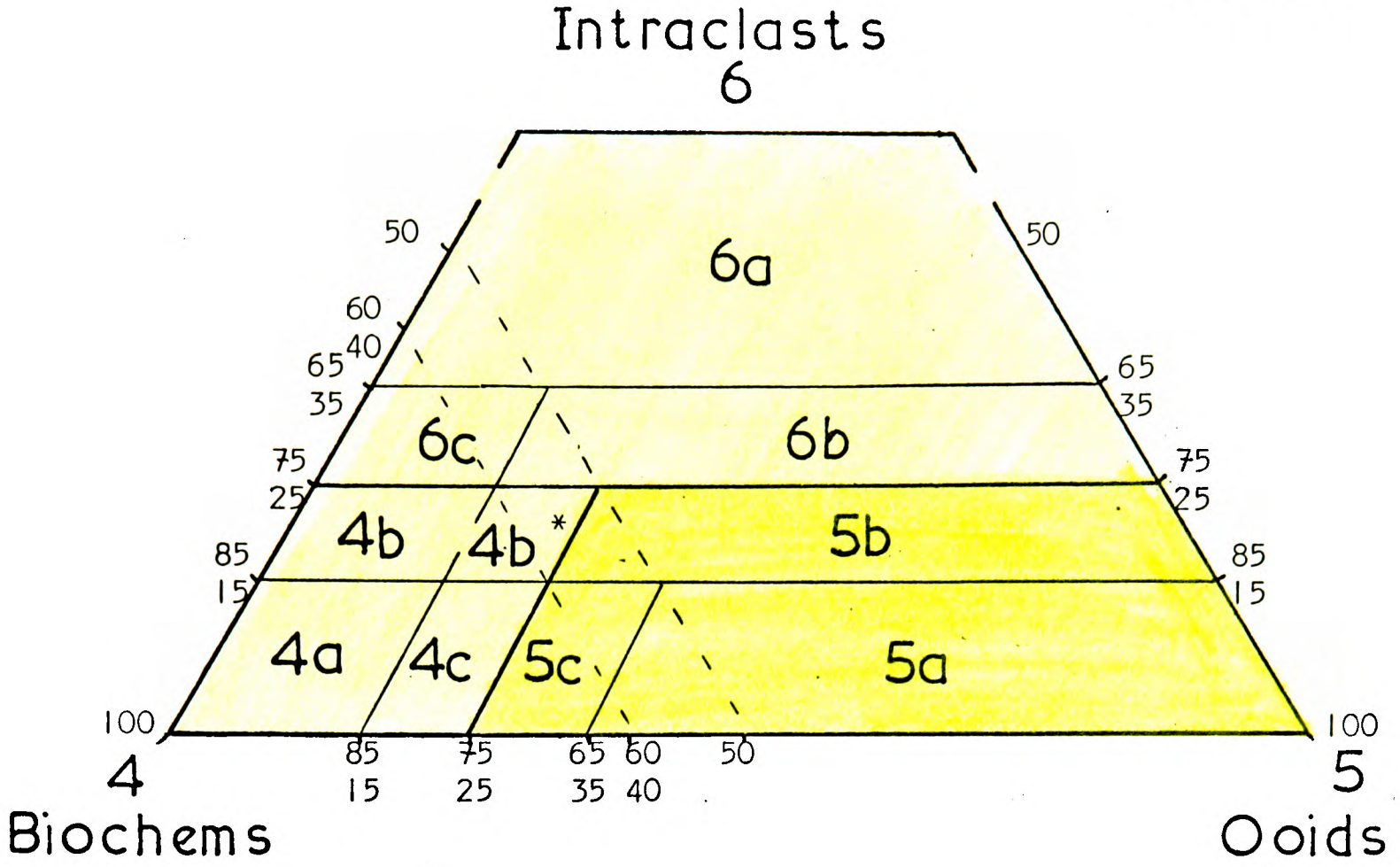
Accessory allochems are Pachastrella spicules which, when concentrated by current action or by minimal disintegration of the whole sponge, act as focal points for redistribution of silica and subsequent silicification produces cherts (Raisin 1903). The

FACIES & SUBFACIES OF CARBONATE SAND, PORTLAND LIMESTONE FORMATION,

DORSET. BASED ON ALLOCHEM RATIOS

Fig 39

(after Folk)



FACIES NO: SEDIMENT	ROCK	FOLK prefix to -SPARITE	INTRA-CLAST %	OOID %	BIO-CHEM %
4a Biochem sand	Biocalcarenite	BIO -	0-15	0-15	70-100
4b *Intraclast* ----	*Intraclastic* ----	*Intrabio* -	15-25	0-15*	60-85
4c OOID ----------	OOLITIC ----------	OOBIO -	0-15	15-25	60-85
5a OOID SAND	OOLITE	OO -	0-15	35-100	0-65
5b *Intraclast* ----	*Intraclastic* ----	*Intraoo* -	15-25	25-85	0-60
5c BIOCHEM -------	BIOCHEMICAL ----	BIOOO -	0-15	25-35	50-75
6a (Intraclast Sand)	(Intraclast calcarenite)	(Intra -)	35-100	0-65	0-65
6b (Ooid ----------)	(OOlitic --------)	(OOintra -)	25-35	65-75	0-60
6c Biochem -------	Biochemical ----	Bio intra -	25-35	0-15	50-75

4b* If 15-25% Ooids, add (ooid, oolitic & oo -) to names.

CAPITALS - Common
Italics - Less common
Ordinary type - Rare
(Brackets) - Not represented

NOTE

Order of importance of the three end-member allochems is:

INTRACLAST>OOIDS>BIOCHEMS.

quartz proportion is not more than about 1% and glauconite is about 10% of the quartz proportion. There are also rare intraclasts and small ooids (c.400μ).

Remarks:

This is the basic component of the two mixed biochem sand facies and is thought to have accumulated in an area of more rapid subsidence (or lower overall energy) than that in which intraclasts and ooids could be added, although the depositional structures are similar to those of the ooid areas. The lack of significant lime mud and the medium grain size indicates deposition in an area of stronger current action than that for facies 3 where the grains are fine and mud is an essential component. Assuming that these two facies are produced by deposition from currents moving from an area of skeletal fragmentation, then facies 4a is nearer to that area than 3.

Occurrence:

Purbeck East. Coastal sections. Part of Lower Freestone Beds.
Purbeck East. Inland, Pbk 20. Part of Lower Shelly Freestone Beds.
Purbeck East. Inland, Pbk 18. Part of Upper Shelly Freestone Beds.
Isle of Portland, e.g. WS6, 7 & 9. Part of upper and lower parts of Freestone Beds.

4b Intraclast Biochem sand

This contains admixed intraclasts and occasional ooids to form the subfacies varieties, intrabiosparite and oolitic intrabiosparite.

Intrabiosparites:- Allochems are generally poorly to moderately sorted, medium to coarse grained skeletal sand recognisable as derived from bivalves, echinoids, algae and gastropods as well as indeterminate micritised grains. Intraclasts range from 0.5 to 2mm in diameter and are biomicrite, oomicrite and composite micritised pelletal grains. Occasionally silica Pachastrella spicules occur, also the odd micritised ooid. Quartz sand is less than 1%, fine to medium grain, sometimes with a micritic superficial ooid coating.

Orthochems:

The allochems are grain supported and usually have a sparite cement although this depends on the degree of compaction; sometimes a diagenetic packstone can result.

Occurrence:

East Isle of Purbeck. Typically as the matrix to shell beds of the Lower Shelly Freestone, which are discussed in context when describing the successions. They contain sparite-filled trigoniid moulds and calcite shelled pterioids. The Lower Freestone (lower part) at Sections Pbk 10 and 6 is a poorly sorted medium intrabiosparite with common Pachastrella spicules. At Pbk 18 and WT (Pbk West) this facies occurs in the Upper Shelly Freestone Bed and intraclasts are composed of micrite lumps, bivalve biomicrite, Rhaxella biomicrite and oomicrite.

Oolitic intrabiosparites:

This is the same as above but with a subordinate admixture of ooids which are a little smaller than those of the oolite-rich sediments. ie. about 3-400μ instead of 500μ; some are superficial on quartz grains.

Occurrence:

East Isle of Purbeck. Pbk 18. This comprises the base of Lower Freestone/top of Upper Cherty Beds but mostly occurs at the junction of shell beds in the Lower Shelly Freestone and the matrix between. The sediment between the shell beds is often very compacted and diagenetically altered by pressure solution, thus it is not easy to decipher what the original sediment was. The oolitic intrabiosparites are above and below these alteration horizons and probably comprise the original sediment all through. In Purbeck West (WT) this subfacies variety occurs between shell beds below the base of the Top Grey Micrite. Here the ooids are about 500μ in diameter.

Central Area. Part of the Upper Shelly Freestone at Lul 1 and 2.

Portland. Part of the upper part of the Freestone Beds at WS2.

Remarks:

More will be said in context of the succession but the

occurrence of intraclasts in current deposited shell beds succests that the intraclasts came from erosion of nearby oomicrite and biomicrite. It is probable that in the long periods of still-stand of a relatively thick ooid or biochem sand mass the surface was colonised by the fauna which was more prolific in the shell sand facies (4a). Lime mud was probably trapped by organisms during feeding processes and the surface was possibly kept bound by a mucous mat (as described in the Bahamas by many authors) which trapped ooids and biochem grains to form patches of oomicrite and biomicrite. When periodic disturbances, such as storms, provided enough energy for erosion of the surface and mass movement of the sediment body, the top was reworked, shells transported, intraclasts eroded and cross-strata formed. When the energy level dropped, the sediment settled and the top became a shell bed consisting of shells in an intraclastic biosparite (or oosparite). Subsequent bioturbation usually destroyed the structures formed by current deposition to a depth of 0.5 to 1 metre, probably depending on the depth of current reworking and mobility of the sediment.

4c Ooid biochem sand

This contains admixed ooids and occasional intraclasts to form oobiosparites and intraclastic oobiosparites. Allochems are micritised biochems such as bivalve and echinoid fragments, and range from poor to well sorted, fine to coarse grained sand, but mostly medium in both characteristics. Ooids average about 500μ but can reach 650μ and are often intensely micritised so as to be recognisable only by the spherical shape, presence of nucleus and of ghost laminations often bored concentrically. Boring and secondary solution produced very porous ooids.

Accessory components include < to ≤ 1% medium quartz sand, often with a superficial coat of micrite to form superficial ooids 2-300μ in diameter. Silica Pachastrella spicules are common and when concentrated, form chert nodules. Intraclasts are minor additions.

Orthochems:

All the sand is grain supported and, except when compacted,

has sparite cement. Compaction and solution can form diagenetic packstone.

Occurrence:

East Purbeck. Topmost part of the U. Cherty Beds. Pbk 20.
L. Freestone Beds. Pbk 6.
L. Shelly Freestone Beds. Pbk 20, 6.
U. Freestone Beds. Pbk 18
U. Shelly Freestone Beds. Pbk 20

West Purbeck. Upper part of U. Cherty Beds. WT.
Upper part of L. Freestone and U. Freestone. WT.

Central Area. Upper part of Cherty Beds. Lul 1-6.
Upper part Freestone Beds. Lul 1-4.

West Mainland. Upper part of U. Cherty Beds. Cliff House, Ringstead

Facies 5 Ooid Sand Facies (see Fig 39) With subfacies a, b & c

5c Relatively pure ooid sand

The essential allochems are ooids which average medium-sand grain size but vary from 300-600μ in diameter. Sorting varies from poor to medium. The nucleus is usually a shell fragment but can be a quartz or glauconite grain; the cortex is generally well developed with well defined concentric laminations and radial calcite, unless micritisation has occurred (Plates 27,28).

Accessory allochems include shell and algal fragments, biochems and intraclasts.

Orthochems:

In some cases there is no appreciable cement in the spaces between the self-supporting grains and a very soft, loose sand exists which is very porous and permeable (e.g. West Mainland. CH). The degree of cementation varies and more than one stage can sometimes be detected. Some of the ooid grainstones are very compacted and are cemented by pressure solution between the grains, a process which can eliminate all the original porespace and produces a very hard dense rock. In this case, no substantial porespace precipitation took place before compaction. Other examples are less compacted due to an early rim cement, which, if no further stage

took place, reduces the original porosity but the rock remains porous (although exceedingly less permeable). Usually this form of cement takes the form of a "fuzz" around grains and consists of microsparite growing at right angles to the grain surface.

In one noteworthy example there is an early, light brown fibrous calcite growth, with a micro-stalactitic orientation; that is, aragonite grew downwards from grains and shells and is seen on the undersides only, replaced by calcite (Plate 6O). A later, clear sparite cement fills most of the remaining pore space. The early microstalactitic cement is similar (if not better developed) to that illustrated by Taylor & Illing (1969) from Holocene intertidal beach rocks in the Persian Gulf and by Purser (1969) from very shallow water Bathonian limestones of the Paris Basin. The presence of this cement on the underside of grains forming the roofs of large pores indicates evaporation of droplets which form repeatedly at the same sites as a result of gravity when the pores are occupied by air. Taylor & Illing regard this texture as environmentally significant and in this thesis it is taken to indicate subaerial emergence and the formation of beach-rock. The original cement was probably aragonite but is now replaced by calcite, as indicated by examination under crossed polars and by a negative result of a chemical test for aragonite (see Appendix).

The commonest cement is clear sparite pore space precipitate which filled the voids left after an early (if occurred) rim cement. All the calcite in the Portland Limestone Formation was found to be iron-free on reaction with a mixed alizarin red-S/ potassium ferricyanide stain. Edmunds & Schaffer (1932) studied the weathering properties of the economic Freestones on Portland and describe "macropores" due to incomplete precipitation of intergranular cement, and "micropores" due to secondary porosity developing whithin ooid grains, probably due to boring organisms. They conclude that it is the presence of micropores which makes certain horizons of the "Portland Stone" less durable than others used for building.

Remarks:

The ooid sand contains in places, cross-strata of a size which suggest original submarine dunes up to about two metres high at times. It is reasonable to suppose that the thickest accumulation of ooid sand occurred in the areas of maximum formation of ooids and in these areas the mean environmental energy level was higher than that in the areas of accumulation of facies 1-4.

Occurrence:

Central Area. Lower Freestone Beds. Lul 1-6.
Top of U. Freestone Beds. Lul 4-6.
West Mainland Area. Freestone Beds. Cliff House. Ringstead.
Isle of Portland. Freestone Beds. (dominant sediment)

5b Intraclast ooid sand

Essential allochems are the ooids of facies 5a with 15-25% intraclasts. These are usually composite, being ooids on mud pellets with a micrite matrix, and range from 50-5,000μ. The sediment is poor to moderately well sorted and has a medium-sand mean grain size. Accessory allochems include bivalve, echinoid, serpulid, bryozoa, and algal fragments, quartz (max 5%) and fine glauconite sand. All these may have a superficial ooid coating and be partially micritised. Pellets of lime mud 100-200μ sometimes occur and may compact to give micrite patches in a generally grain supported sediment (packstone).

Orthochems are either sparite cement or patches of lime mud, but in some cases there is hardly any cement at all (W. Mainland. CH).

Remarks:

This sediment formed when there was sufficient lime mud in the area for periods of formation of soft oomicrite on the sea floor during periods of stillstand of the sand bodies. The formation of the intraclasts is as that envisaged for those of facies 4b. The likelihood of oomicrite intraclasts forming is increased as an area of lime mud accumulation is approached. The

area immediately behind the high energy ooid sand masses would be relatively sheltered and hence experience a lower mean energy level and thus be an area of lime mud deposition (facies 1, 1a or 2). Micritic intraclasts would form in the zone where the two major facies types adjoin, i.e. where the sand and lime mud mix.

Occurrence:

Purbeck East. Upper part, L. Freestone Pbk 6.
Central Area. Topmost part of Freestone Beds. Lul 5 & 6.
West Mainland Area. Middle of Freestone Beds. Cliff House, Ringstead.

5c Biochem Ooid Sand

Essential allochems are 25-35% ooids and 50-75% biochems. The ooids are as previously described and can vary from excellent preservation to being very bored and micritised. The mean size is medium sand and some are superficial on f.-m. quartz sand. Biochems are usually micritised fragments of bivalves, echinoids, serpulids, bryozoa and algae which generally form moderately well sorted medium sand.

Accessory allochems include intraclasts (micrite matrix) 500-700μ, f.-m. quartz sand <1% and occasional silica Pachastrella spicules. Orthochems are either sparite cement or virtually non-existent.

Remarks:

There is a gradation from facies 5a to 5c to 4c to 4a, as is evident from Fig.39, and, bearing in mind the remarks made about the interpretation of the end-members 4a and 5a, these subfacies are thus related to the distance from the site of ooid generation and accumulation. There is such a gradation from the east part of the West Mainland Area to the Central Area and eastwards to the West and East Purbeck Areas.

Occurrence:

East Purbeck. Inland. Lower and Upper Freestones. Pbk 20.
West Purbeck. Lower parts of Lower and Upper Freestone Beds. WT.
Central Area. Part of lower part of Freestone Beds. Lul 1-5.
Middle and upper part of Freestone Beds. Lul 4-6

Facies 6 Intraclast Sand Facies (see Fig.39 With subfacies)

6a Relatively pure intraclast sand
6b Ooid intraclast sand
} Neither of these was detected.

6c Biochem intraclast sand

The essential allochems are 25-35% intraclasts and 50-75% biochems. The intraclasts are either ooids or biochems in a micrite matrix, or just lumps of lime mud. The latter vary from 100µ to 600µ and the oomicrite ones average 800-1,000µ. The biomicrite intraclasts can reach several millimetres as often they are merely shell fragments with lime mud adhering to the surface. Broken surfaces of biochems and ooids are convincing evidence of the erosive mode of formation of this type of sand grain and such breaks are often seen (Plate 32).

There are very few accessory allochems except perhaps the rare ooid, but none were seen in the Isle of Portland examples. Quartz sand is virtually non-existent.

Orthochems:

The sands and pebbles of this facies are cemented by sparite.

Remarks:

The formation of intraclasts has already been discussed (facies 4b & 5b). The biomicrites with algal, bryozoan and shell debris were probably derived from the mud areas surrounding the sand dunes and eroded during the destructive phases which produced blocks of reef and sea floor described later. The biochems entered the mud areas from the colonised stagnant dunes and were mud coated and partially mud-bound prior to erosion and fracturing.

Occurrence:

Central Area. Upper part of Freestone Beds. Lul 6.
Isle of Portland. Upper part of Freestone Beds. WS 7.

3. The Portland Limestone Formation in the East Area, Dorset. Isle of Purbeck

A. Introduction

The only localities where complete successions are visible from the Portland Sand Formation through the Portland Limestone Formation to the base of the Purbeck Beds are at St. Alban's Head in the east (Grid Ref. SY 9675) (Frontispiece), at Smedmore Hill, (SY 9180), and at the Gad Cliff area in the west (SY 8879) (Plate 10). It is not always possible to separate these formations within a transitional half metre at the base of the Portland Limestone, nor is it always possible to decide categorically at which point within a similar interval is the division between the Portland and Purbeck Beds.

In the east the horizontal or gently southwards dipping beds are precipitously exposed in the cliffs between Hounstout (SY 9577) and Durlston Head (SZ 0377) and several sections were measured there with the aid of ropes and other climbing equipment (Plate 34). The complete succession of the Lower Cherty Beds is best exposed and most easily examined under the east side of St. Alban's Head below the disused quarries at the cliff top, and six to seven hundred metres further east where they have been down faulted to sea level. Another complete section is in the cliff of Emmitt's Hill but is less suitable for a comfortable examination; however, the fallen blocks at sea level provide useful information. Eastwards from St. Alban's Head most of the sections show only the upper parts of the Lower Cherty Beds, the rest being below sea level. In places (e.g. Pbk 5) (SZ 001768) faulting has upthrown the contact with the Black Dolomite Beds, but these exposures are only accessible from the sea. Several sections have been measured in the Lower Cherty Beds and the details are given in Fig. 40 .

The Upper Cherty Beds are more accessibly exposed in the cliff tops or at sea level at such well known localities as Winspit, Seacombe, Dancing Ledge and Tilly Whim"Caves" (old quarries), but several other sections have also been examined in detail. The Freestone Beds are exposed at most of the same latter localities

and details of both Beds are given in Fig.42 .

At Swanworth Quarries (Old Worth Quarries SY 969784) the Portland Limestone is worked for roadstone aggregate and the lowest exposed beds are almost half way down the Lower Cherty Beds. Less details are visible in this fresh exposure than in the sea-weathered coastal sections. Near Kingston village, by the road to Encombe, there is a large overgrown quarry in the Portland Freestone Beds (SY 950791) but the undergrowth is so dense that very little rock is visible for close examination; that which is available does not seem to contain any chert.

Further west, the dip increases to about 30 degrees north and two disused quarries at Smedmore Hill, by the road to Kimmeridge village, expose the complete succession from the Black Dolomite Beds in the south end of the roadside quarry (SY 918800) to the basal Purbeck Beds in the north end of the one behind (SY 919880). The details of these very prominent exposures have not been previously recorded. At Gad Cliff most of the two-kilometre section is inaccessible, being high in the cliff, but at the eastern end the Lower Cherty Beds and part of the Upper Cherty and Freestone Beds can be reached, although the steep inland dip and loose nature of the rock makes close study of the exposures dangerous (Plate 44). Once the section had been established it was found to be more beneficial to study the massive fallen blocks at sea level (Plate 45). The section for the central part of Gad Cliff was measured on a huge fallen block and several other blocks along this part of the shore provide important details of lithology, structure and fauna. The beds at the west end of Gad Cliff dip north-west and the Lower Cherty Beds are accessible by climbing up from the section in the Black Dolomite Beds. Details are much more easily obtained from the seaward side of Worbarrow Tout and Pondfield Cove; the succession over this short distance is so uniform that the details in Fig.46 have been justifiably compiled from the different convenient sections available. (Plate 48).

B. Description of the Beds

EAST (124 thin sections were studied)

(i) The Lower Cherty Beds

These are about 14m thick, the base being defined by the top of the Black Dolomite Bed of the Portland Sand Formation and the top by the top of J'. The beds are composed of a lower 7.5-9m of facies 1a (sponge spicule lime mud) and an upper 5.5-6.5m of facies 3 (muddy fine biochem sand) (Plate 35).

(a) Lower part: This consists of brown, mottled and siliceous limestone, originally finely laminated but bioturbated by horizontal and cross-cutting burrows ("Teichichnus"?), which can give a false impression of small-scale cross-stratification on vertical surfaces. Cementation by redistributed calcite and silica forms impure nodules which are tabular and grey or the same colour as the sediment. The sediment was fairly homogeneous before silicification and the chert horizons seem to be unrelated to any primary differences in the sediment. No body fossils have been seen and it seems that the only life on the sea floor at the time was sponges and burrowing organisms, probably mostly crustaceans. Pressure solution has accentuated the sedimentary structures produced by bioturbation and it seems to accompany or post-date early silicification as there is some compaction round the chert nodules. There are two major massive rough weathering blocks about 4.5m and 2.5m thick and some thinner ones (Plate 9). In some horizons decalcification of silicified levels gives an extremely light and porous rock, e.g. at section Pbk 15 (Fig. 40). The limestones contain c.5% v.f. quartz sand.

(b) Upper part: (see Fig. 40) An obvious change from below, apart from the microfacies, is the abundance of fossils and especially shell beds, serpulid horizons and ammonites (see Fig. 41). Also noticeable is the marked decrease in the amount of silicification leading to the virtual absence of cherts in the eastern end (Pbk 2 & 3). The rock is hard, grey-brown with occasional black chert nodules. A typical feature is the occurrence of bioturbated

SECTIONS IN LOWER CHERTY BEDS. PURBECK EAST. FIG 40.

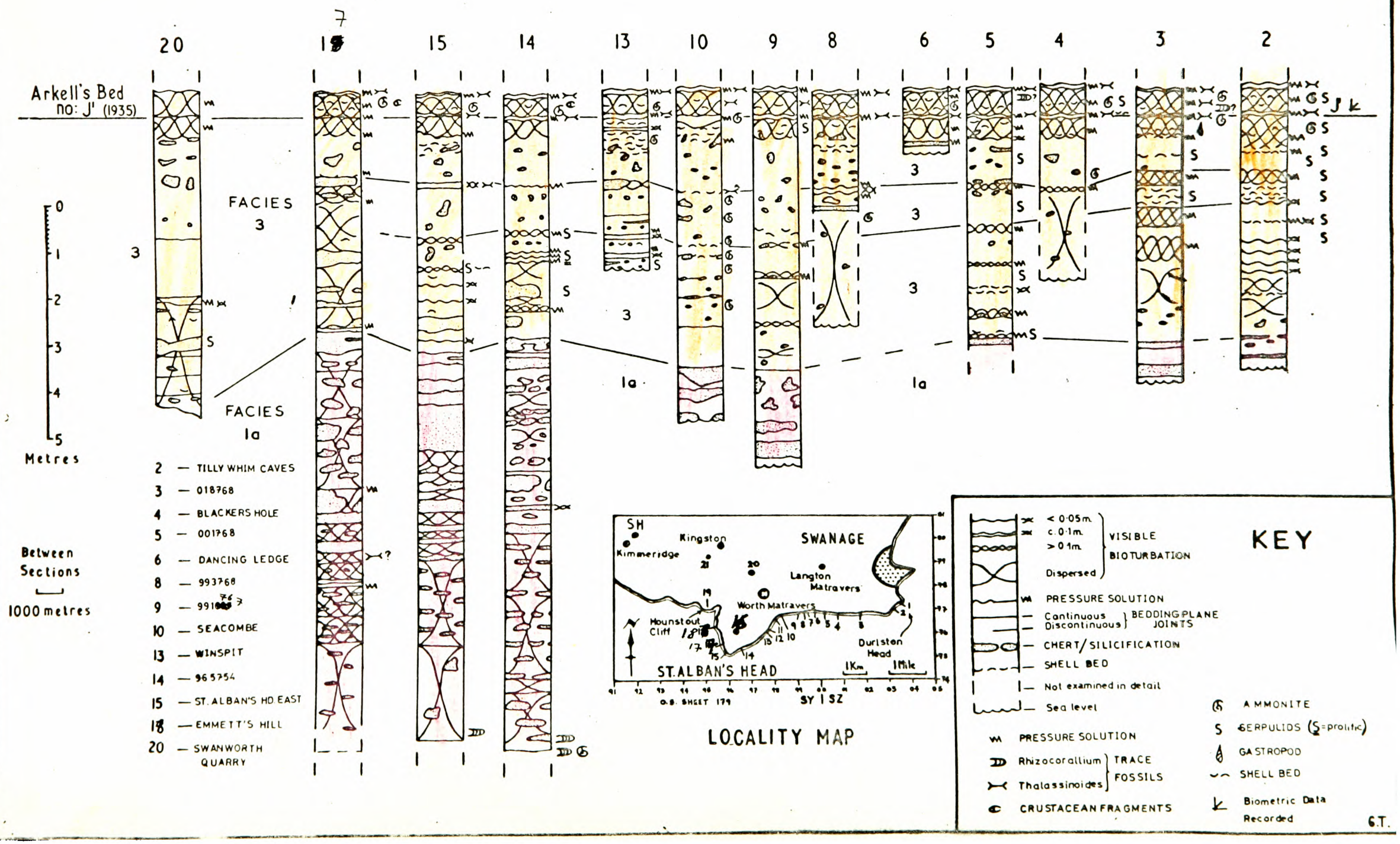
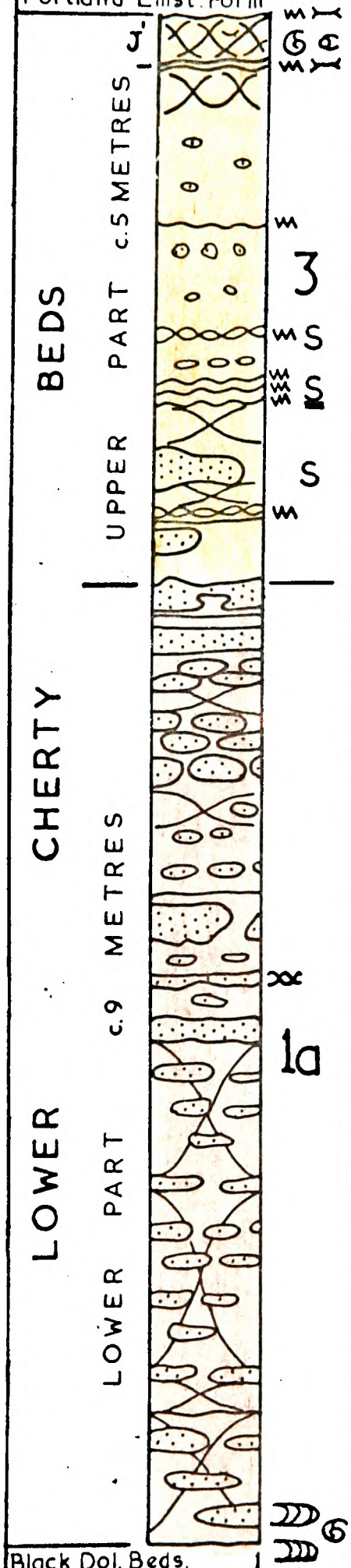


FIG 41

REPRESENTATIVE SECTION OF THE LOWER CHERTY BEDS PORTLAND LIMESTONE FORMATION. ISLE OF PURBECK EAST. SECTION 14. (GRID REF. SY 965754)



METRES	SEDIMENT	FOSSILS
0.4-0.45	Intense pressure solution of bioturbated sediment. 0.1-5%.	Thalassinoides, Ammonites, bivalves, crustacean fragments.
1.40	Grey-brown limestone. Scattered small black chert nodules.	Distinct bioturbation of top part. Scattered bivalve fragments.
c.1.1	Scattered small black chert nodules. Pressure solution horizons and concentration of Glomerula.	Occasional bivalve and echinoid fragments. Glomerula knots. Whole shells rare, frags often silcified.
0.60	Q.c 5%.	Glomerula abundant at base, shell frags larger.
1.05	Obscure depositional structs? Impersistent large chert nodule horizon.	Occasional shell frags, much bioturbated. Occasional Glomerula.
0.80	Chert in places. Black chert, variable in extent.	No body fossils.
c2.55	Black silicification horizon. Structures probable due to pressure solution acting on bioturbated depositional structures. c.50% Rhaxella spicules. Q.5-10%	No body fossils. Rare shell fragments. Bioturbated throughout.
4.6-4.7	Dark grey chert. Whole rock is a grey sandy-feeling limestone with structures due to bioturbation of an originally laminated sediment. Light grey 'blotchy' cherts, replacing bioturbated sediment. No primary differences between silicified and unsilicified sediment. 10-20% Rhaxella spicules. Q < 5%.	No body fossils at all. Only burrowing organisms. c.f. Teichichnus?
1.20	Grey-black cherts. Rock is dark brown-grey and sandy-feeling. Mixture of dolomite and Rhaxella. Transition bed with Black Dolomite Beds. Q.c1%.	Rhizocorallium burrows, vertically retrusive. Ammonites.

levels (Plate 36) up to 0.4m thick, although all the sediment shows signs of having been burrowed. Pressure solution has accentuated these levels and commonly silicification took place along a pressure solution horizon and many of the thin sheet cherts appear to be due to this, which indicates that silicification and pressure solution were penecontemporaneous. The proportion of v.f. - f. quartz sand is generally <1% but can reach 5%. Horizons of Glomerula gordialis are common and these serpulids are concentrated by pressure solution (Plates 36, 39); it was the serpulid-rich horizons in these beds and part of the Upper Cherty Beds that made some past workers suggest a correlation with the Serpulit of the north-west German "Wealden", but this hypothesis now totally discredited. (See Arkell 1933). Although serpulid horizons are common they are not "hardgrounds" or encrusted cemented surfaces and the animals appear to have formed "knots" and encrusted themselves by curling round like a ball of string, or they encrust shell fragments and ammonites, as do Exogyra; this suggests a continuously soft sea floor. The shell beds, as in the Upper Cherty and Freestone Beds, are usually composed predominantly of either originally aragonitic trigoniids or large calcitic bivalves such as Isognomon, Camptonectes and Plagiostoma, which are generally disarticulated and show no preferred orientation. The shells are not broken much and it is likely that the beds are in situ but disturbed, possibly by a sudden current, re-worked and then bioturbated. The trigoniids were shallow, infaunal filter feeders, whereas the pectinids found were mobile epifauna and the fact that shell beds are usually dominated by one type of bivalve is considered to be a reflection of this original sea-bed distribution rather than post-mortal rearrangement by currents. Thin beds of discrete recognisable Thalassinoides occur in the middle and upper part and the top two define Arkell's bed J' and the top of the Lower Cherty Beds.

(c) Bed J': This is an important marker horizon which can be recognised from Durlston Head in the east of Purbeck to Durdle Door in the west of the Central Area, a distance of nearly 22km. (Plates 35, 53, Figs 5, 17). It is about 0.5m thick and bounded top

and bottom by bands 0.1-0.2m thick of intense Thalassinoides bioturbation and pressure solution. The bed is very bioturbated and weathers to a characteristic mottled brown-grey rubbly nodular appearance due to diagenetic redistribution of calcite by pressure solution. The proportion of v.f -f. quartz sand is 1-5%, and there is also a little glauconite (<1%). Ammonites are common and this is the richest bed, for its thickness, of the Portland Group. At Dancing Ledge (Pbk 6) fifty ammonites were measured on a bedding plane area of about 1,000 sq. metres. In the Isle of Purbeck region a total of 69 ammonites have been measured. (See Fig. 125 in Appendix). The concentration of ammonites, which are all encrusted with serpulids and Exogyra (Plate 38) together with the intense bioturbation and general widespread retention of physical characteristics (in spite of slight facies changes) suggest that the bed represents a break in deposition throughout the Dorset area; that is, a period of minimum accumulation of sediment. Its significance is discussed further elsewhere, but it is correlated with the Basal Shell Bed of the Western Areas. The sediment was usually very shelly lime mud but in places shells are not common as at section Pbk 6 (Figs.40, 41).

(ii) Upper Cherty Beds 7.5-8.5m thick

The base is the top of J', the uppermost bed of the Lower Cherty Beds, but the top is not so easy to define precisely. Arkell took the division between his Freestone Series and Cherty Series at a level where the cherts of the beds below become insignificant and the sediment changes to a coarser carbonate grainstone of commercial value. This transition occurs over about a metre but one can only follow Arkell and take the junction as somewhere where the facies changes from 4a to 4b and chert occurs only as small isolated nodules rather than continuous sheets and lenses (see Fig. 42). This works where the lower part of the Freestone Beds is relatively chert free, but lateral variation in chert content at this level makes it difficult in places, for example at St. Alban's Head (Pbk 15). The correlation of the level taken can be made when the sections are traced laterally, i.e. the level

FIG 42

SECTIONS IN UPPER CHERTY BEDS & FREESTONE BEDS. PURBECK EAST.

fig 42

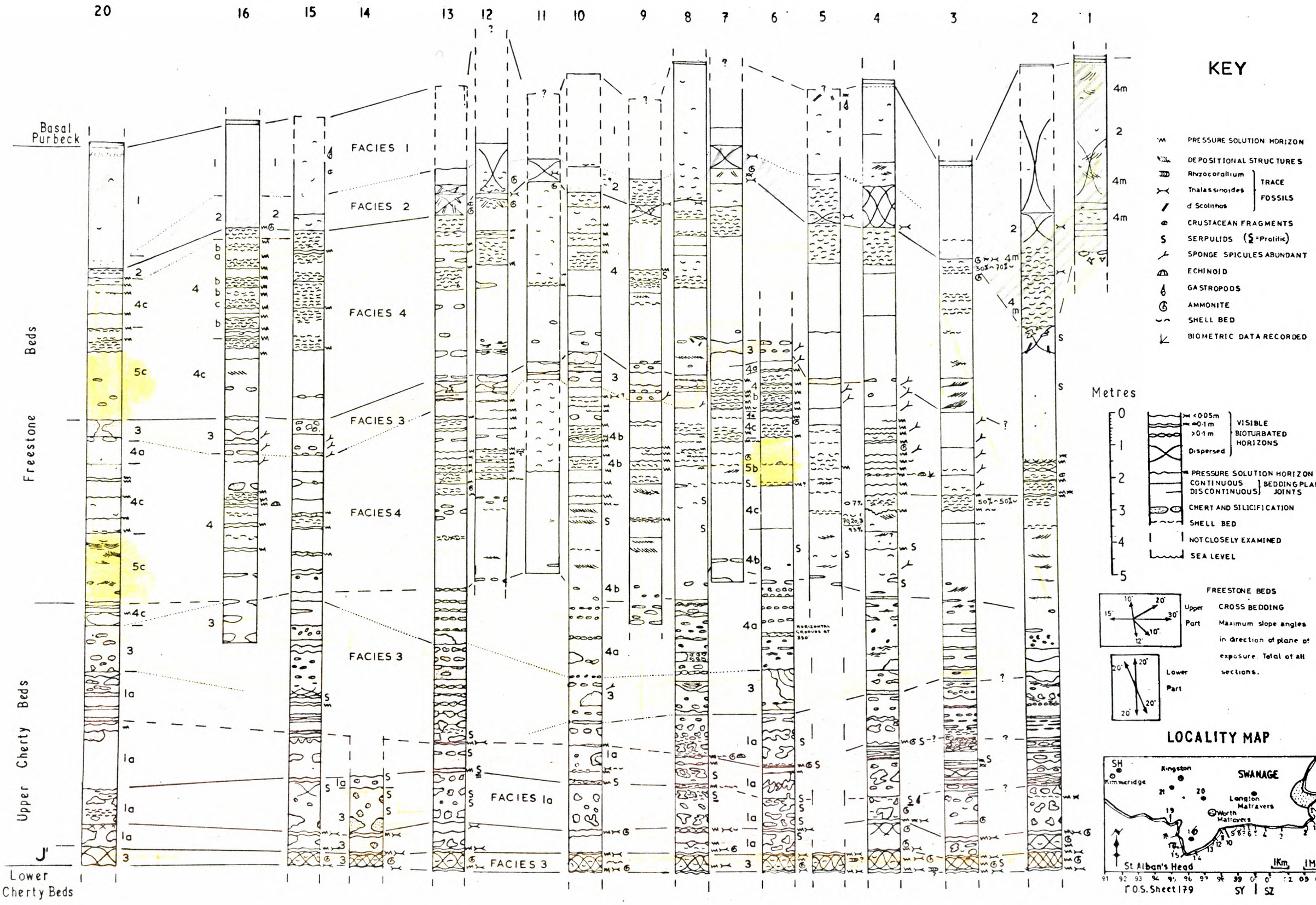
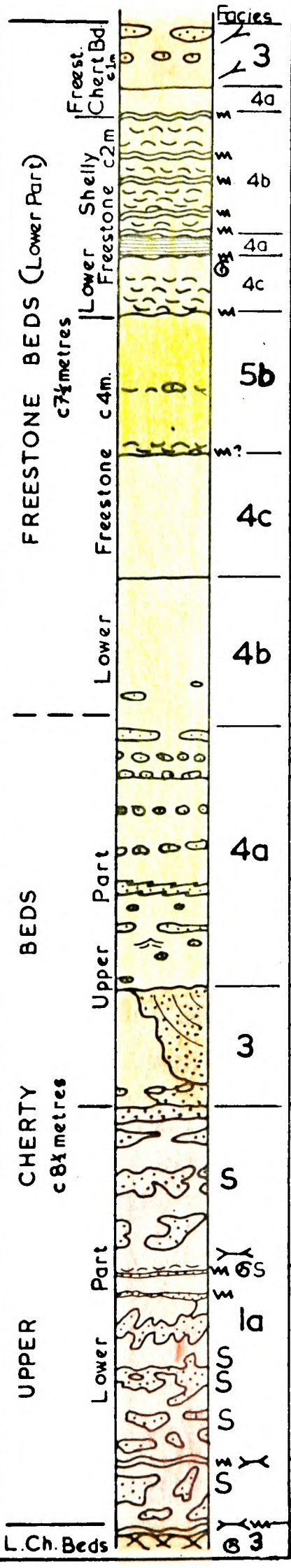


FIG 43

REPRESENTATIVE SECTION OF THE UPPER CHERTY BEDS AND THE FREESTONE BEDS, PORTLAND LIMESTONE FORM^{N}. ISLE OF PURBECK EAST. SECTION 6. DANCING LEDGE. (997769)



Facies	M.	Sediment	Fossils
3	c0.6	Finer grained softer white lmst + pale grey chert nods.	Large number of Pachastrella spicules.
4a	0.7	Current disturbed shell beds with skeletal sand matrix separated by pressure solution horizons in winnowed shell-free matrix.	Shell beds dominantly [illegible] of disarticulated Inoceramus valves. Occasional large ammonites.
4b	0.6		
4a	1.05		
4c			
5b	1.45	Bioclastic intraclastic oolite with occasional silicified patches.	Thin shell layers with Isognomon, Camptonectes, Ostrea.
4c	1.30	Homogeneous micritised oolitic medium skeletal sand.	No body fossils.
4b	1.60	Scattered silicified patches near base. No obvious depositional structures in this particular section.	Occasional Serpulid knot[illegible], often preferentially silicified.
4a	0.40	Horizons of small light-grey chert nodules.	
	1.10		
	1.20	Grooved chert sheet. (330°) Occasional small light-grey chert nodules.	No obvious fauna, [illegible] occasional Pachastrella spicules on weathered surfaces.
3	1.10	Massive grey silicification, in places masses 2 x 1 m.	
S	1.70	Large black chert nodules.	Glomerula [illegible] below.
		Pressure soln forms a pseudoconglomerate at base.	Shell bed. Camptonectes, [illegible]
1a	1.90	Large black chert nodules. Rhaxella spicules 30-40%	Abundant [illegible] bivalve shell[illegible]
S	0.65	Grey limestone with black chert nodules.	Thalassinoides [illegible] at base.
3	J'	Q.c5%.	

where the transition from chert-rich to chert-poor rock occurs in the east of the Purbeck east sections is not the same level as the St. Alban's Head area,but the sedimentary facies transition is about the same level.

It is more meaningful for interpreting the successions if sediment changes are traced and then the reason for chert distribution evaluated. This problem becomes more difficult where the successions are thinner and chertier as in Purbeck West and the Central Area. It must be noted that the correlations are based on facies changes with the notable exception of that for J' which is regarded as the nearest to a time horizon available in the Portland Group.

(a) Microfacies: These vary but the three following types all occur: 1a, 3 and 4a, i.e. sponge spicule lime mud, muddy fine biochem sand and medium biochem sand. They can be divided into a lower 4-5m of facies 1a and an upper 2.5-4m of facies 4a and/or 3.

(b) Lower part: As much information as possible has been put on Fig. 42 and an example of a typical section is given (Fig. 43). These figures are intended as substitutes for lengthy written descriptions. Immediately above J' there is a similar hard brown-grey cherty limestone about 0.5m thick, bounded top and bottom by thin horizons of Thalassinoides and pressure solution, rich in ammonites and sometimes bivalves. (Plate 22) Above is a block up to 2.0m thick with large black chert nodules and very rich in serpulid horizons (Glomerula) which are a persistent feature all along these coastal sections.

The effects of pressure solution on shell beds can give a pseudo-conglomeratic appearance and casual examination of certain horizons may give the false impression of penecontemporaneous erosion of the sea bed.

(c) Upper part: The sediment becomes a carbonate sand and is lighter in colour. The cherts are thinner, more tabular and light grey (Figs 42,43). Occasional traces of depositional sedimentary structures are visible but only as remnant "wisps" of current bedding with small foresets with bimodal direction. (See Fig 42).

R.C. Wilson (unpublished manuscript) mentions that "occasional small ripple marks are just discernible, especially within some chert nodules". No convincing structures have been seen in chert nodules other than those which appear to be purely chemical in origin, but the structures seen in the limestones in places may well be ripple marks and Wilson's observation cannot be discredited. These upper beds are remarkably lacking in fossil remains except for the cherts which are rich in Pachastrella sponge spicules.

The Upper Cherty Beds contrast with the Lower Cherty Beds in that although the sequence is similar, that is to say facies 3 over facies 1a, the faunal content in the former is mostly restricted to facies 1a, whereas in the Lower Cherty Beds it is in facies 3. This is probably related to rate of deposition and stability of the substrate, linked with overall environmental energy. The uppermost 1-1.5m of the Upper Cherty Beds at Seacombe, Dancing Ledge and probably further east is facies 4, i.e. a biochem sand as in facies 3 but with no essential lime mud and a medium sand mean grain size. At Pbk 20 and 18 the equivalent level is facies 3.

The general concentration of serpulids, shell beds and thin, intensely bioturbated horizons may imply a generally slow deposition as at the top of the Lower Cherty Beds culminating in J'.

ii)Freestone Beds 14-16m

These are divisible into six local informal units which correspond to the somewhat unedifying quarryman's names used by Arkell:—

Terms used in this thesis		Purbeck Beds	Arkell's terms (1933, 1935, 1947a) Fig 44a
FREESTONE BEDS	Upper Part	Top Grey Micrite	"Shrimp Bed"
		Upper Shelly Freestone	"Titanites Bed"
		Upper Freestone	"Pond Freestone"
		Freestone Chert Bed	"Chert Vein" &"Listy Bed"
	Lower Part	Lower Shelly Freestone	"House Cap"
		Lower Freestone	"Under Picking Cap" & "Under or Bottom Freestone"
		Upper part of Upper Cherty Beds	"Cherty Series"

"FREESTONE SERIES"

(a) Lower part: The Lower Freestone and Lower Shelly Freestone together are about 6-7m thick all along the outcrop, but the amount of shells and number and thickness of shell beds varies, as is seen in Fig.42 . The Lower Freestone is generally facies 4b (intrabiosparite) but at Pbk 20 to the north-west it is 4c and 5c (ooids and biochems mixed). Apart from one or two thin shell "strings" (Camptonectes, Isognomon,) within the bed the sediment is relatively pure and homogeneous. The thickness varies from 3-4m with occasional bimodal cross-strata preserved which dip to the NNW and SSW but there are not enough suitably weathered exposures for this to be taken as significant. The cross-strata are usually erosional planar tangential and sigmoidal with graded avalanche foresets picked out by shell fragments, sometimes with slumping (Plate 42). Occasional small white chert nodules occur and these are silicified Pachastrella-rich patches of sediment, also seen sometimes are knots of large serpulids. The upper part of this bed is facies 4c (grain supported ooid biochem sand) all along the outcrop. The shelly Lower Freestone varies from 5b to 4c and b, but 4b (intrabiosparite) seems the commonest matrix in the shell beds.

The shell beds are usually composed of sparite casts of disarticulated trigoniid valves often matrix-supported with 50-100% valves concave side down; about 50% seems the commonest. Up to seven discrete shell beds can occur with pressure solution horizons above and below. The beds vary from 0.10-0.40m thick and large Titanites sometimes occur in the shell beds as well as crustacean fragments attributed to Callianassa (Wood, in Arkell 1935). The shell bed development seems to be "cyclic" in that the sequence is a repetition of the following:- (a) creamy coloured shell bed; (b) brown "winnowed" and pressure solution horizons; and (c) shell bed. This gives a banded appearance to the rock (Plate 41).

It is likely that the lower part of the Lower Freestone represents a semi-mobile carbonate sandbank which moved in intermittent high energy conditions and was too unstable to support a bivalve population. When stabilized, perhaps by moving into deeper less turbulent water, its surface was colonised by shallow infaunal

trigoniids and was burrowed by crustaceans. Occasional high energy currents disturbed the inhabited surface, produced intraclasts by erosion and left a deposited surface of winnowed material on dying away. Re-colonisation took place and left a bed of finer bioclastic material between the two shell beds which acted as a focal plane for pressure solution. This results in the concentration of insoluble residues, high compaction and the development of "diagenetic packstones". The repetition of this event, whether with shells or not, is apparent from the sections of Fig. 42 , where up to 12 pressure solution horizons occur in the fifteen sections figured. These horizons can be traced laterally, as can some shell beds, for several hundreds of metres. Some small chert nodules occur in the Lower Shelly Freestone, Pachastrella spicules become common in the upper part and are often seen on weathered rock surfaces in great concentrations.

→ The Freestone Chert Bed ("Chert Vein" & "Listy Vein" of Arkell) is a bed of 3 or 4a facies rich in Pachastrella spicules and 0-1m thick. The amount of chert present is greatest in the western eight sections, as it is in the Lower Freestone generally. As the horizon is traced eastwards the content of chert decreases, sponge spicules have a greater vertical distribution and eventually no chert is present, just spicules. This change continues until at Pbk 2 (Tilly Whim) spicules are not significant, there is no chert, and the Upper Freestone rests directly on the Lower Shelly Freestone. This is best seen by studying the changes from sections Pbk 9 to Pbk 2 in Fig. 42 . This situation could be described as due to an incursion from the south-west of topmost Upper Cherty Bed conditions, possibly of slightly deeper and/or relatively less agitated water. No obvious fauna other than sponges is associated with this incursion of muddy sand, as is the case for the upper part of the Upper Cherty Beds. An example is given using Pbk 6 (Dancing Ledge) as a representative section in Fig. 43 .

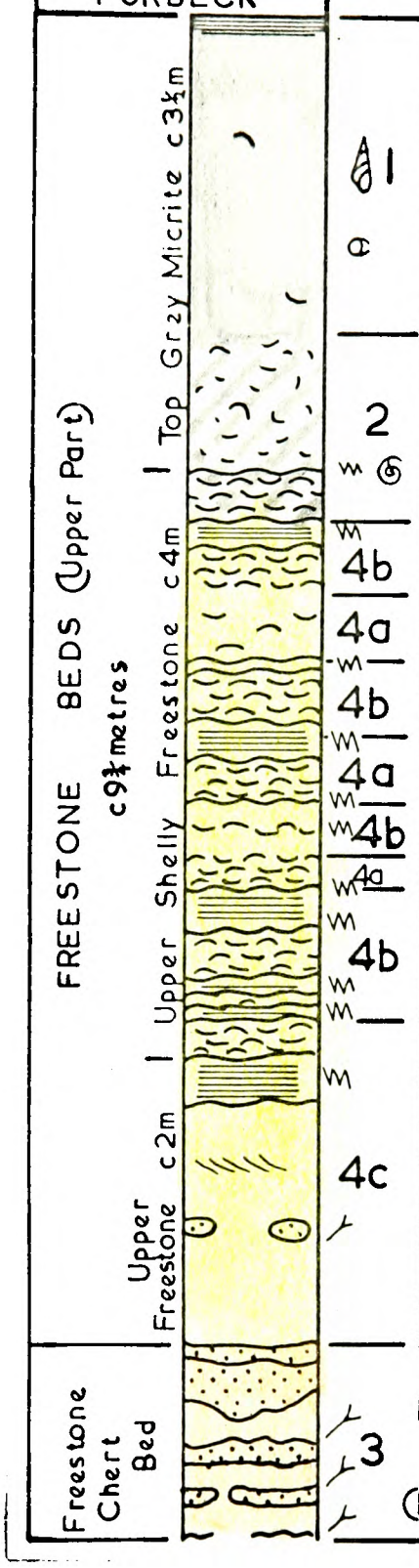
Note: Detailed measurements at Seacombe (Pbk 10) failed to substantiate Arkell's figure showing variation of thicknesses in the Lower Freestone and Lower Shelly Freestone (Arkell 1935).

(b) Upper Part: The Upper Freestone and Upper Shelly Freestone together vary from 4.75-5.75m measured from the base of the Top Grey Micrite to the top of the Freestone Chert Bed, where present. In the far eastern sections absence of the latter makes it difficult to compare the thickness but it is about the same. As is the case with the Lower Freestone and Lower Shelly Beds the total thickness is generally constant along the outcrop, but the amount of shells and number and thicknesses of shell beds varies, See Fig. 42, 44.

The Upper Freestone thickens from about 2.0m in the western sections (Pbk 20, 16, 15) to 3.5-4.0m at the far east (Pbk 4, 3, 2). The original sediment consisted of a medium grained mixture of micritised ooids and biochem sand. At Pbk 16 the latter dominates and the facies is 4c but at Pbk 20 to the north there is an increase in ooid content to form facies 5c. Occasional small white chert nodules occur, but not east of Dancing Ledge (Pbk 6), and often these are seen to be silicified concentrations of Pachastrella spicules on foresets. Some form of depositional structure is usually visible on weathered surfaces and takes the form of herringbone, or bimodal, small scale trough or planar cross stratification with foresets to the west or NE-SE. Occasionally high angle vertical burrows are visible (c.f. Skolithos). Shell "strings", single layers of the large flat bivalves (pectinids), are a common occurrence and bedding plane surfaces are often exposed in the roofs of the disused coastal quarries. These are byssate, epifaunal bivalves capable of withstanding quite high energy conditions and probably inhabited the surface of the carbonate sand bodies during periods of relative stillstand. Within the area of any given exposed bedding plane surface the shells are about the same size (large), unfragmented and probably articulated; this probably indicates sudden overwhelming of an originally full-grown local population by a high energy event instigating further deposition. At the east end of the East Purbeck sections scattered "grit" of quartz and lydite (black detrital chert) occurs scattered through the carbonate sand, but otherwise the quartz sand content is about or <1% of the allochems.

REPRESENTATIVE SECTION OF THE UPPER PART OF THE FREESTONE BEDS, PORTLAND LIMESTONE FORMATION, ISLE OF PURBECK EAST. SECTION 16. (SY 964761) ST. ALDHELM'S QUARRY.

FIG 44



M	Sediment	Fossils
c3.2	Laminated bituminous ostracodal limestone at top. Algal mat development? Hard porcellaneous micrite. Scattered shells. Bioturbated. Occasional current structs seen. Q.<1%.	Diverse fauna. Protocardium, Camptonectes, Trigonia, several gastropods, ostracoda, forams, algal fragments. Rare ammonites.
	Shell fragments. Poorly sorted. Micrite matrix, grain supported. Q.<1%. Poorly sorted shell bed in micrite matrix, current depd.	Fragments of bivalves, echinoids, algae, sponge spicules, forams, gastropods. Shell bed. Trigonia, ammonites, Camptonectes, Isognomon.
1.80	Current disturbed shell-beds and shell fragment horizons. Several pressure solution horizons in winnowed shell-free matrix. Medium grained micritised skeletal sand with admixed intraclasts and ooids.	Shell beds dominantly sparite-filled casts of disarticulated Trigonia valves. Occasional large ammonites, Isognomon, Camptonectes.
1.35		
1.40	Q.<1%.	More shells in this section than elsewhere in the area of Isle of Purbeck East.
1.70	Current bedded (to east) micritised oolitic medium skelctal sand. Occasional silicified nodules with Pachastrella concentrated. Q.< 1%.	No body fossils. Pachastrella concentrations.

FREESTONE BEDS (Lower Part)

FIG 44a

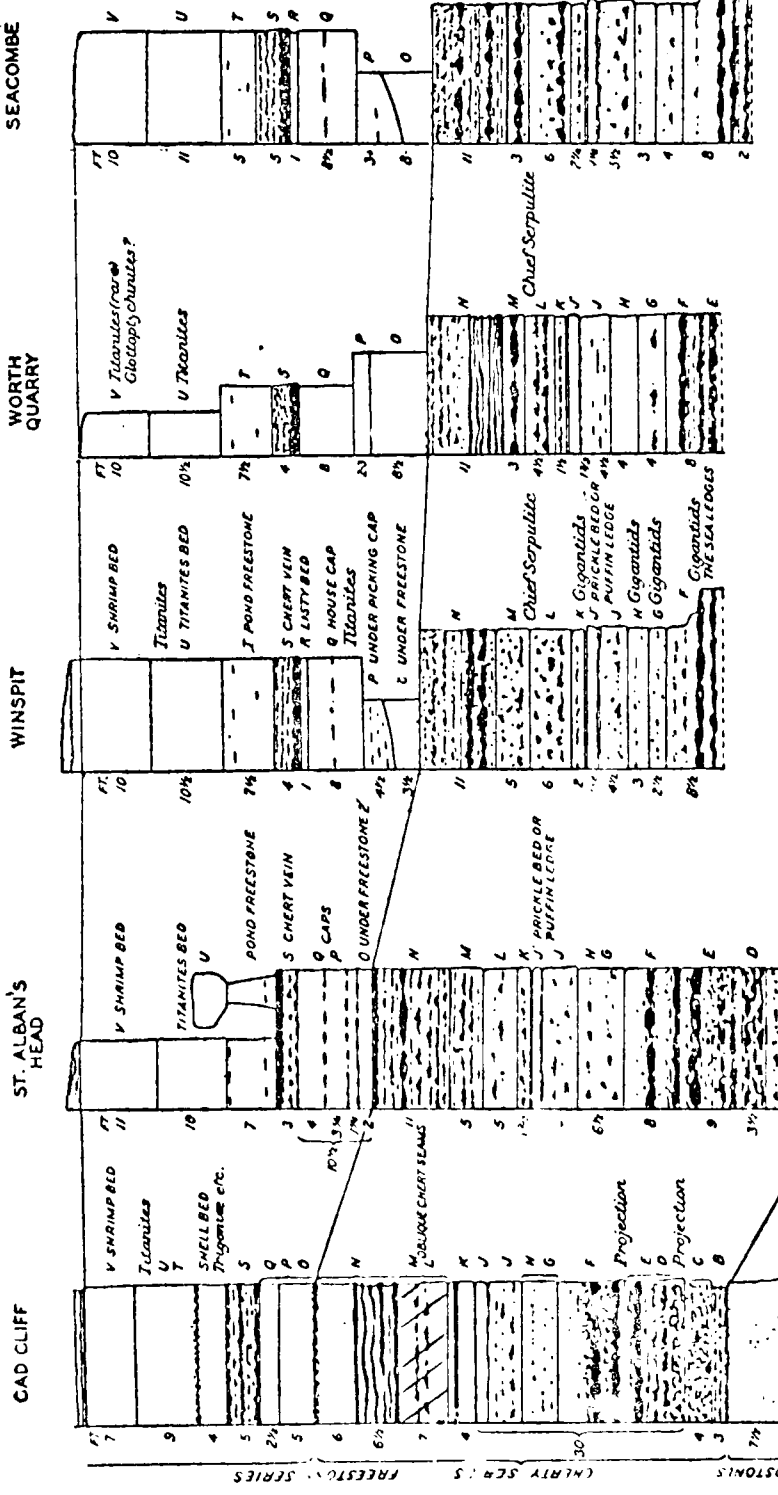


Fig. 29.—*Profiles of the Portland Stone at the principal exposures in Purbeck.*
Black denotes chert, dots denote sandstone or sandy limestone. (After Arkell, *Proc. Geol. Assoc.*, vol. xlvi, 1935, p. 301.)

The Upper Shelly Freestone is very similar to the lower shelly beds with the exception of the topmost shell bed. Although concentration and number of shell beds varies, there is generally a densely packed trigoniid bed at the top of the Upper Freestone, in which the orientation of the disarticulated shells is random and valves can be concave up or down, and vertical. This is considered to be due to rapid re-working of a populated sand-body surface by currents, followed by bioturbation which further disoriented the valves. Often a shell bed traced laterally over several hundred metres will fade to a bed of shell fragments with the development of stylolites and pressure solution horizons; the latter can reach a thickness of 0.35m. Apart from sparite-filled trigoniid moulds, serpulid "knots" and Camptonectes are common as well as the occasional oyster. The original sediment between the highest and lowest shell bed was generally a medium grained intraclast biochem sand, but the topmost shell bed, below the Top Grey Micrite, was poorly sorted, coarse biochem sand with a lime mud matrix (facies 2). This contains current depositional structures in places with cross-bedded valves (to the east and west) and fragments occasionally weathering out (Pbk 4). Apart from trigoniids there are commonly Camptonectes, Isognomon, oysters, ammonites, crustacean remains (Callianassa?), Thalassinoides in bedding planes and vertical "Skolithos", all of which weather to give a grey, flaggy honeycombed appearance. Burrowing mixed lime mud from the Top Grey Micrite downwards and sometimes as far down as the top of the Upper Shelly Freestone shell beds below. Crustacean burrows occur and are especially well seen at the base of a thick shell bed at Tilly Whim Caves (Pbk 2) where nearly 3.0m of shells accumulated between the top of the Upper Freestone and the base of the Top Grey Micrite. The base of this "Tilly Whim Oyster Bed" is burrowed to a depth of half a metre but occasionally to one metre; the burrows were filled with shell fragments and ooids from the basal sediment above.

The "Tilly Whim Oyster Bed" does not extend more than 300-400m to the east and, although above the level of erosion

immediately to the west, it does not occur at the next available point about 0.5km away. The lower part has the micritised biochem sand matrix of the beds below, but becomes micritic upwards. It is probably the combination of the Upper Shelly Freestone and shell bed at the base of the Top Grey Micrite, except that instead of dominantly trigoniids there is a patch-accumulation of Ostrea expansa, Isognomon, Exogyra thurmanni and E. nana with subordinate Plagiostoma, Plicatula, serpulids and algal fragments. A large number of bivalves have been bored, probably by annelids, sponges and Lithophaga. The lower 1.5m is composed mostly of Ostrea and Exogyra which are horizontally bedded and probably current deposited as whole and disarticulated valves, encrusted "nests" and fragments. Transport was probably over only a very short distance and may merely have been a result of rapid high energy destruction of an in situ assemblage. The sandbank surface must have been sufficiently coherent for burrows to be infilled and preserved, but soft enough to be burrowed. This lower 1.5m fines upwards in overall bioclast size, but above is a level c. 1.0m thick of large Isognomon and Camptonectes with horizontal Thalassinoides seen on bedding plane surfaces picked out in shell fragments. The basal contact is planar over a large area but undulating in detail. The whole rock is a good example of a shelly bicalcirudite-biomicrudite.

Above, for nearly another metre, is a bioturbated (Thalassinoides) mixture of shell-fragments <10m and lime mud lacking whole shells or valves. For at least 3.0m above, equivalent to the Top Grey Micrite elsewhere, is a shell-fragment limestone containing oyster debris and occasional clasts of solenoporacean algae with a micrite matrix (probably a compacted pelmicrite.) The algal fragments reach 20mm but generally the sediment consists of micrite-enveloped sparite casts of aragonite bivalve material plus calcite bivalves and gastropod fragments (Plate 31). The upper part of the exposed bed contains algal fragments 5-10mm and fragments of calcitic and aragonitic bivalves, gastropods and echinoids. The topmost preserved sediment is sand grade but contains algal fragments about 3mm across. Laterally at Pbk1 on top of the Upper Shelly Freestone there is 0.9m of soft, honeycombed biomicrudite followed

by 1.5m of bioturbated shell-fragment rich micrite fining up for the next 4.5-5m to the base of the Purbeck Beds. However, the topmost 0.5-1m is again coarse and contains rolled solenoporacean fragments and bivalve debris up to 10-20mm. Above, the transitional laminated gastropod-ostracod rich limestone occurs- then stromatolitic algae. (Note: this is the only knownoccurrence of solenoporacean algae in the Portland Limestone Formation outside the Isle of Portland.)

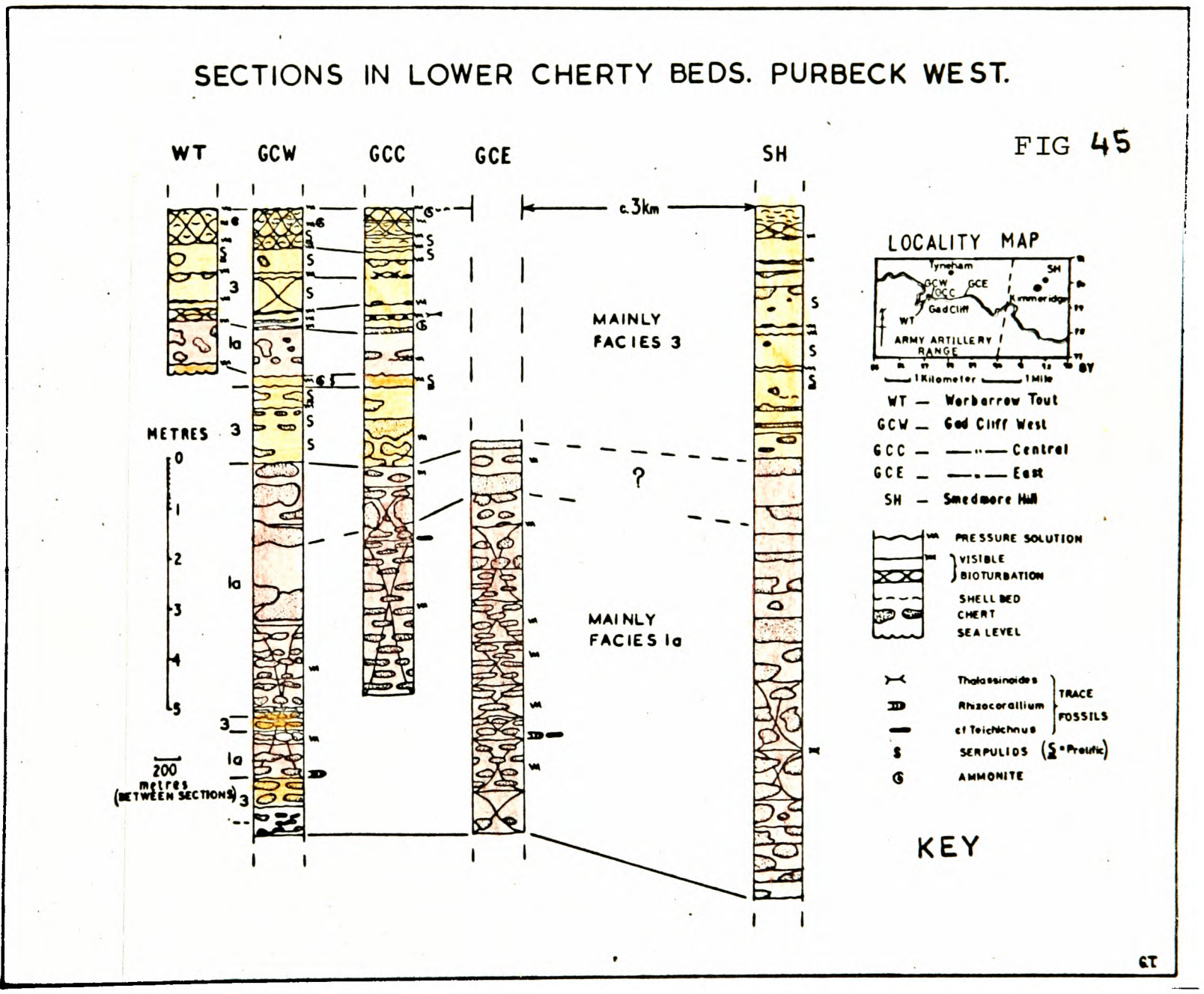
The Top Grey Micrite elsewhere is constant in its character with a basal metre of shell fragment rich micrite containing ammonites and Thalassinoides as well as whole bivalves. Cross-stratification is sometimes seen in this basal part as well as high angle straight burrows of the "Skolithos" type. The uppermost 3-4m is a uniform, hard, grey porcellanous limestone with scattered whole and disarticulated bivalves as well as common gastropods. Bioturbation and occasional current deposition structures are seen by weathering picking out shell fragment distribution. This sediment (facies 2 and 1) is a compacted original pelletal lime mud and must represent deposition in quiet water, probably very shallow, and between the supratidal deposits of the basal Purbeck and the higher energy carbonate sandbank areas seawards. The level of erosion is usually too low for complete preservation of the topmost bed but it is a constant feature in all the sections in the Purbeck East Area. This topmost bed, the junction with the Purbeck, consists of a laminated bituminous micrite with the "Cast Bed" in its lower part. This contains a fauna of ostracods, minute bivalves and gastropods, and extends at least as far east as Durlston Castle (Pbk 1).

WEST (52 thin sections were studied)

(i) Lower Cherty Beds

These thin westwards from 14m at SH (as in East) to 12.5m at GCW (see Fig. 45). The base and top are defined as in Purbeck East and the general division into an upper facies 3 and a lower facies 1a is applicable although there are detailed variations as exemplified by the section at GCW.

(a) Lower part: This has a transitional half metre of quartzose dolomitised micrite (quartz about 5%) and is followed by an extremely silicified and bioturbated massive block about 4m thick which is mostly facies 1a with Rhaxella spicules comprising up to 70% of the sediment in places (quartz about 1%). Facies 3 is present at some levels (see Fig. 45) and in these the quartz sand content can reach 15-20%. No body fossils have been found, except for one ammonite cast. The sediment is intensely bioturbated and this is accentuated by pressure solution and silicification. "Teichichnus" (?) burrows are seen on bedding planes (Plate 47).



(b) Upper part: This is facies 3 with an intercalation of facies 1a. Quartz content is about 1% but can be concentrated by pressure solution in Glomerula-rich horizons to 5%. This serpulid is very common in these beds and forms almost solid "serpulite" levels, but apart from the latter and skeletal fragments, there is very

little other fauna except for the occasional ammonite and echinoid. The chert content decreases upwards and the topmost bed is recognisable as J' of Purbeck East although it contains a higher proportion of shells. The description of the same beds in the Purbeck East Area generally applies here and apart from noting the approximate 10% decrease in thickness from Purbeck East and SH, to GCW, no more will be said at present.

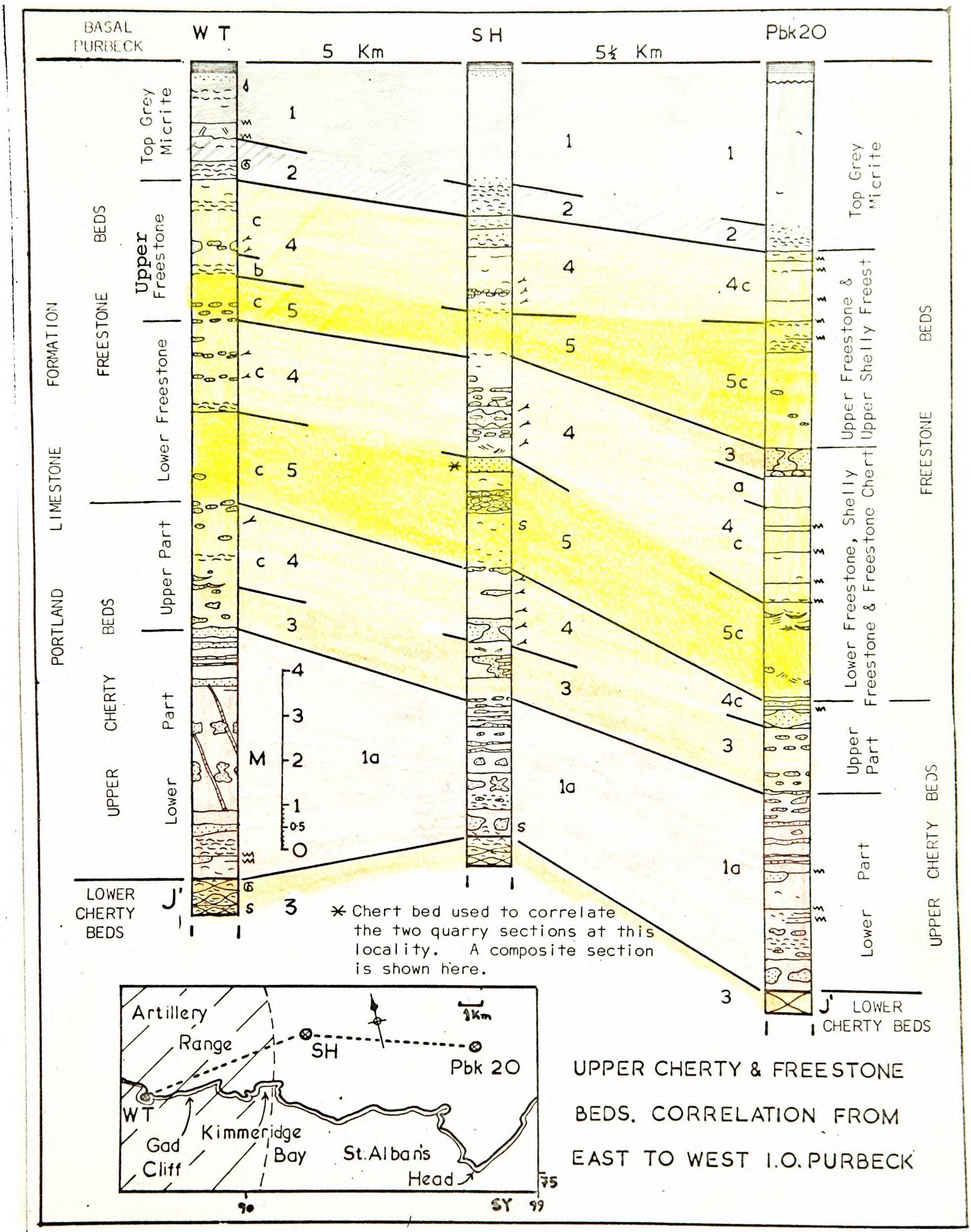
(ii) Upper Cherty Beds (6.5-8.5m)

It is not immediately obvious where to place the division between the Upper Cherty Beds and the Freestone Beds at SH in the east and WT in the west. The point taken is the transition from facies 4c to 5c at WT, which coincides with that taken by Arkell (1933). This can also be found at SH, making the beds only 6.5m as opposed to 8.5m at WT to the west (c.f. 7.5-8.5m in Purbeck East). The facies sequence is similar to that for Purbeck East, that is 1a-3-4, but instead of the upper part being 4a it is 4c (ooid biochem sand), an obvious reflection of the fact that the composition of the overlying bed is a biochemical oolite. This must reflect the proximity of West Purbeck to the site of ooid accumulation.

(a) Lower part: (facies 1a) This is 3.0m at SH and 5.5m at WT, but in both cases there is a very shelly bed (trigoniids) at the base followed by very cherty Rhaxella-rich micrite. Quartz sand is very rare or absent. The beds at WT are very fine grained and white weathering with big black chert nodules and oblique tectonic secondary chert veins. This facies is the most easterly extension of that found in the Central Area whereas at SH the beds are much more similar in physical characteristic to those at Purbeck East. In both sections the beds are not fossiliferous which is a contrast to the Purbeck East equivalents.

(b) Upper part: In both sections this consists of about a metre of muddy biochem sand facies followed by about 2.0m of medium biochem grainstone which by microscopic study at WT is seen to be facies 4c, in which the quartz sand content is < or = c.1%. Grey cherts occur as nodules and lenses silicifying sedimentary

FIG 46



UPPER CHERTY & FREESTONE BEDS. CORRELATION FROM EAST TO WEST I.O. PURBECK

structures, Pachastrella spicules are common throughout and at WT a shelly horizon develops (see sections in Fig. 46).

The Upper Cherty Beds are about the same thickness as in East Purbeck but much less rich in fauna; especially noticeable is the absence of well developed serpulid levels and the presence of admixed ooids. This may well represent a higher overall environmental energy and suitable for the accumulation of organic remains and may indicate proximity of an ooid sand body. The rare coral, Isastrea oblonga, has been recorded from an unknown horizon in the Cherty Beds (Woodward 1895, p. 193).

(iii) Freestone Beds

These thin from c.11.0m at SH to about 9.5m at WT (c.f. 14m-16m Purbeck East). Of the six informal units used in Purbeck East only the Top Grey Micrite and a general division into Upper and Lower part can be applied.

(a) Lower Part: This is about 4m thick and the original sediment consisted of a mixture of ooids and biochems. Thus, the lower half is facies 5c and the upper half 4c. At WT this lower 2.0m is homogeneous except for occasional small chert nodules, but at SH it is chertier and has shells and occasional serpulid knots. The upper 2.0m at WT has a basal shell bed followed by horizons of small black chert nodules in a Pachastrella rich sediment. At SH there is even more chert and a continuous basal sheet 0.3m thick makes a useful marker horizon for tying up between two quarry sections. On comparison with Purbeck East this lower 2.0m is thought to be a lateral facies equivalent of the upper part of the Lower Freestone and the upper 2.0m equivalent to the Lower Shelly Freestone and Freestone Chert Bed. The quartz sand content is < or c.1%.

(b) Upper part: This is about 3m thick. The lower metre is facies 5c with chert nodules at the base and occasional shells and obscure sedimentary structures throughout. The quartz sand content is less than or about 1%. This passes up through a shelly transitional 4b facies into a cherty shelly (trigoniids and pectinids) 4c facies at WT, see Fig. 46 .

The Top Grey Micrite is about 3.5m thick at SH and 2.5m at WT (c.f. 4-5m at Purbeck East). In both areas there is a basal shell bed 0.5-1m thick. It contains trigoniids at WT, but at SH it is composed mostly of Camptonectes, Isognomon and oysters. The trigoniids are mostly disarticulated with random orientation in all planes and a short biometric study confirmed the presence of two distinct genera Laevitrigonia gibbosa and Myophorella incurva (see Appendix, Fig. 16). Both types are preserved as approximately in situ death assemblages probably disturbed by current activity giving the typical inverted texture of facies 2. Other fossils include Protocardia, Ostrea, ammonites and crustacean remains. The quartz sand content of the sediment is very much less than 1% or zero. Above, the facies changes to the familiar white-weathering sublithographic limestone of Purbeck East (facies 1), with scattered shell horizons of Camptonectes, trigoniids and Glomerula. Also common are large vertical trace fossils ("Terebella") gastropods and shell fragments. The lower half of the topmost 0.5m contains minute casts of gastropods and bivalves - the "Cast Bed" of Purbeck geologists - and the upper part consists of finely laminated bituminous dark brown limestone which underlies the basal Purbeck algal limestones. The combination of these two is a characteristic feature throughout much of Dorset and makes a useful datum line as far east as Pbk 1.

4. The Portland Limestone Formation in the Central Area, Dorset

A. Introduction

This is a less extensive area than that in the Isle of Purbeck or the Western Area, being restricted to the coastal cliffs from Bacon Hole (SY 839796) (Mupe's Bay) in the east to Durdle Door in the west (SY 805803), a distance of 3.6km (Fig. 17). The dip along this stretch varies from 30-50° to the north but although the Portland Limestone Formation is at its thinnest here there are no complete sections in the Portland Sand Formation, below the Black Dolomite Beds. None of the cliff sections can be examined in comfort except that at Dungy Head, but even there the steep dip and associated faulting adds complications. One compensation, however, is that when one actually does scramble to a section, preferably at low tide and in calm weather, the salt water weathering greatly facilitates study of the rock and the fossils, contrary to the opinion of Arkell (1935, p. 319) who decided that "the rock is too sea-etched to favour examination". The best examples of this are on the seaward sides of Stair Hole (SY 821798) and Durdle Door, the latter of which can be reached only by sea (in my case by swimming).

Six sections in the Portland Limestone have been measured, two of which extend down to the upper part of the Portland Sand Formation, (SBW & DH). The eastern three sections are on the Lulworth Artillery Range but the hazards of visiting those are far less than those encountered at Gad Cliff.

B. Description of Beds (30 thin sections were made)

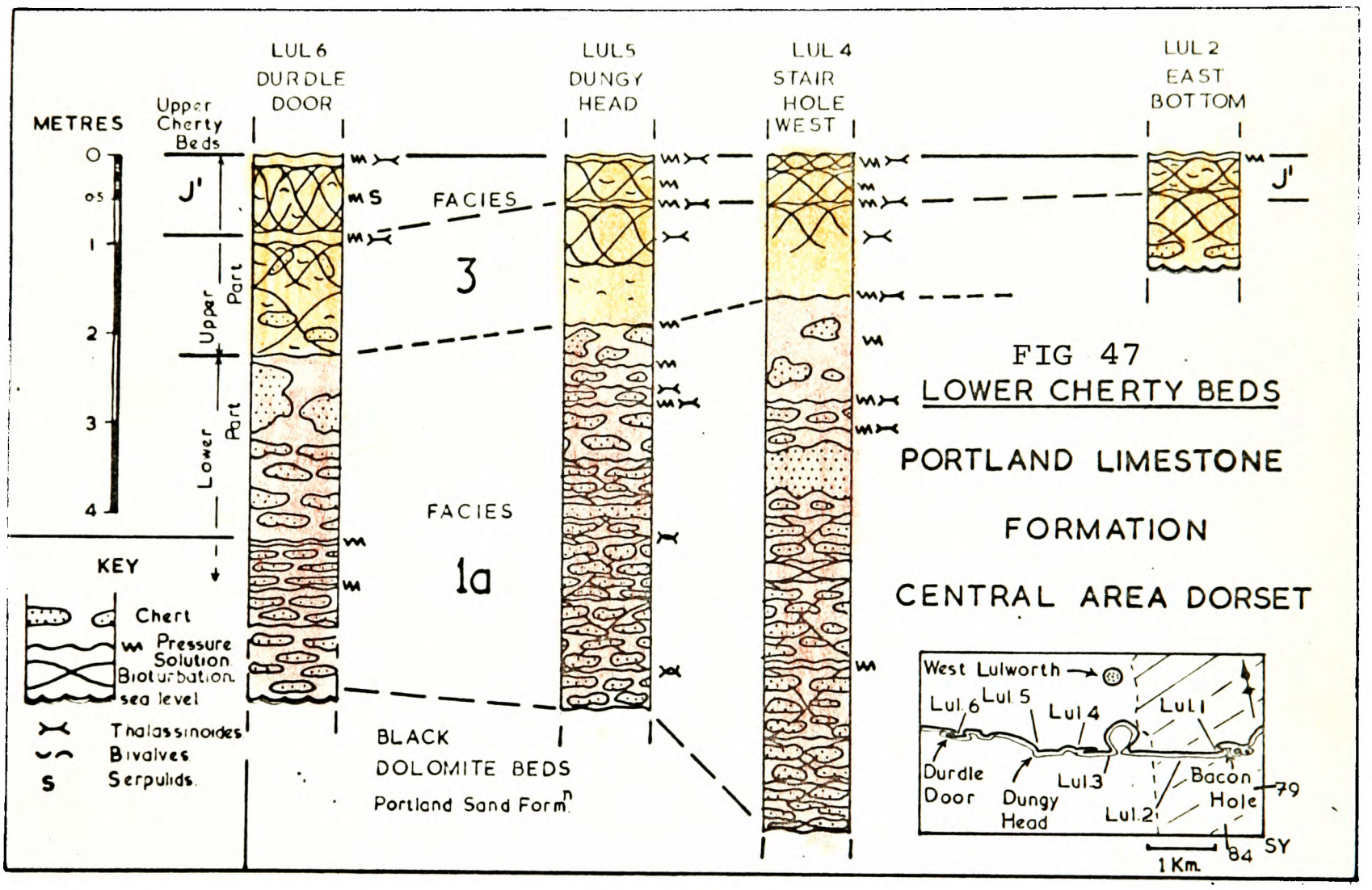
The Lower Cherty Beds and J', the Upper Cherty Beds and Freestone Beds are all still recognisable although the Top Grey Micrite becomes oolitic from east to west and then the name cannot be applied in the western section where the Upper and Lower Freestones become one unit.

(i) Lower Cherty Beds 8.0-7.5m (Fig. 47)

It is still possible to define these by the top of J' and the top of the Black Dolomite Beds below. They can again be

divided into a lower 4-6m facies 1a and an upper 1.5-2m facies 3.

(a) Lower part: This has the typical development (as at Gad Cliff, Purbeck West, for example,) of highly silicified limestone with Rhaxella comprising up to 60% of the sediment. The effects of pressure solution on bioturbated siliceous sediment are as elsewhere and the general remarks made on the Purbeck West equivalents apply here. The quartz sand content is very much less than 1%.



(b) Upper part: This is about 1.5-2m thick and similar to that in Purbeck West except that serpulids are no longer common and very little fauna occurs at all, except for scattered shell fragments and a few bivalves at Lul 6 (Durdle Door). There is not much chert either, and quartz sand content is about 1% (see Fig. 47). Bed J' thickens from 0.5-1.0m from east to west and is fairly shelly with a quartz sand content much less than 1%. The section at Lul 6 is the most westerly extension of this bed recognisable as J'. It must be noted here that the "condensation" in the Portland Limestone Formation takes place most drastically in the Lower Cherty Beds.

Arkell's section for Dungy Head is given in Fig. 19 (Chapter 3).

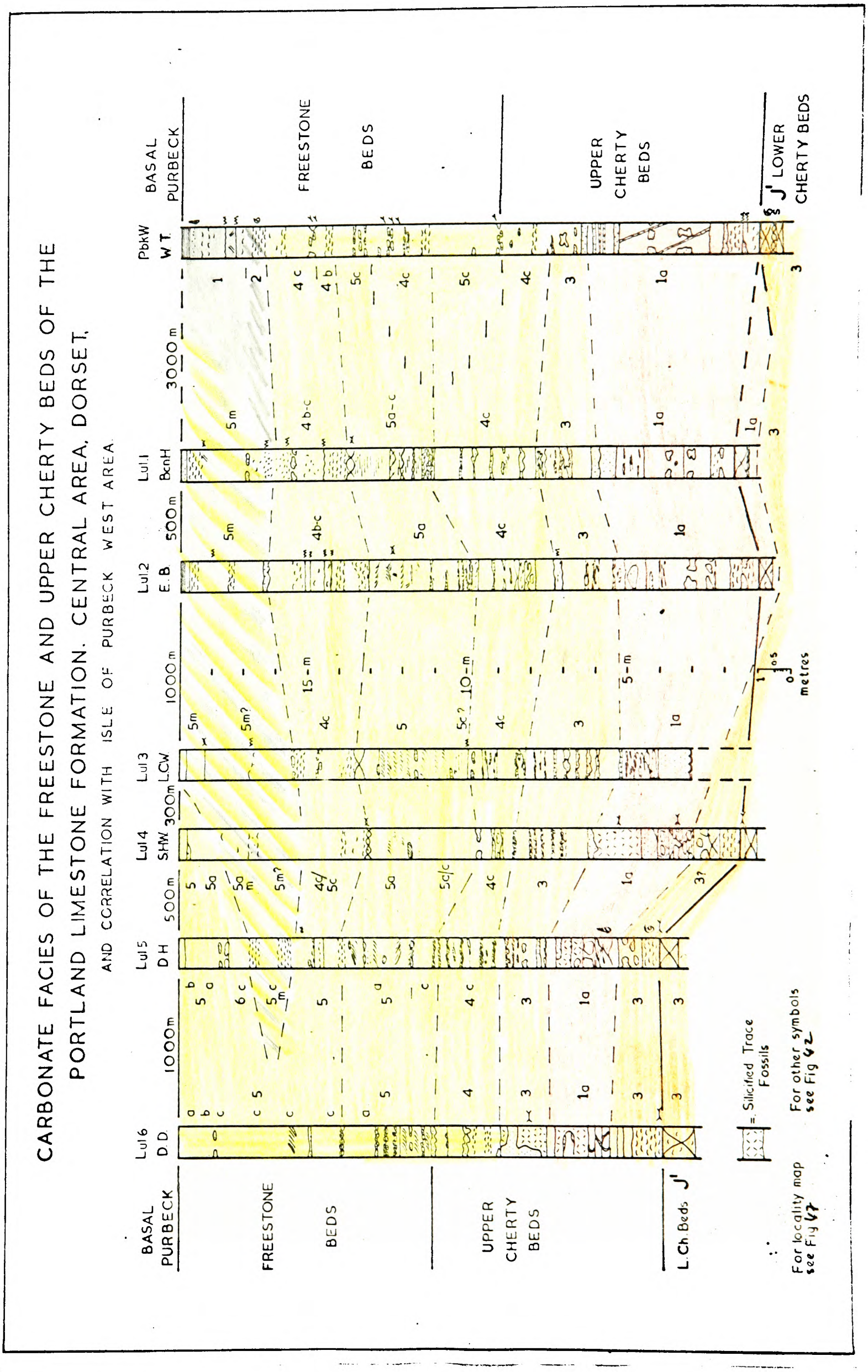
(ii) Upper Cherty Beds (about 7.5m) (Fig. 48, 50)

There is some difficulty in dividing this from the Freestone Beds in the field so the boundary between facies 4 and 5 is taken (as at GCW/WT). This is recognisable at Dungy Head (Lul 5) as the base of the lowest current bedded oolite and makes the Upper Cherty Beds there about 4.5m thick. The facies sequence is as for Purbeck West, i.e. 1a-3-4c, except for the lowest bed which is facies 3, as is J' below. The shell bed overlying J' contains a diverse, well preserved fauna akin to that of the Basal Shell Bed of Portland and the Top Grey Micrite of the Isle of Purbeck, i.e. several types of bivalve, Glomerula, ammonites, large and small gastropods and occasional echinoids. The sediment is poorly sorted and originally the matrix is mostly micropelletal lime mud which compacted to micrite when not protected by shell fragments. Immediately above, the lower part of facies 1a contains shell fragments but otherwise is relatively fossil free. The quartz sand content is very much less than 1%.

The eastern three sections are similar to the ones at Purbeck West in having the white micritic limestone (facies 1a) with large black cherts. In the western three, the upper part of this facies 1a sediment was burrowed (Thalassinoides) and the tubes have been selectively silicified to give a white rock with black chert burrows running through it (Plate 50, 51). In places this very distinctive rock has been resilicified and the early chert recrystallised to fine grained quartz giving a dark grey rock with light grey patches. This is best seen at Lul 3 in association with local folding and faulting.

Above this fine grained, very silicified, limestone the rock is facies 3, that is to say the sediment changed to a fine carbonate sand with a lime mud matrix. At Dungy Head (Lul 5) the upper part (suddenly) contains 10-15% fine quartz sand (quartzose biomicrite). Small grey chert nodule horizons are common at closely spaced intervals and probably represent spicule-rich depositional horizons. Above this, ooids become an accessory constituent and the sediment

Fig 48


CARBONATE FACIES OF THE FREESTONE AND UPPER CHERTY BEDS OF THE PORTLAND LIMESTONE FORMATION. CENTRAL AREA, DORSET,
AND CORRELATION WITH ISLE OF PURBECK WEST AREA.
BASAL PURBECK
FREESTONE BEDS
UPPER CHERTY BEDS
L.Ch Beds J'
Lul6 D.D
Lul5 D H
Lul4 SHW
Lul3 LCW
Lul2 E.B
Lul1 BcnH
PbkW WT
1000m
500m
300m
3000m
= Silicified Trace Fossils
For locality map see Fig 42
For other symbols see Fig 42
metres

grain size increases to medium biochem sand with 10% quartz in the lower part. No body fossils or obvious shell fragments are seen at this level. Where facies 4c immediately underlies 5c of the Freestone Beds the original sediment was poorly sorted ooid biochem sand with patches of lime mud matrix.

(iii) Freestone Beds (about 8m) (Lul 5) (Fig 48, 50) (Plate 49, 51)

The divisions used in the Purbeck West Area can no longer be applied. The Top Grey Micrite becomes oolitic, but can be delineated in most of the sections as the Top Oolitic Micrite (see Fig. 48 Facies 5M). The Upper and Lower Freestones merge into one sequence of oolite which is here locally divided into Oolite Beds and Shelly Oolite Beds above. This division may possibly correspond to the division between facies 5 and 4 in the Upper Freestone of west Purbeck (Fig. 46).

Oolite Beds: The original sediment was generally a homogeneous ooid sand (oosparite), often with a transitional biochem ooid sand at the base. It is, on average, 3m thick and shows well preserved depositional and bioturbation structures. Minor silicification exists but is associated with depositional structures and varying composition of the sediment. Good examples are seen at Bacon Hole (Lul 1) and on the west side of Lulworth Cove (Lul 3), see Fig. 49. The ooid sand was probably deposited as small dunes, with trough cross strata, which moved in varying directions at intermittent periods. During quiet conditions the tops of the units were burrowed and structures destroyed to a variable depth. Some straight high-angle tubes occur with a micritic lining which presumably indicates that the sand was unstable at the time of burrowing.

Shelly Oolite Beds: Above the main oolite bed there is a shell accumulation (except at Lul 6) which is often burrowed down. Above this in the eastern three or four sections the sediment was originally shelly intraclastic and oolitic biochem sand, or in the western sections shelly biochem ooid sand. The shell beds are dominantly the typical current-disturbed trigoniid beds (calcite casts or empty moulds) with occasional horizons of

SEDIMENTARY STRUCTURES IN THE FREESTONE BEDS IN THE CENTRAL AREA, DORSET.

FIG 49

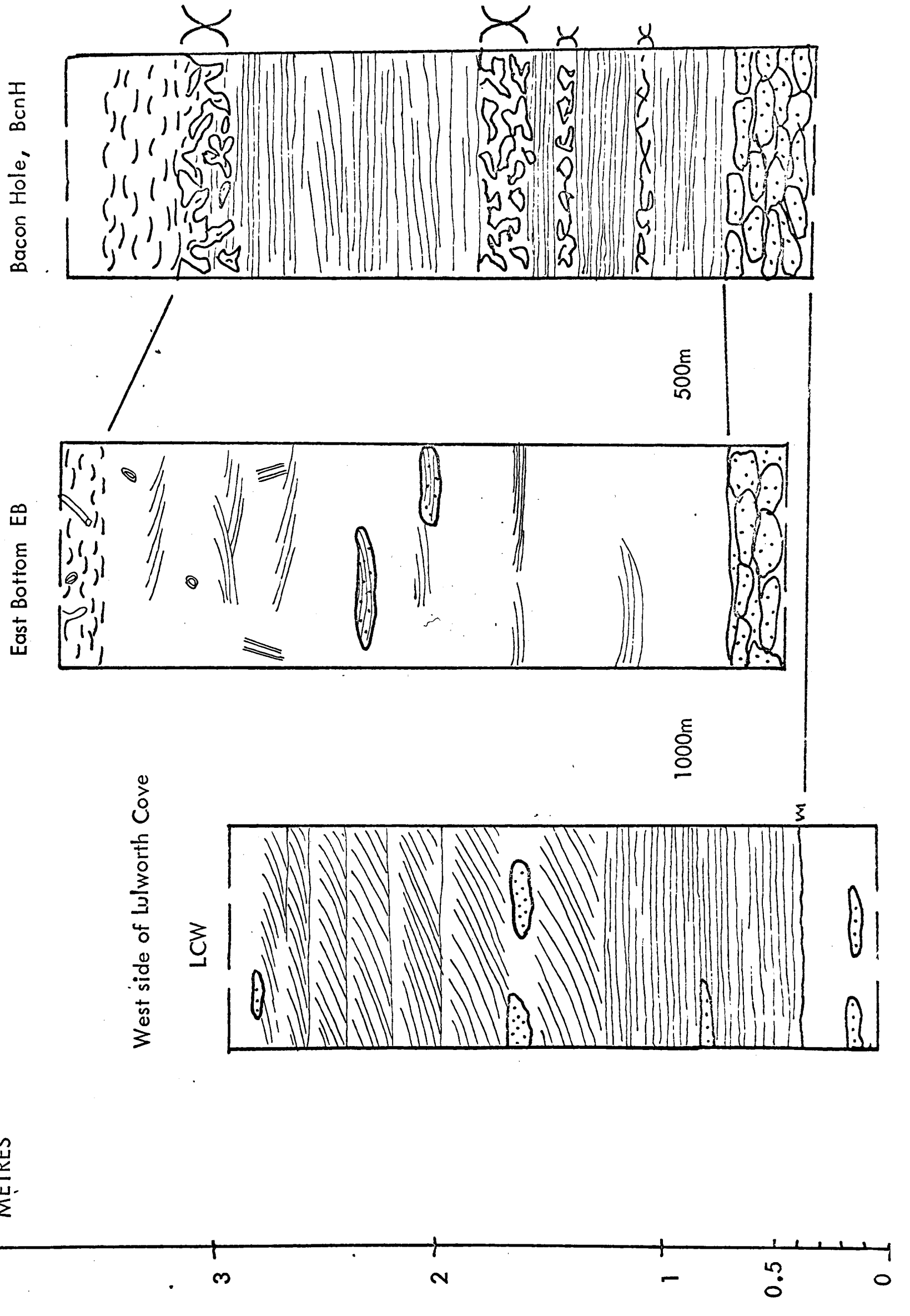


FIG 50

REPRESENTATIVE SECTION OF THE UPPER CHERTY BEDS AND THE FREESTONE BEDS, PORTLAND LIMESTONE FORM.ᴺ CENTRAL AREA, DORSET. SECTION LUL5, DUNGY HEAD (SY 816799)

BASAL PURBECK

PORTLAND LIMESTONE FORMATION

UPPER CHERTY BEDS — c.7½ metres

FREESTONE BEDS (Upper Part) — c.8 metres

Facies	M	SEDIMENT	FOSSILS
5b	0.20	Poorly sorted intraoosparite.	Minute bivalves
5a	1.10	Well sorted medium oosparite (ooids not micritised).	Bivalve fragments.
	0.30	Brown chert.	
6c	0.65	Bioclastic intrasparite. Calcite bivalve shell bed at base.	
	0.30		Isog., Gamet.
5c m	0.60	Bioclastic oomicrite with intraclasts of oo- and biomicrite. Q. < 1%.	
5c	0.40	Compacted bioclastic oosparite with stylolite seams. Shell beds with aragonite dissolved to leave empty moulds ('roach') Q. < 1%. Some silicification at pressure solution horizons.	Trigonia. shell beds.
	0.65		
	0.40		
	0.40		
	0.25		
5a	0.60	Compacted oosparite. Partial silicification of structures.	No fossils.
	1.45	Current bedded medium oolite with occasional white silicified nodules. Cross sets to NW and SE.	Shell fragments at top.
5c	0.60-0.65	Well sorted } Bioclastic oosparite. Q. < 1%.	No body fossils.
	0.20	Poorly sorted }	
4c	0.75	Poorly sorted. Patches of micrite and sparite. (Packstone). Scattered ooids.	
	c.0.75	Q. c1%.	
	0.50	Q. 10%. Oolitic biosparite.	
3	0.40	Q. 10-15% of sediment. Biomicrite.	Occ. shell fragments.
	0.95	Very mixed sediment. Patches of Rhaxella spicules and occasional ooids. Q. -0.	No body fossils.
	0.60	High proportion of Rhaxella. Q-0.	
1c	0.60	Early silicification of trace fossils.	Thalassinoides (silicified)
	0.70	Later massive silicification of whole rock. Q-0.	
1a	0.75	White micrite. Some black chert nodules. Q. 1%.	Scattered tiny bivalves and gastropods.
	0.75		
S3	0.55-0.60	Very hard, grey, poorly sorted shelly biomicrite. No chert. Q. 1%.	Bivalves, ammonites Glomerula, tiny gastropods.

Camptonectes and Isognomon. The rock contains occasional chert nodules and styolite seams.

Top Oolitic Micrite and associated equivalents: In the Purbeck Area the beds at this level are lime mud facies with or without shells, but in the central area the original sediment was composed generally of ooids with a lime mud matrix - a grain-supported packstone or oomicrite (facies 5M) which is often shelly and stylolite-shot. Its distribution is visible on Fig.48 . The topmost transition with the Purbeck Beds is the usual laminated ostracodal limestone with small bivalves and gastropods. In the three western sections, however, the oomicrite facies fades out to be replaced by a mud-free oolite; i.e. a continuation of the underlying beds.

At Dungy Head (Lul 5) (Fig 50) there is >1.0m of biochemical oomicrite (5cM) with biochemical oosparite below. Above is a biochemical intrasparite followed by a topmost oosparite and intraclastic oosparite. At Durdle Door (Lul 6) the sequence is biochemical oosparites all the way to the top except for an uppermost metre of intraclastic oosparite and oosparite. The intraclasts are generally oomicrite indicating contemporaneous erosion of facies 5cM. Thus, at Dungy Head, the vertical sequence in the Freestones 5c-5a-5c-5cM-6c-5a-5b is interpreted as representing an initial ooid sand mass (5a) which covers a substrate of 4c in a high energy slow deposition environment which eventually became low energy and shell beds developed 5c. This sediment then became mixed into a low energy environment and ooids became set into a lime mud matrix (5cM). After this, however, another high energy event occurred and erosion of 5cM produced intraclasts, 6c. This was followed by a thin homogeneous mud-free ooid sand which finally itself contained intraclasts forming facies 5b before being covered by the basal Purbeck algal facies.

5. The Portland Limestone Formation in the West, Mainland, Area. Dorset.

A. Introduction

The most westerly exposure is about 1km east of the village of Portesham, where the Jurassic is faulted against Cretaceous, and is about 16km WNW of the most easterly outcrop of the area at Ringstead Bay (Fig.21). Between these two extremes there are less than half a dozen localities where the beds may be seen and only two where the whole succession is available.

The critical, atypical exposure is at Ringstead Bay, (SY 7681) and is described in detailed sections which include the upper part of the underlying Portland Sand Formation. (Fig.52,53). This outcrop is 4.7km west of the westernmost Central Area section (Durdle Door) but is much more comparable with the latter than with the quarry at Poxwell 2.7km to the north-west (SY743835). There is such a distinct facies change from Ringstead to Poxwell that it is very difficult to correlate subdivisions of the Formation within this distance and further west (see Fig.54a). Another detailed section is hence given of the more typical situation in the Western Area, at Chalbury Camp Quarry about 4km north of Weymouth (SY 694838) (Fig.44).

B. Description of the Beds

100 thin sections were studied.

RINGSTEAD BAY

The details at this locality are combined from two close sections, underlying Cliff House (SY 762815) and Holworth House (SY 764815). The beds dip at c.30° on the southern limb of the Upton Syncline and are downfaulted against the Upper Kimmeridge Clay beds, visible under Cliff House. This latter section shows a complete sequence from Purbeck Beds to the Portland Sand Formation but the transition with the latter is best seen in the eastern (less accessible) exposure. Holworth House stands on the overlying unconformable Upper Cretaceous and for general details of the geology of the area one is referred to the excellent

1:21200 map by Arkell in the relevant Survey Memoir (Arkell 1947a) Isolated outcrops of the Basal Shell Bed also exist at Ringstead Bay (SY 753820) and South Down Farm (SY 757822).

Reference to Fig. 51 will show how it is suggested that Bed J' of the Eastern and Central Areas (which defines the top of the Lower Cherty Beds and is constant in form, despite slight facies change, for nearly 22km) is equivalent to and correlatable with the Basal Shell Bed of the Western Area. There are many reasons for coming to this opinion and these are discussed in the section on the Isle of Portland.

When the top of the Portland Sand Formation is defined by the top of the Black Dolomite Beds, as is already accepted in the Eastern and Central Areas (Arkell 1935), it is seen that the lowest beds of the Portland Limestone Formation are a calcareous clay followed by lime mud and a shell bed; these are equivalent to the Lower Cherty Beds.

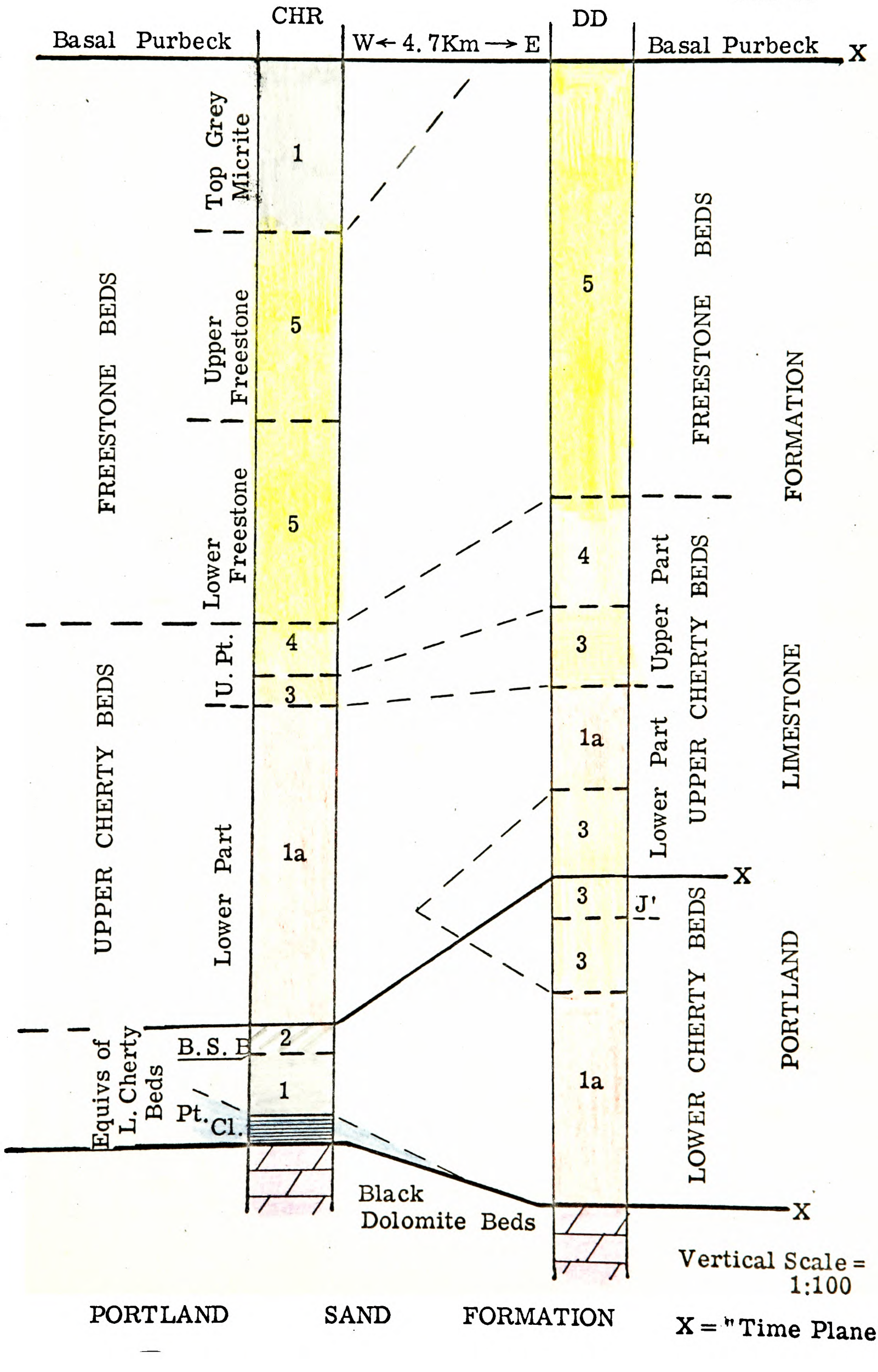
(i) Lower Cherty Beds (Portland Clay Beds and Basal Shell Bed) (Fig. 52 , also see Fig. 25).

(a) The Portland Clay Beds: These are a lateral facies equivalent of the lower part of the Lower Cherty Beds and at this locality the clay is only 0.25-0.3m but increases in thickness to the south and west to about 4m at Chalbury and a maximum of c.6m in the north of the Isle of Portland. Between this clay and the Basal Shell Bed is 1.3m of bioturbated chalky limestone which appears to be laterally equivalent to the upper part of the Portland Clay Beds elsewhere in the West Area because elsewhere the Basal Shell Bed rests directly on the Portland Clay. This sort of correlation is disputable but on consideration of the overall model to be later developed it is a reasonable conclusion (see Fig. 82).

(b) The Basal Shell Bed: This is only 0.7m thick (Durdle Door, J' = 0.75-1.0m) but contains the usual assemblage of trigoniids, Pleuromya, Protocardia, Camptonectes and ammonites as well as echinoid debris and gastropods in a bioturbated lime-mud matrix. This is regarded as a correlatable bed over all the Western Area, including the Isle of Portland. It will be discussed in more

FACIES CORRELATION AND BED NOMENCLATURE OF THE PORTLAND LIMESTONE FORMATION FROM THE CENTRAL AREA TO THE MAINLAND WEST AREA, DORSET. DURDLE DOOR & DUNGY HEAD TO CLIFF HOUSE, RINGSTEAD BAY.

FIG 51



PORTLAND SAND FORMATION

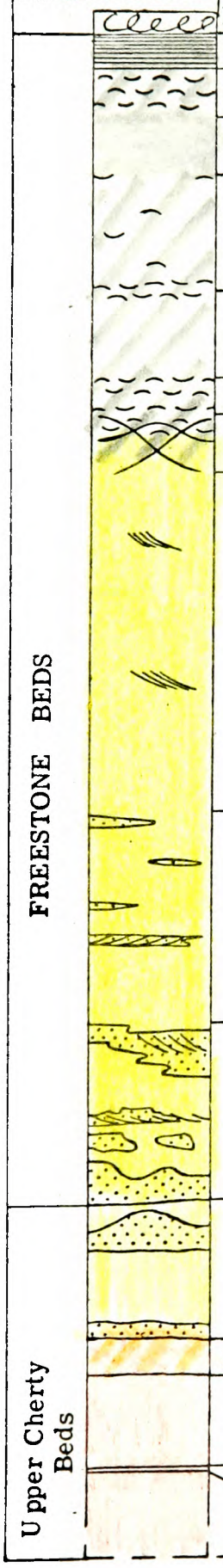
SECTION IN THE LOWER PART OF THE PORTLAND LIMESTONE FORMATION AND THE UPPER PART OF THE PORTLAND SAND FORMATION. WEST MAINLAND AREA. RINGSTEAD BAY. CLIFF HOUSE AND HOLWORTH HOUSE. (SY 764815)

FIG 52

		Facies	M.	Sediment	Common Fossils
PORTLAND LIMESTONE FORMATION	UPPER CHERTY BEDS	1a	1·40	Lime mud with 5-10% *Rhaxella* spicule voids but also with high proportion (prob > 50%) very fine straight spicules. Horizons of black chert nodules and later, highly-inclined, tectonic sheets.	No fossils other than *Rhaxella*.
		1a	0·7		
			c0·2	Q=0.	
			c0·55	Lime mud with *Rhaxella* and a lot of *Pachastrella* voids.	*Pachastrella* *Rhaxella*
			c0·6	Lime mud with < 10% *Rhaxella*. Also *Pachastrella, biv & Gast frags.*	
		2	c0·5	Lime mud with shells and fragments. < 1% *Rhaxella*.	
		S 1a S	1·50	Lime mud with current oriented (?) serpulids. 10-20% *Rhaxella* voids.	*Glomerula*
	LOWER CHERTY BEDS — Basal Shell Bed	2	0·70	Bioturbated lime mud with shells and fragments of calc & arag bivs, gastropods, echinoderms & *Rhaxella*.	Bivalves, Ammonite.
		1	c1·30	Bioturbated lime mud. (soft chalky white micrite). Occ shell fragments.	Occ. fragments.
	Equiv. to Portland Clay beds		0·25-0·30	Argillaceous lime mud. < 1% Q.	Occ calc biv frags.
PORTLAND SAND FORMATION	Equivalent to CAST BEDS and BLACK DOLOMITE BEDS		c0·55	Dedolomitised. No quartz.	
			c0·4		
		A'' -Rh	c1·45	Lime mud with 60-70% *Rhaxella* casts. Silicification horizons.	Ammonites *Rhizocorallium* bioturbation.
			c0·25	Rhomb mosaic dolomite. Q<1.	
		S B+ A''	1·70	Partial silicification and decalcified shell bed. Dolomite. Partial dolomitisation of lime mud. Residual nodules of shelly micrite in dolomite matrix.	Serpulids, *Trigonia*, *Camptonectes*.
		B	1·0	Rhomb mosaic dolomite, probably argillaceous. Originally lime mud.	Scattered tiny moulds.
		C	0.55	Argillaceous dolomite. Partly dedolomitised.	Exogyra
	EXOGYRA BEDS		c 0·9	Quartoze shelly biomicrite. Q. c10% (vf-f). *Exogyra* shells in lime mud matrix. Frags of calc and arag bivs, gastropods and serpulids.	*Exogyra*, ammonites.

SECTION OF UPPER PART OF PORTLAND LIMESTONE FORMATION IN THE WEST MAINLAND AREA. RINGSTEAD BAY. CLIFF HOUSE. (SY 763816)

FIG 53



Basal Purbeck	Facies	M.	Sediment	Common Fossils
FREESTONE BEDS	1	0·25	Laminated lime mud + ooids & pellets.	Minute bivs & gasts plus ostracods.
	2	0·40	Shell bed, decalcified.	*Trigonia* moulds, *Camptonectes* and minute bivalves.
	1	0·50	Lime mud.	
	2	1·0	Scattered bivalves with shell bed at base. Lime mud with bivalve fragments.	Scattered *Trigonia* and *Camptonectes*. Ammonites.
	2	0·7	Lime mud with admixed carbonate sand.	
	2	0·3	Bioturbated shell bed. Q = 0.	*Trigonia* moulds.
	5M		Bioturbated contact with bed above gives mixture of ooids and lime mud.	
	5a	c3·3	Very porous, poor to moderately well sorted, medium ooid sand. Current bedding with graded foresets seen but exposure very soft and weathered. General direction to south.	No fossils except occ forams and shell fragments as sand grade constituents.
			Quartz c.1% medium.	
	5b	c1·0	Intraclastic (oolitic) poorly sorted medium ooid sand. Variable degree of cementation. Partly silicified current depositional structures.	No fossils.
		c0·75	Q.1-5 med.	
	5a	1·5	Well sorted fine ooid sand, only part cemented, very friable. Ooids superficial on qtz and shell fragments. Silicification horizons. Q.1-5 med.	
	4c	0·45	Porous, only partly cemented fine to medium ooid biochem sand. Q.1-5M.	
		c0·75	Chert at base. F. well-sorted pellet sand?	
Upper Cherty Beds	3			
	1a/3	1·10	Admixed biochem sand and lime mud. Lime mud with 30-40% *Rhaxella* voids and casts. Q = 0.	*Rhaxella* spicules.
	1a			
		0·02m	Laminated argillaceous lime mud with c30% siliceous *Rhaxella* spicules.	

detail in the description of the latter area.

The Lower Cherty Beds at Ringstead are thus only about 2.25m thick whereas in the Central Area they are 6-7.5m and in the Eastern Area 12.5-14m. At Chalbury Camp the Portland Clay and Basal Shell Bed total about 4.5m and on Portland they are about 7.5m. Thus, as already noted, condensation of beds in the Portland Limestone Formation in Dorset takes place most dramatically in the lowest division, the Lower Cherty Beds and its lateral facies equivalents. This Ringstead Bay outcrop also displays the thinnest sequence of the Portland Sand Formation and it is here that the Kimmeridge Clay thins to half the thickness it is at Kimmeridge and two-thirds that further west around Portesham.

(ii) The Upper Cherty Beds (7.75m)

The facies is essentially lime mud with varying proportions of Rhaxella and Pachastrella spicules, bivalves and serpulids, totalling about 7.75m. (Central Area c. 7.5m, Eastern Area maximum 8.5m, Isle of Portland 14-15m?) and is described with the section in Figs.52,53 and can be compared with that for the Central Area in Fig.51 . The Topmost 1m contains pellet sand, ooids and biochems.

(iii) The Freestone Beds (9.5m)

These can be divided into the Lower Freestone Beds, 3.25m of unfossiliferous cherty oolitic biocalcarenite and biochemical oolite, followed by the Upper Freestone Beds, 3.3m of unfossiliferous oolite,and the Top Grey Micrite Beds, 3.15m of shelly micrite underlying the Basal Purbeck (Fig.53). The facies of the top division is similar to that at the top of the Portland Limestone Formation in the Isle of Purbeck which becomes a muddy ooid sand in the east part of the Central Area (Figs.46,48) and a mud-free ooid sand at Dungy Head. West of Ringstead, on the Mainland, this lime mud facies becomes dominant through the whole carbonate succession, (Figs.54, 54). This takes place within only 2.7km, but similar changes can be studied in detail within shorter distances on the Isle of Portland where there are many local variations and all mixtures of ooids, biochems and lime mud are

represented. The Freestone Beds at Ringstead are about 11m but are only about 8m on Portland and in the Central Area and do not thicken until the Isle of Purbeck where in the west they increase from 9.5 to 11m and in the east from 14 to 16m.

CHALBURY CAMP SECTION

In the summer of 1969 a Gas Council pipeline trench was dug across the hill immediately west of Chalbury Camp and some detailed mapping of the area was possible (Fig. 22) (Townson 1972 in press). The trench repeated the succession visible in the large quarries by Coombe Valley Road on the west hillside of Chalbury Camp and extended it, southwards, down through the Portland Sand Formation to the upper part of the Kimmeridge Clay. The quarry in Chalbury Camp hillside exposes the lowest of the Purbeck Beds and all the carbonate facies of the Portland Limestone Formation; the Portland Clay Beds were exposed in the trench section and thus the whole succession was examined. As is seen from the detailed section (Fig. 54) the carbonate facies is all lime mud with varying proportions of shells and sponge spicules. With the exception of the Ringstead outcrop it is no longer possible to apply the bed names used elsewhere in Dorset and all the beds above the Basal Shell Bed are termed the Cherty Micrite Beds and divided into Beds A, B, C, and D which must be equivalent to the Freestone Beds and the Upper Cherty Beds. No correlation is attempted other than that depicted in the general sections of Fig. 59a.

(i) Lower Cherty Beds

(a) The Portland Clay Beds (c.4m): These beds are never permanently exposed but when seen in the temporary trench section the sediment was a dark grey-brown clay, apparently unfossiliferous, which seemed identical in characteristics to that more satisfactorily exposed on the Isle of Portland. The beds in the trench section were very much distorted by hill-creep and cambering so the thickness of 4m is an approximation calculated after taking into account the effect of the disturbances.

SECTION OF PORTLAND LIMESTONE FORMATION. CHALBURY CAMP QUARRY. (694838) MAINLAND WESTERN AREA, DORSET.

FIG 54

Basal Purbeck		Facies	M.	Sediment	Common Fossils
CHERTY MICRITE BEDS	BEDS A		0.4	Laminated Micropelletal lime-mud.	
		1	c1·2	Porous micropelletal lime mud with bivalve fragments and occasional intraclast.	Occ. *Camptonectes*, and moulds of *Protocardium*.
			3·1	Very fine-grained lime mud (<1μ) with scattered grains of very fine biochem sand. No quartz grains.	
				Lime mud with occasional scattered casts of *Pachastrella*, *Rhaxella*, minute gastropods and fine bivalve and echinoderm fragments.	Occ. *Pleuromya* moulds. *Pachastrella* *Rhaxella*, gastropods echinoderms, bivalves
	BEDS B	1a	0·9	Lime mud (micropelletal) and scattered casts of *Pachastrella*. *Rhaxella* casts and voids c. 20%.	*Pachastrella* and *Rhaxella*.
		c	0·8	Bioturbated lime mud with *Rhaxella* casts and voids c. 40%.	Trace fossils and Crustacean fragments
		6	0·7	Lime mud, rich in bivalve fragments in lower part. No *Rhaxella*.	Occasional forams, ammonites, poorly preserved bivalves. *Trigonia?*
		1	1·0		
	BEDS C	1a		Micropelletal lime mud. *Rhaxella* 30-40% + skeletal fragments.	*Rhaxella* and frags of biv, gast & ech.
			1·0	c1%	
		1	0·5-0·6	c5%	*Rhaxella* throughout.
			0·4-0·45	1-5%	
			0·50	c20%	
			0·60-0·65	30-40%	Occasional *Pleuromya* and *Trigonia* moulds.
			0·40		
		1a	0·3	Lime mud with varying proportions of casts and moulds of *Rhaxella* spicules, plus occasional scattered bivalve echinoderm and serpulid fragments, occasional forams and (?) ostracods. Quartz = 0.	
			0·55	30-40%	
		m?	0·1	Thin soft argillaceous lime Mud horizon.	Occasional small *Camptonectes*.
			0·2	c30%	
			0·3	1-5%	
			0·3-0·35		
	BEDS D	1	c1·2-1·3	5-10%	Occasional *Isocrinomen*
		6	c0·7	Bioturbated micropelletal lime mud with shell fragment sand. Only scattered *Rhaxella*.	Trace fossils and shell fragments in burrows.
		1	c0·5		
			GAP	NO EXPOSURE	
BASAL SHELL BED			c0·5		
		2	c0·4	Shelly lime mud with poorly sorted whole and fragmented biv, gast & ech remains, scattered *Rhaxella* casts.	*Pleuromya*, *Camptonectes*, *Trigonia*, crustacean frags, tiny gasts, serpulids, *Pachastrella* and *Rhaxella*.
		Total = about 17¼m			
PORTLAND CLAY BEDS				By comparison with a nearby temporary exposure, Basal Shell Bed is about 0·4 m and below is about 4 m of Portland Clay Beds.	

(b) The Basal Shell Bed (0.4m): This directly overlies the clay. In the trench, immediately above was a bed rich in serpulids, (basal D) as at Ringstead, then the succession was as in the quarry and as depicted in the Fig. 54. Above are beds D, C, B & A in ascending order.

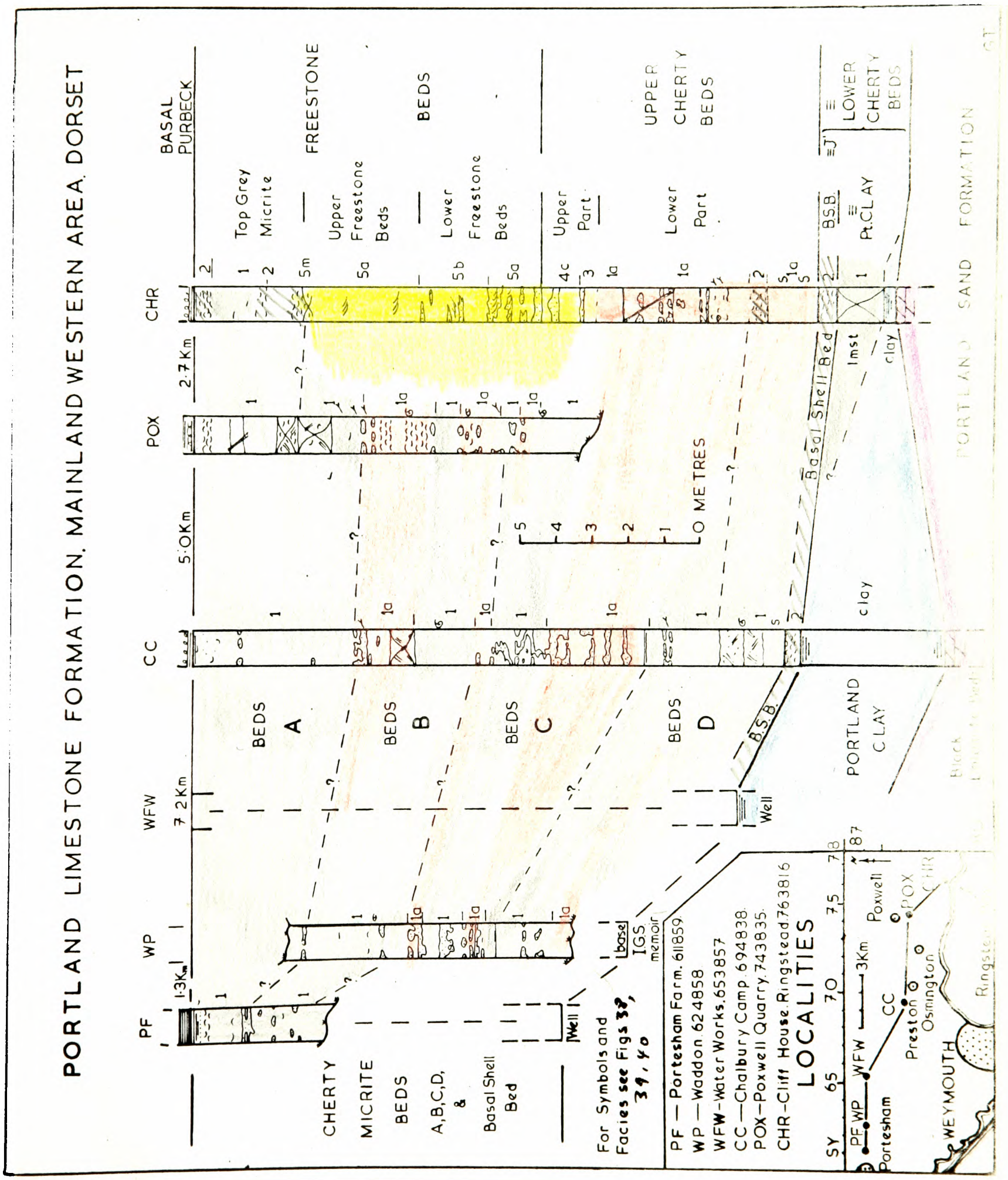
(ii) Upper Cherty Beds and Freestone Beds (Cherty Micrite Beds)
Beds D 3.75m: The lower half is a visibly bioturbated lime mud with shells, serpulids, debris and ammonites. The upper part contains black "flint-like" chert nodules and Rhaxella spicules become an essential component of the sediment.

Beds C 4.45m: The base is defined by a thin argillaceous lime mud "seam" which is probably accentuated by pressure solution and which may be possibly represented at the quarry at Waddon (Fig. 54 WP). Beds C contain a lot of sponge spicules, which are now seen as empty voids or as sparry calcite casts in the limestone but in the cherts they are preserved as the original silica sterrasters. These beds are the most silicified in the succession and the black cherts appear in a variety of large grotesque forms up to half a metre thick and in discontinuous nodular horizons.

Beds B 3.4m: The base is taken at the top of the last chert level of Beds C and at the facies change from 1a to 1. The lower half is spicule-free but the upper half contains up to 40% and is cherty, shelly, bioturbated and there are some casts of the sponge spicules Pachastrella.

Beds A 4.7m: The base is taken as the top of the chert horizon of Beds B and again marks a transition from facies 1a to 1. The sediment rock is a white "chalky" limestone with a few scattered small black chert nodules and at a cursory inspection has, as have the beds below, an appearance similar to that of the Upper Cretaceous chalks of England. Scanning electron microscope studies have not detected any coccoliths - just micrite with a crystal size <1μ. There are some typical bivalves near the top and then the beds are overlain by the basal Purbeck stromatolites, with a transitional 0.4m of laminated algal-mat sediment, as is the typical situation over the whole Dorset area.

FIG 54a


PORTLAND LIMESTONE FORMATION. MAINLAND WESTERN AREA. DORSET
POX
CHR
BASAL PURBECK
Top Grey Micrite
FREESTONE BEDS
Upper Freestone Beds
Lower Freestone Beds
Upper Part
UPPER CHERTY BEDS
Lower Part
BSB
Basal Shell Bed
Imst
clay
Pt.CLAY
LOWER CHERTY BEDS
PORTLAND SAND FORMATION
2·7Km
5·0Km
PF
WP
WFW
CC
1·3Km
7·2Km
CHERTY MICRITE BEDS A,B,C,D, & Basal Shell Bed
BEDS A
BEDS B
BEDS C
BEDS D
PORTLAND CLAY
Well
For Symbols and Facies see Figs 38, 39, 40
Basal IGS memoir
PF — Portesham Farm. 611859.
WP — Waddon. 624858
WFW-Water Works. 653857
CC—Chalbury Camp. 694838.
POX—Poxwell Quarry. 743835.
CHR-Cliff House. Ringstead. 763816
LOCALITIES
SY
65
70
75
78
87
PF WP WFW 3Km
Portesham
Poxwell
CC
Preston
Osmington
POX
CHR
WEYMOUTH
Ringstead

It is implied that Beds A and B are very probably equivalent to the Freestone Beds at Ringstead. See Fig. 82 and discussion in the synthesis.

OTHER EXPOSURES

Other exposures in the Mainland West Area are poor but, with the exception of a small pit near Friar Waddon (SY 645854), are depicted in Fig. 55 . The noteworthy feature shown in the figure is the overall thinning of the carbonate sequence of the Portland Limestone Formation westwards. Thicknesses for the three westerly outcrops have been obtained from Wilson et al (1958) and Whitaker & Edwards (1926). The Portland Clay is included in the "Portland Sand" in these records and it is only possible to give the thickness for the "Portland Stone". However, as the "Portland Sand" thins and becomes coarser in grain size further west it is reasonable to suppose that the Portland Clay beds thin and/or become sandier. The limestone beds thin from about 17m at Chalbury to about 10.5m at Portesham.

It should be noted that the sections in Fig. 55 show a facies change in a north-south direction and that the lateral continuity westwards of the Ringstead Bay facies is unknown due to non-availability of the Portland Group on the Mainland due west of Ringstead.

6. The Portland Limestone Formation of the Isle of Portland, West Area, Dorset (Fig 55)

A. Introduction

"To the generality of untravelled folk, Portland is nothing but a quarry and a prison. It is both and more." (C.G. Harper 1904).

This triangular island is a wedge of Upper Jurassic sediments sloping southwards, connected to mainland England by the double tombolo of Chesil Beach and Portland Harbour Beach. The highest ground (480') is in the north, at the Verne, and the southernmost point is only about 20' above sea level, at Portland Bill. The Island is 6.5km long and up to 2.7km wide. Although the shape of the island is due to the gentle southerly dip of the strata, in detail the beds in the north dip to the south-west and those in the south dip, albeit at a very low angle, to the south-east. These changes in strike are a reflection of the configuration of the folds offshore, namely the Weymouth-Purbeck Anticline and the Shambles syncline. This outlier surrounded by Kimmeridge Clay, provides the best exposures in the Portland Limestone Formation in Dorset but despite this more has been written in the past about the mainland outcrops. The limestones form a continuous vertical cliff encircling the island but in many places the beds have been quarried from the top leaving a natural exposure in only the Upper and Lower Cherty Beds. The many quarries, working and disused, in the Freestone Beds enable a detailed, if somewhat patchy, picture of the internal structure of the rocks to be drawn and permit a little insight into the environments of deposition.

B. Description of the Beds

120 thin sections were studied.

(i) Lower Cherty Beds (Portland Clay Beds and Basal Shell Bed)

(a) The Portland Clay Beds

According to Arkell (1947a) "At the north end of the island under Verne Fort temporary exposures have proved 10-20ft. of clay, the Portland Clay, below the Basal Shell Bed of the Cherty Series, but this feature dies out rapidly southwards." (see also Damon 1884,

SY 67 68 69 70 71

74 SY 74

73 73

72 72

71 71

70 70

69 69

WEST BAY

Pier Pier Pier Pier Jetties Inner Breakwater

Portland Castle

Helicopter Sta

Castletown DOCKYARD

Hospl

Chesil

Fortuneswell

The Verne

HM PRISON TRAINING CENTRE

King's Pier

Rame Head

CG Lookout

Sch

Verne Yeates

Wavecroft Quarries

King Barrow Quarries

Admiralty Quarries Disused

Folly Pier

East Weare

West Weare

West Cliff

Withies Croft Quarries

Tout Quarry (Dis)

HM Borstal

Tar Rocks

PORTLAND UD & CP

Grove

Trade Quarries (Dis)

Mill

Inmosthay Quarry

Independent Quarries (Dis)

Ilsh Headlands Quarry (Dis)

CG Sta

Crown Farm

France Quarries

Playing Field

Broadcroft Quarries

Cemy

Sch

Easton

Yedlands Quarry

Silkjake Quarries

Durdle Pier

Blacknor

Westcliffe Site

Pol Ho

Lawnsheds

Perrydale Quarries

Shepherds Dinner

Bottom Coombe Quarries

Future Castle remains of

Church remains of

Grangecroft Quarries

Suckthumb Quarry

Weston

ISLE OF PORTLAND

Southwell Landslip

Lawnsheds

Southwell

Pol Ho

Sweet Hill

DONOVAN & STRIDE 1961

God Nore

Limekiln Cave

Sand Holes

Field System

Bronscombe Lodge

CG Lookout

Lloyds Cottage

Lawnsheds

Cave Hole

Bay View

Rocket Post

PH

Blow Hole

Coastguard Station

White Hole

Pulpit Rock

Land Mark

1Km

BILL OF PORTLAND

GEOLOGY FIG 55

W.G.Townson 1968/70

Pleistocene Raised Beach

Purbeck Beds

Portland Limestone Formation

Portland Sand Formation

Kimmeridge Clay

Strahan 1898). A poorly exposed section under the Verne indicates that the clay must be about 6m thick at that point and, unless there is considerable variation in thickness, it is likely that the quoted 20' is more accurate. It is not true that it "dies out rapidly southwards", however, as at the following distances from the Verne the thicknesses are:-
West coast: 2.0km SSW, (SY 682720) 3.9m; Wallsend Cove: 4.5km SSW, 5m (± 0.25m).
East coast: Grove Cliff 2.0km SSE, 3.7m; Freshwater Bay 3.7km due S, 3.5-4m at low tide and the base is not exposed. (For localities see Figs.57,61). Thus the bed is not, as previous authors have implied, confined to north Portland. The only general conclusion to be drawn is that it is restricted to the Western Area and thickens from Ringstead westwards to Chalbury Camp and south-westwards to the Isle of Portland, possibly attaining its maximum of about 6m in the north of the Island. The beds are not purely clay and where well exposed it is found that the lowest half metre contains fine-grained euhedral dolomite rhombs in the clay matrix. This forms a transition from clay above to the Black Dolomite Beds of the underlying Portland Sand Formation. The clay facies is 2.4m thick, followed by a metre of light coloured, fine-grained dolomite and a transitional 0.5m of argillaceous dolomite and dolomitic clay immediately underlying the Basal Shell Bed (Fig. 56). No identifiable fossil remains have been found but preservation potential is low.

(b) Basal Shell Bed (2.75m thick. Facies 2)

This bed has been examined in detail at eleven separate localities on the Isle of Portland and is remarkably uniform. At each locality the same features are visible and traceable as far along the outcrop as possible; for example, along the west coast for about 4.5km (Figs.59,60). Details vary from place to place but the following description applies to any exposure.

The matrix is micropelletal lime mud facies with a low proportion of fine to medium biochem sand; there are less than 10% Rhaxella casts and these are generally insignificant. The

REPRESENTATIVE SECTION OF PORTLAND LIMESTONE FORMATION (EXCEPT UPPER PART OF THE FREESTONE BEDS) ON THE ISLE OF PORTLAND WESTERN AREA, DORSET. SECTION WS 2. WEST CLIFF.

FIG 56

		Metres	Facies	
FREESTONE BEDS Lower Part		1.05	1a 5aM 1a	*Rhaxella* casts (c.40%) in lime mud. Occasional oolds, *Paohantrella* & serp frags. Oolds & *Rhaxella* voids (c.20%) in lime mud. Shelly. *Trigonia*.
			5a	Oolds increase, part mud and part no matrix. Packstone - grainstone.
		1.80	5aM	Partly micritised oolds in lime mud matrix. Packstone.
CHERTY BEDS (UPPER) Upper Part 5.4M		1.00	1a	*Rhaxella* casts c.30%, also *Paohastrella* voids.
		1.60		*Paohastrella* - *Rhaxella* lime mud (c.30%) plus occasional large bivalves and fragments. Shelly and serpulitic with *Paohastrella* casts. Some blotchy silicification. *Paohastrella* sponge spicule lime mud. Mostly voids.
		0.30-0.35		*Camptonectes* - *Isognomon*. Calc *Rhaxella* 40-50%
		1.15		Massive prominent light grey to black chert bed silicified to a variable extent. Some lenses of remnant limestone (30-40% *Rhaxella* voids).
	S S S	1.30		Lime mud with 40-50% *Rhaxella* and with a high abundance of *Glomerula gordialis* forming a 'serpulite'. Shell bed at base (*Rhaxella* c.10%).
		1.00		*Rhaxella* 10-15% (silica and casts) plus bivalve and serpulid fragments and thin sheet chert.
	G	0.75	2	*Camptonectes* - *Isognomon* shell bed with ammonites. Lime mud matrix, only a few spicules.
Lower Part 8.5M		0.95	1a	*Rhaxella* 10-20%. Some serpulids. Lime mud.
		1.20		Black, inclined 'tectonic' cherts. Siliceous spicules in bioturbated pressure solution horizons in the lower part.
		0.70		
		0.60	1	Lime mud plus some very fine biochem sand with <1% v.f. quartz. Large black cherts. Fauna rare except for occasional serpulids. Ammonites and minute bivalves at base.
		1.20		
		1.00		
	G	0.55	1a	*Rhaxella* lime mud (up to 50% spicules). Horizons of bioturbated and 'winnowed' sediment acting as pressure solution planes and concentrating siliceous spicules. Encrusted ammonites and *Thalassinoides* common.
	G	0.50		
		0.20		
BASAL SHELL BED Equivalents of Lower Cherty Beds		0.45	2	Lime mud and micropelletal lime mud (50-100μ) with abundant diverse bivalve fauna (epifaunal genera approx equal to no. of infaunal); also ammonites, gastropods, echinoids, serpulids, bryozoa, asteroid ossicles, crustacean fragments, fish teeth and reptile remains. Bioturbated at several horizons. *Exogyra* common at certain levels. Origin multi-depositional.
		2.30		
PORTLAND CLAY BEDS		1.50		Dolomitic clay with *Exogyra* fragments at top. Very fine dolomite rhomb mosaic (5-20μ). No fossils found.
		2.40		Soft, dark grey-brown clay with fine dolomite rhombs (c.10μ) at transition top and bottom. No recognisable fauna. Occasional black pyritic 'smudges'.
Black Dolomite Beds				Argillaceous dolomite.

PORTLAND SAND FORMATION

bed gets its name from the vast number of bivalves it contains, usually in such high proportion as to be self-supporting. The sediment generally has a packstone texture, but the packing is dependent on the size of bivalves. The commonest are the large Isognomon and Camptonectes abundant throughout the Portland Limestone Formation carbonate facies, which are preserved as the original calcite skeleton. The other common bivalves are Laevitrigonia, Myophorella, Plagiostoma, Exogyra and Ostrea; the former as sparry calcite internal casts and the latter three as original shells but often partially silicified (beekitised). Gastropods are common, especially minute forms, as also are minute bivalves. Large serpulids, the "knotted" serpulid Glomerula gordialis, and large ammonites are common. Four genera of echinoid have been recorded and specimens can be found. There are seventeen genera of gastropod recorded and fourteen each of epifaunal and infaunal bivalves (Cox 1925).

The Bed has three or four "discontinuity" horizons which are levels of fragmented shell debris bioturbated by Thalassinoides and altered by pressure solution. They vary in thickness from 0.1-0.3m. The major beds between these thin layers are also bioturbated but trace fossils are not satisfactorily assignable to any particular ichnogenus. The distribution of shells varies but the lowest and topmost parts of the bed contain the greatest concentration of the largest bivalves and some of the bioturbation/solution horizons contain a large amount of Exogyra. Although the epifaunal ostreiids, pteriids and serpulids can reach "solid proportions", there are no obvious hard-grounds developed. There is no evidence that the sediment matrix was already lithified at the sediment-water interface at the time of colonisation by bivalves.

The "discontinuity" horizon nearest the top of the bed is always present and the contact with the sediment below is distinctly burrowed, the sediment being piped down in such a way as to give a superficial appearance of being a mud-flake breccia which might imply a very shallow water origin (desiccation or sea-bed erosion of stiff mud to form intraclasts). However, close examination of this horizon at many localities has shown that these are "pseudoclas

produced by burrowing organisms. Crustaceans may have been responsible as skeletal fragments of these animals can be found in the Basal Shell Bed. There are some black chert nodules at most localities in the upper part.

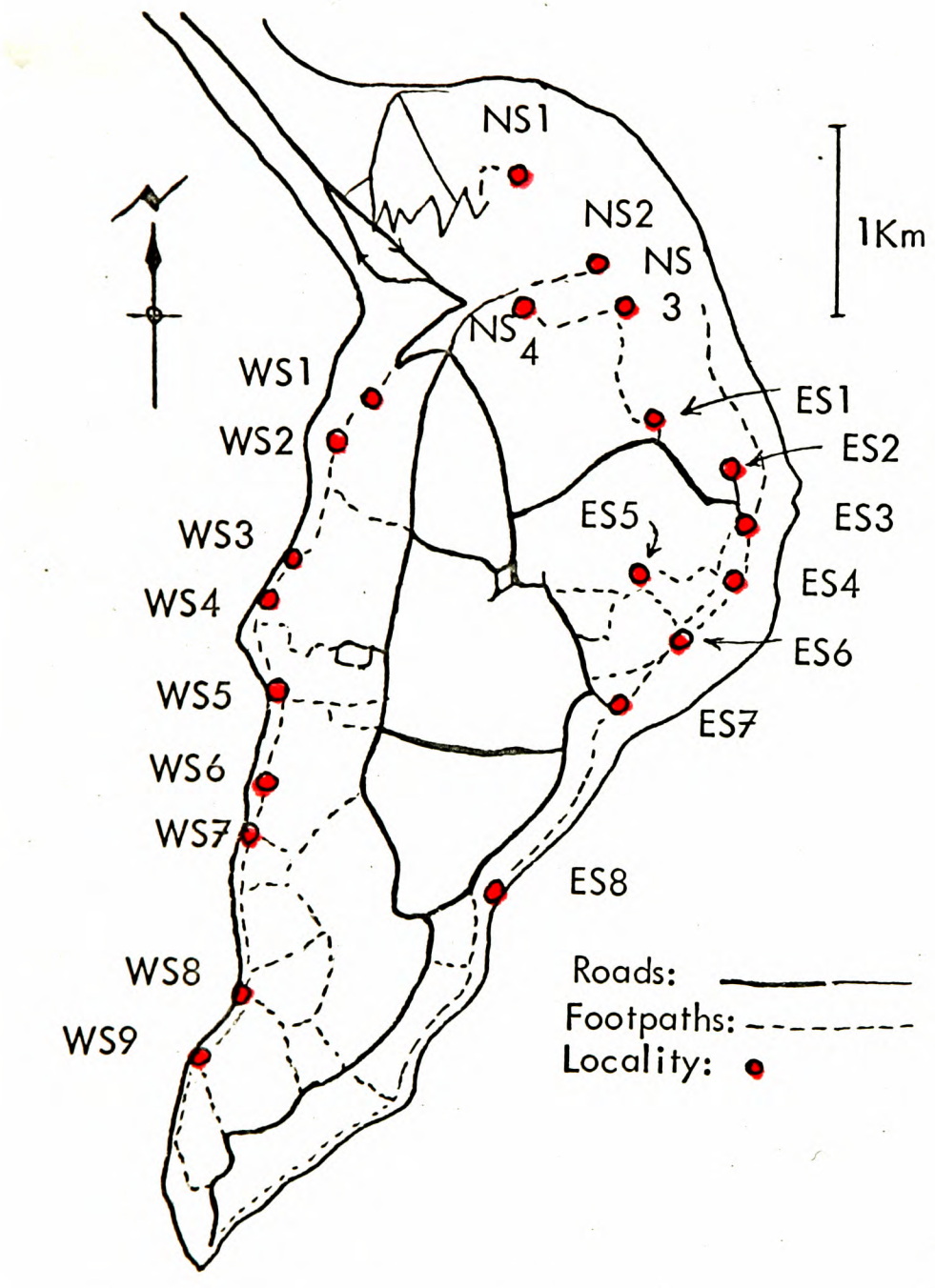
The biofabric of the bed is complex as there are many phases of deposition represented. In some places bivalve shells are disarticulated anddbviously current deposited, whereas in others the valves are together and the animal was obviously rapidly "swamped" by a sediment influx - this applies to both infaunal and epifaunal elements. Closed valves of Isognomon, Camptonectes and Lima can occur preserved in this way. In some places there is evidence of very slow accumulation, non-deposition, where several generations of Exogyra encrust large bivalves and ammonites. The latter are always encrusted on the upper surface and often to a lesser extent on the outer whorl of the underside, implying settling of ammonites on a stiff substrate. The ammonites sunk into the sea bed and were colonised where exposed, although to a lesser advantage on the under side. An alternative interpretation is that there was periodic winnowing and scouring around the sides of the skeletons which were generally partially buried.

The overall conclusion drawn from the above is that the Basal Shell Bed is a slowly-accumulated deposit which was subjected to many different sea floor processes and rates of deposition through a long period of time. [This is contrary to the opinion of Cox (1925) who concluded that the facies suggests very rapid deposition.] The accumulation of bivalves and ammonites would suggest this as well as the repeated discontinuity and bioturbation horizons. It is likely that only a very small proportion of time is represented by sediment, but the bed is not taken to be a true "condensed bed" in the sense of the Middle Jurassic "Snuffbox Bed" or the Lower Jurassic "Junction Bed" of the Dorset coast. There is no concentration of glauconite (less than in several other Portland Group horizons) and no phosphatisation or hard-ground development. One specimen of a phosphatised pavlovid (?) ammonite was found at locality WS5 (Mutton Cove) and three small black clasts similar to the "lydites" found outside Dorset.

These are rare examples and not considered significant in this context.

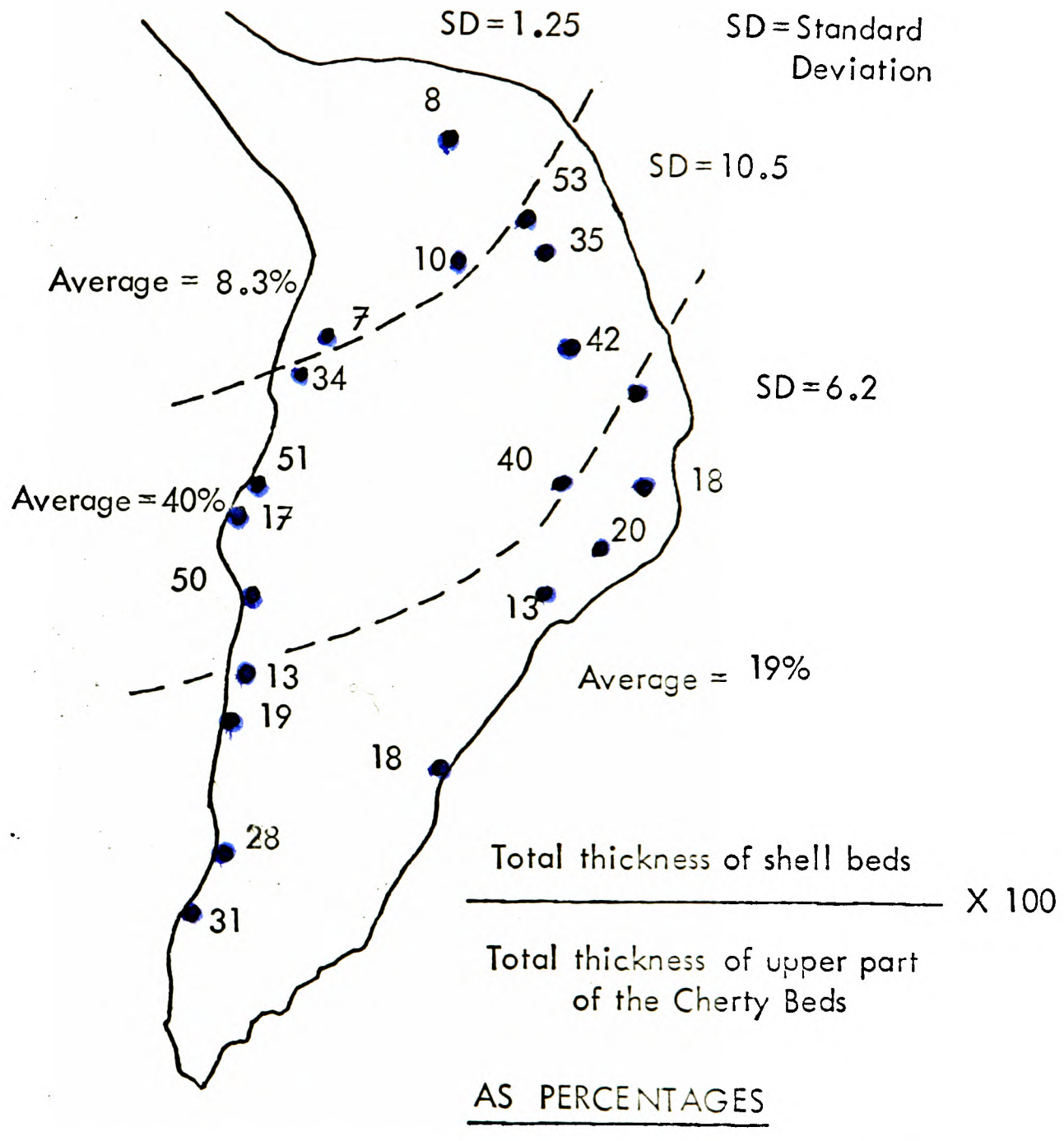
It has been suggested earlier that the Basal Shell Bed may be correlated with bed J' of the Eastern and Central Areas of Dorset. Superficially the topmost unit of the Basal Shell Bed is identical in appearance to J' in degree of bioturbation and the development of a nodular appearance, and in shell content and ammonite concentration. The similarity is most striking at locality ES8 (Freshwater Bay). However, this alone is no basis for a correlation. The litho-facies changes from East to West Dorset from 3 to 1a, to 3 to 2, but the constancy of the horizon has already been affirmed from the furthest east of the Isle of Purbeck to the furthest west of the Central Area by Arkell (1935). In the Central and Eastern Areas the bed J' demarcates a point of slow or non-deposition at the top of a shallowing phase (facies 1a to 3) and above there is another deeper and shallowing phase repeating the vertical facies sequence. In the Western Area the sequence from Black Dolomite Bed to Portland Clay Bed and Basal Shell Bed is also thought to reflect a shallowing phase and the lower part of the Upper Cherty Beds a deeper phase. Study of the Figs. 82 will show that, on thickness considerations for the Portland Group, the correlation with J' is more acceptable than correlating the Basal Shell Bed with the base of the Lower Cherty Beds in the Eastern and Central Areas. Blake (1880) states that the Basal Shell Bed forms the base of the Portland "Stone" at St. Alban's Head in the Eastern Area (Pbk 15) but no-one has since been able to locate it and the somewhat convenient "observation" is discredited.

Ammonite evidence does not disprove the proposed correlation of the Basal Shell Bed with J'. Although all Portlandian ammonite identification is here regarded with a certain degree of scepticism a small, biplicate-ribbed glaucolithitid was found in J' in the Eastern Area at Pbk 18 (Emmitt's Hill) and these occur in the Basal Shell Bed on Portland. The most common ammonite in both beds, however, is the large "Behemoth" with only the outer whorl preserved. Glaucolithites is, in fact, the zone ammonite for the upper part of the Portland Sand Formation. The correlation proposed



LOCALITY MAP FOR SECTIONS IN CHERTY BEDS. ISLE OF PORTLAND. DORSET. See Figs 59,60

FIG 57



SHELL BEDS IN THE UPPER PART OF THE CHERTY BEDS (UPPER). ISLE OF PORTLAND. DORSET.

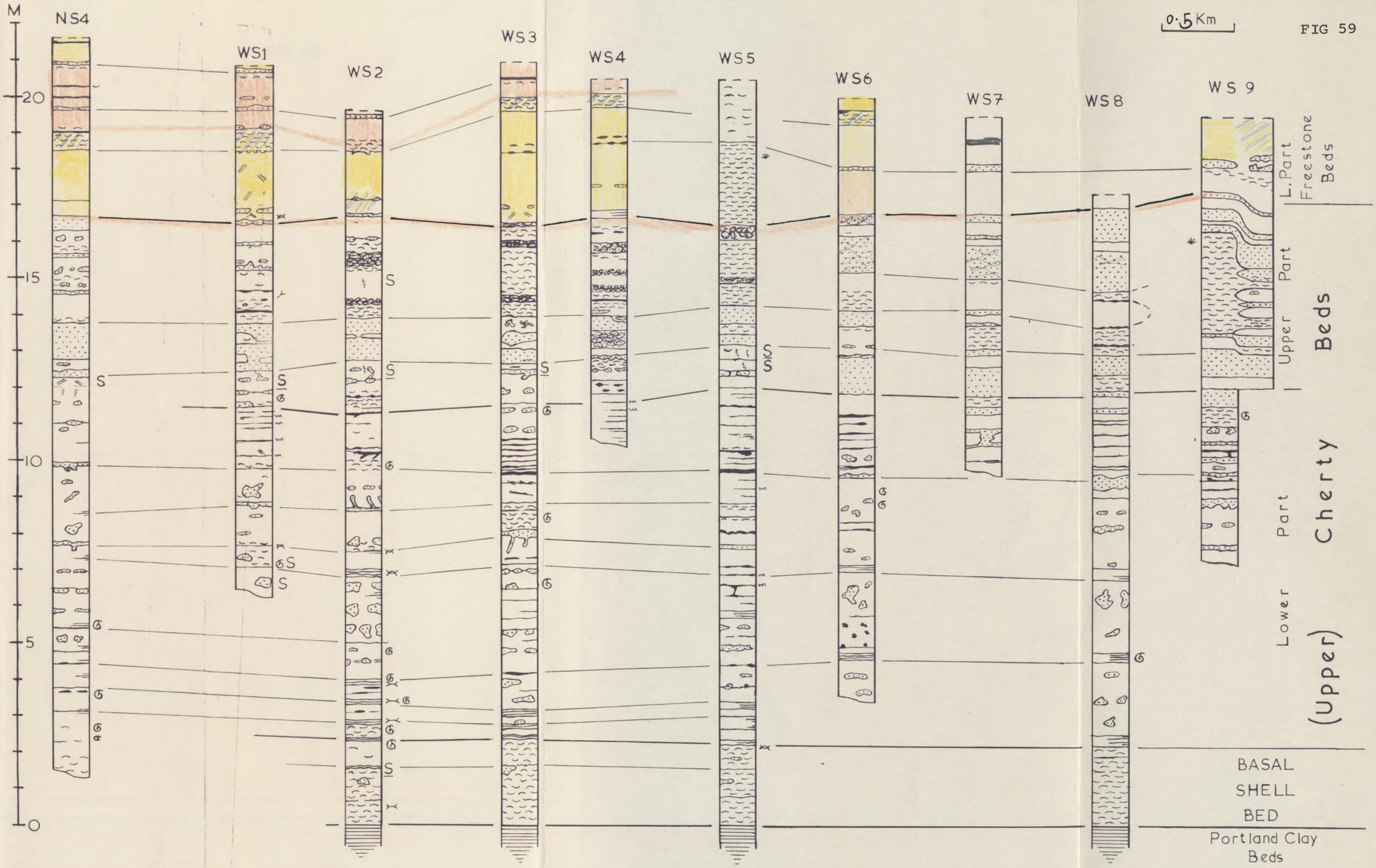
FIG 58

FIG 59

Between sections:

0·5 Km

FIG 59



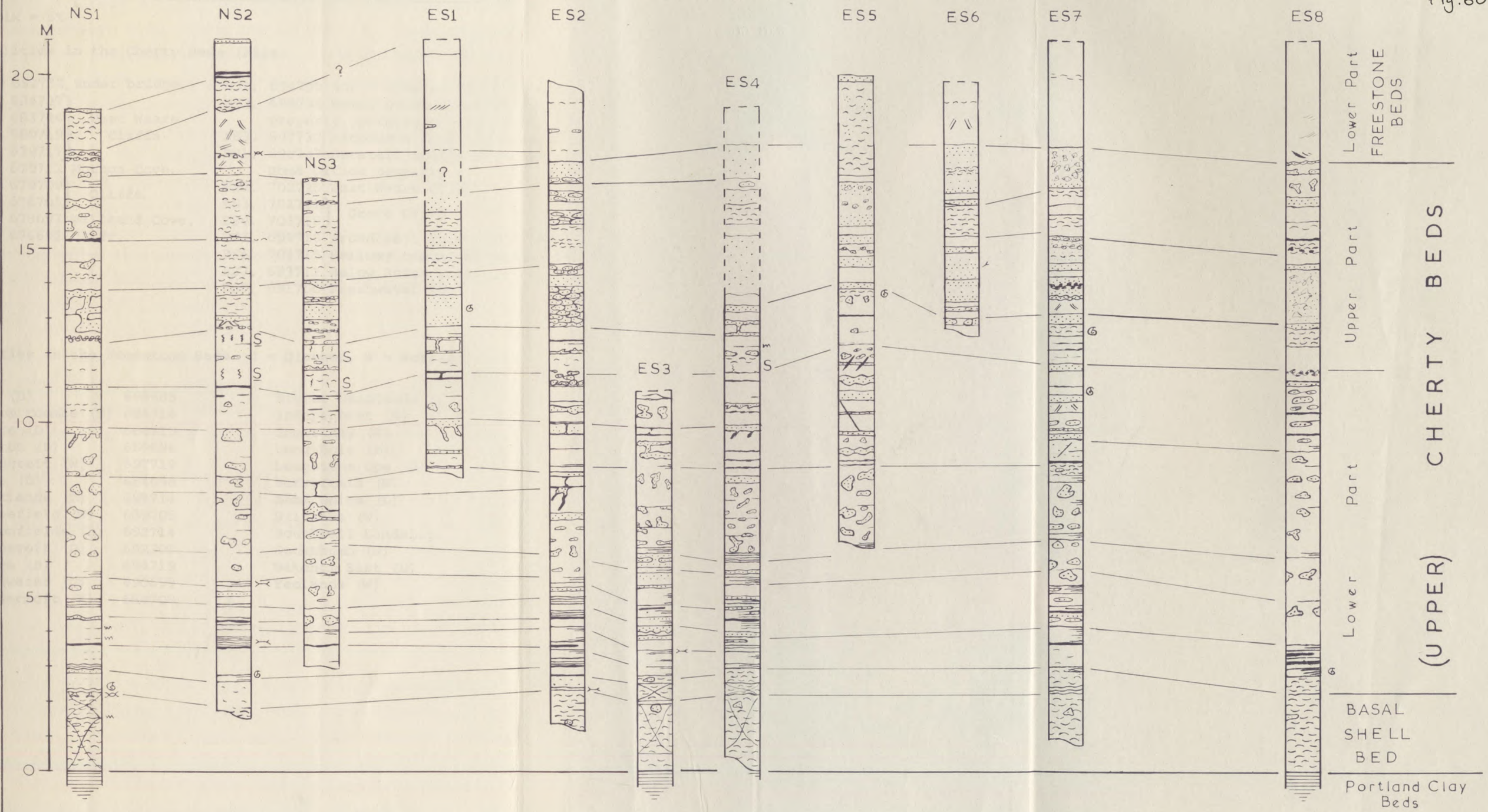
SECTIONS IN THE PORTLAND LIMESTONE FORMATION ALONG THE WESTERN SIDE OF THE ISLE OF PORTLAND, DORSET.

SEE LOCALITY MAP Fig 57

FIG 60

Between sections: 0·5Km

Fig.60



SECTIONS IN THE PORTLAND LIMESTONE FORMATION ALONG THE EASTERN SIDE OF THE ISLE OF PORTLAND, DORSET. (SEE LOCALITY MAP) (Fig 57)

Grid References of Localities on Portland Mentioned in the Text

Prefix = SY

Localities in the Cherty Beds (Figs.)

NS4. 692732, under bridge.
WS1. 684727
WS2. 683724 West Weare
WS3. 680719 Cliffs.
WS4. 679717
WS5. 679712 Mutton Cove.
WS6. 679709
WS7. 678703 Cliffs.
WS8. 678697 Wallsend Cove.
WS9. 676692 Cliff.

NS1. 692739 North side of Verne [illegible]
NS2. 696734 Verne Ditch (Home Office property, permission required)
NS3. 697732 Nicodemus Knob and area.
ES1. 698727 Borstall sports ground. Home Office property.
ES2. 702725 East Weare Cliff.
ES3. 703721
ES4. 703718 Grove Cliff.
ES5. 698719 Broadcroft Quarry, Worth[illegible]
ES6. 702715 Railway track, d[illegible]
ES7. 697712 Below Rufus Castle.
ES8. 691700 Freshwater Bay.

Quarries in the Freestone Beds D = Disused, W = Working

Bill (D)	695685	Higher Headlands (D	
Bottom Coombe (D)	694714	Independent (W)	
Bowers (D)	684719	Inmosthay (W)	
Breston (D)	689696	Long Acre (D)	
Broadcroft (W)	697719	Longstone Ope (D)	
Butts (D)	684688	Perryfield (W)	
Chalklands (D)	697714	Sand Holes (D)	
Coombefield (W)	689705	Siltlake (W)	
Cottonfields (D)	692714	Southwell Landslip	
Duncecroft (D)	692703	Suckthumb (W)	
France (D)	694719	Wakeham East (D)	
Freshwater (D)	690699	Yeolands (W)	
Grangecroft (W)	684708		

is not lithostratigraphical or biostratigraphical because the lithofacies changes slightly and because the ammonites are not well enough known to be of any precise use. The correlation is one of "event" based on an interpretation of the origin of the depositional and diagenetic fabric of the two beds by using an environmental model, that is to say, the processes that give the beds their physical characteristics, other than sediment type only. They have the same position in two vertical sequences which are interpreted as showing the results of the same overall environmental changes. This is the strongest evidence and when the circumstantial ammonite evidence does not deny this possibility it will be taken as a workable correlation and one which makes the beds the nearest to a time-equivalent phase of deposition as is possible under such circumstances (a chronostratigraphic horizon). Thus, it is considered almost as a time plane, or band, all over Dorset. It must be remembered that the area in which the Basal Shell Bed - J' horizon outcrops is only 36 x 16km, the longer distance being along the general facies strike. The problem of inherent diachronism in any dynamic model is discussed later.

(ii) Upper Cherty Beds (c. 14-15m thick) (Plates 22,54)

These are defined as the beds above the Basal Shell Bed and below the lowest oolite bed of the Freestone Beds. It is not always easy to place the upper limit, as in some localities the lowest beds of the Freestone Beds are not oolite but massive shell beds (Figs. 59,60). The beds can be informally subdivided into an upper and lower part, not so much on sediment type as on general characteristics.

(a) Lower Part (8.5-9.7m): This consists of lime mud facies with or without Rhaxella spicules, very few shell beds and with large black chert nodules (c.f. upper part). The most obvious feature of the basal 2-3m is the repetition of hard and softer beds, the number of which varies with the degree of pressure solution, silicification and weathering. (Plates 54). The beds are 0.2-0.4m thick and the hard light grey horizons contain micrite and calcite Rhaxella casts, whereas the softer brown

levels contain silica spicules (up to 50%) in a slightly argillaceous micrite. The original sediment, facies 1a, was the same throughout, but the processes applied to it must have differed. The soft levels contain well-preserved, easily recognisable Thalassinoides, whereas in the hard beds these are not obvious. It is not known if this is a primary feature but it is suspected that the density of burrows was greater in what are now the soft beds. A possible interpretation of depositional events could be as follows:- slow deposition of sponge spicule lime mud; occurrence of a comparatively higher energy event bringing in clay, winnowing and sometimes concentrating the silica spicules; settling and formation of a roughly laminated deposit which was then burrowed by crustaceans because it was richer in nutrients than usual. After burial the spicules in the pure lime mud dissolved and released silica (leaving voids to be filled with calcite) which migrated a little up and/or down to be precipitated as a sheet of nodules parallel to the bedding (Plate 54). This is an early diagenetic process followed by a later, deeper burial process of pressure solution along the horizons of bioturbation. This concentrated the silica spicules which were not dissolved, presumably somehow due to the presence of the clay minerals, and increased the proportion of other insolubles such as fine quartz sand and clay.

Large ammonites are common in these lowest beds and this is considered to be a sign of overall moderately slow deposition. Above the thin beds are more massive beds of lime mud which are virtually fossil free except for occasional thin "strings" of minute bivalves and the ubiquitous Rhaxella spicules (up to 20%). Black chert nodules range from 0.1-0.5m across. There are a few large calcite-shelled bivalve beds but these are exceptional (Fig. 59 WS1 to WS3). There is a distinctive horizon of high angle inclined cherts which must be post-tectonic (Lower Cretaceous or Tertiary) (Figs. 59,60 WS2 & WS3, NS1, ES1, ES2, ES4, ES5).

(b) Upper part (4.8-6.5m)

This consists of lime mud facies with Rhaxella, but Pachastrella is also an important contributor. It differs from the lower part in being very rich in shell beds and serpulids, and in being

usually intensely silicified by thick horizons of light to dark grey chert. The lowest metre or two is a current deposited Glomerula "serpulite" of the type already described in the Isle of Purbeck, and this is traceable over an area of at least 5sq.km. (Fig. 57 area between NS2, ES4 and WS5). The associated shell bed and the overlying massive silicification is traceable over all the island, making a useful marker horizon (Figs. 59,60). Rhaxella casts comprise up to 50% of the proportion of lime mud matrix but, as is seen from the sections (Figs. 59,60), it is bivalve shells which are the most significant constituent of the sediment. These shell beds are interpreted as always being current deposited, although it is thought that the shells did not travel very far. Sometimes the massive beds (up to 4m thick) show imbrication of the large valves and contain overturned and disturbed coral masses. (Isastrea oblonga) up to 0.25m across (Fig. 59, WS9).

The commonest fauna in these shell beds is Laevitrigonia, Myophorella, Camptonectes, Isognomon, Ostrea, Plagiostoma and Pleurotomaria. The trigoniids and gastropods are usually preserved as empty moulds with a loose "steinkern", or as sparry calcite casts; the other genera have the original calcitic structure preserved. In simple terms, the bivalves, which are the major bed constituents, can be divided into shallow infaunal forms originally with an aragonitic skeleton (trigoniids and Protocardia) and the epifaunal and swimming forms with a calcitic shell (Isognomon, Plagiostoma, Ostrea and Camptonectes). The shell beds are most commonly composed of one group or the other and it is only to a much lesser extent that both forms are mixed together. This is probably a reflection of sea floor distribution of the bivalves as it is considered unlikely that shallow infaunal forms would have existed in a substrate covered with the epifaunal ones. However, this may be the case in the mixed beds or, more likely, these may indicate higher energy conditions at the time of disturbance. It is noteworthy that with the infaunal ones it is the rule for the valves to be disarticulated, implying winnowing out and they are more often than not found in the stable, concave down, position. In some cases bivalved Camptonectes shells are

stacked upon each other so as to be self-supporting.

Ammonites are sometimes found in these shell beds and this association may imply that they were dependent on a food supply associated with the substrate in the same way as the bivalves were. They are uncommon in the deeper water sponge mud facies, as are bivalves, and may have swum close to the bottom obtaining food from the sea bed.

These shell beds vary in thickness from 0.05-4.0m and in lateral extent, from a few tens of metres to 3-4km (Figs.59,60). The interstitial sediment is a micropelletal lime mud with Rhaxella and Pachastrella moulds and casts. The silica was dissolved and precipitated in thin diffuse nodule horizons and in massive chert beds up to nearly 2m thick. The silicified levels are usually very persistent and can be traced in the cliffs, from a distance, for several kilometres. (Figs 59,60) (Plates 22,54). The proportion of shell beds in the Upper Part varies from 8.3% in the far north, to 40% in the central area and 19% in the south (Fig. 58) and this may indicate shallower water in the central area.

It is thought that the Upper Part of the Cherty Beds represents a shallower water regime than the lower part, which itself, is deeper than that for the Basal Shell Bed below. The Upper Part of the Cherty Beds may have formed at the same time as the Lower Freestone Beds of the Central and Eastern Areas.

(iii) Freestone Beds (Isle of Portland) Average thickenss 8m

Isopachytes have been drawn, taking the base of the Purbeck as a distinctive upper datum, and the facies change from lime mud of the Upper Cherty Beds to carbonate sand of the Freestone Beds as the lower datum (facies 1, 1a or 2 to facies 4 or 5). The contours are at half metre intervals and show, generally, that the beds are thickest in the NW, centre and SW of the island (8-9m) and that they thin between north, ENE, south and SE (about 6m) (Fig. 62).

160 sections, each averaging 6-7m in thickness have been measured within the available outcrop area of around 8 sq.km. The dominant sediment is ooid sand (Plate 58) but other important types are biochem sand and lime mud. Locally, biochem sand, shells and shell fragments are the sole constituents. In some places small patch reefs occur and debris from these is also locally common. Boulder sized blocks of patch-reef boundstone up to 0.5m across and of seafloor-cemented grainstones occur. A diagram interpreting the relationships between some of these sediments is given as Fig. 81 .

The terminology of previous authors is as below, followed by reasons for no longer using these names, in spite of their antiquity.

ROACH WHIT BED FLINTY BED CURF BASE BED ROACH BASE or BEST BED	As in Arkell 1947 and quoted since, up to Torrens 1969	slightly modified from Arkell 1933 Strahan 1898 Woodward 1895 Gray 1861 Not in Webster 1829

The Base Bed is the lowest and most continuous horizon, and is composed mainly of ooid sand. The Flinty Bed and Curf represent an intercalation of lime mud facies restricted to the northern part of the island (Figs. 63, 71) and thus these divisions are not applicable over most of the area. The upward continuity of ooid sand facies in the rest of the island makes the Base Bed Roach

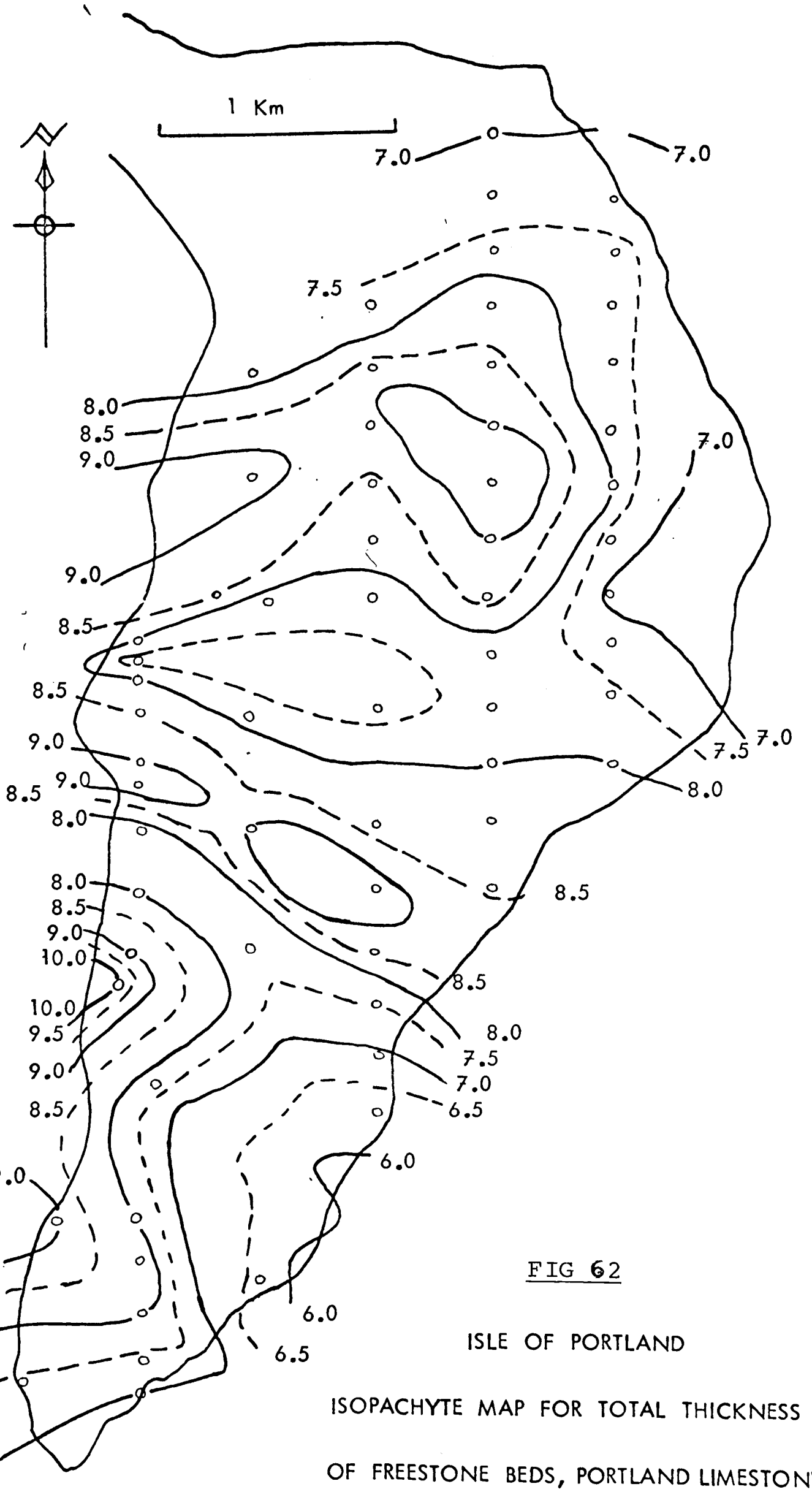


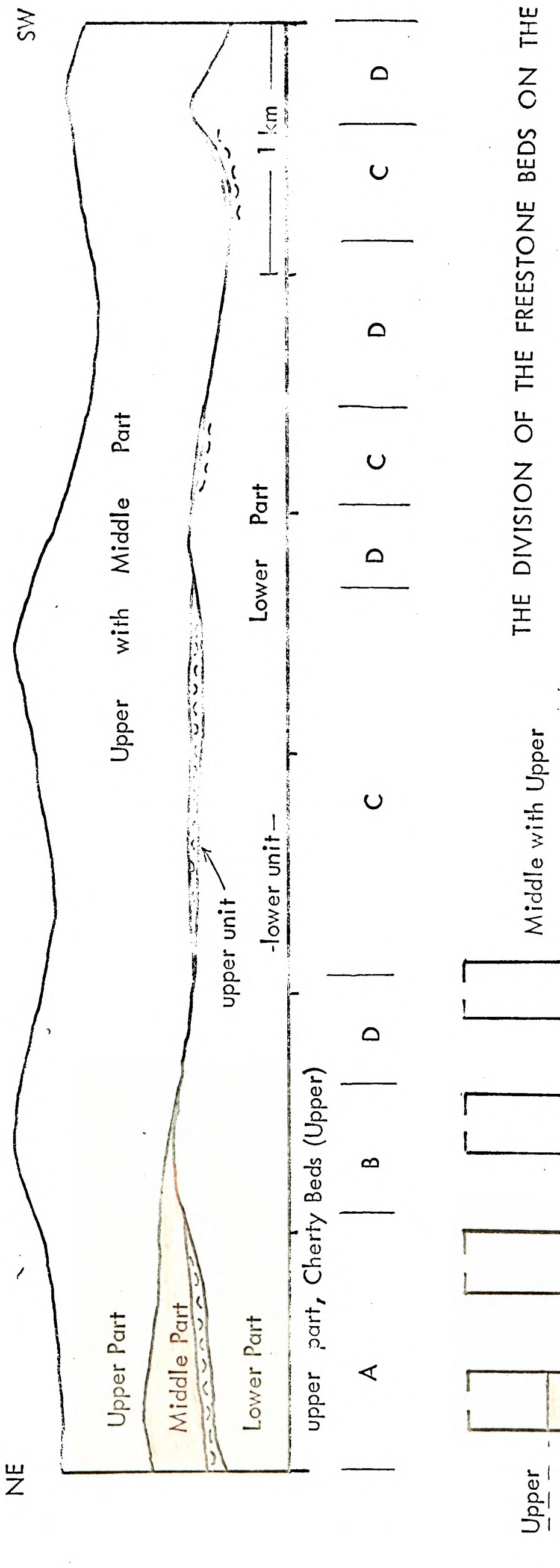
FIG 62

ISLE OF PORTLAND

ISOPACHYTE MAP FOR TOTAL THICKNESS

OF FREESTONE BEDS, PORTLAND LIMESTONE

FIG 63



THE DIVISION OF THE FREESTONE BEDS ON THE ISLE OF PORTLAND

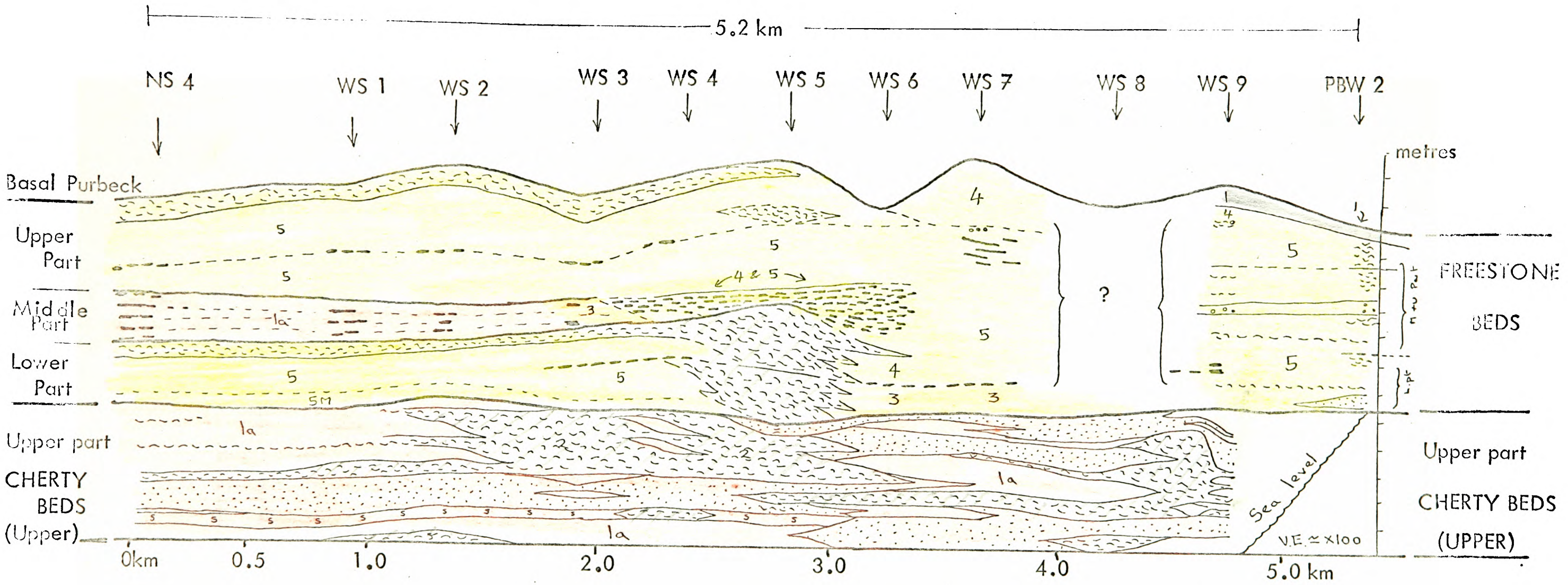


FIG 64

FREESTONE BEDS AND UPPER PART OF THE CHERTY BEDS, PORTLAND LIMESTONE FORMATION.

WEST COAST, ISLE OF PORTLAND, DORSET.

FIG 65

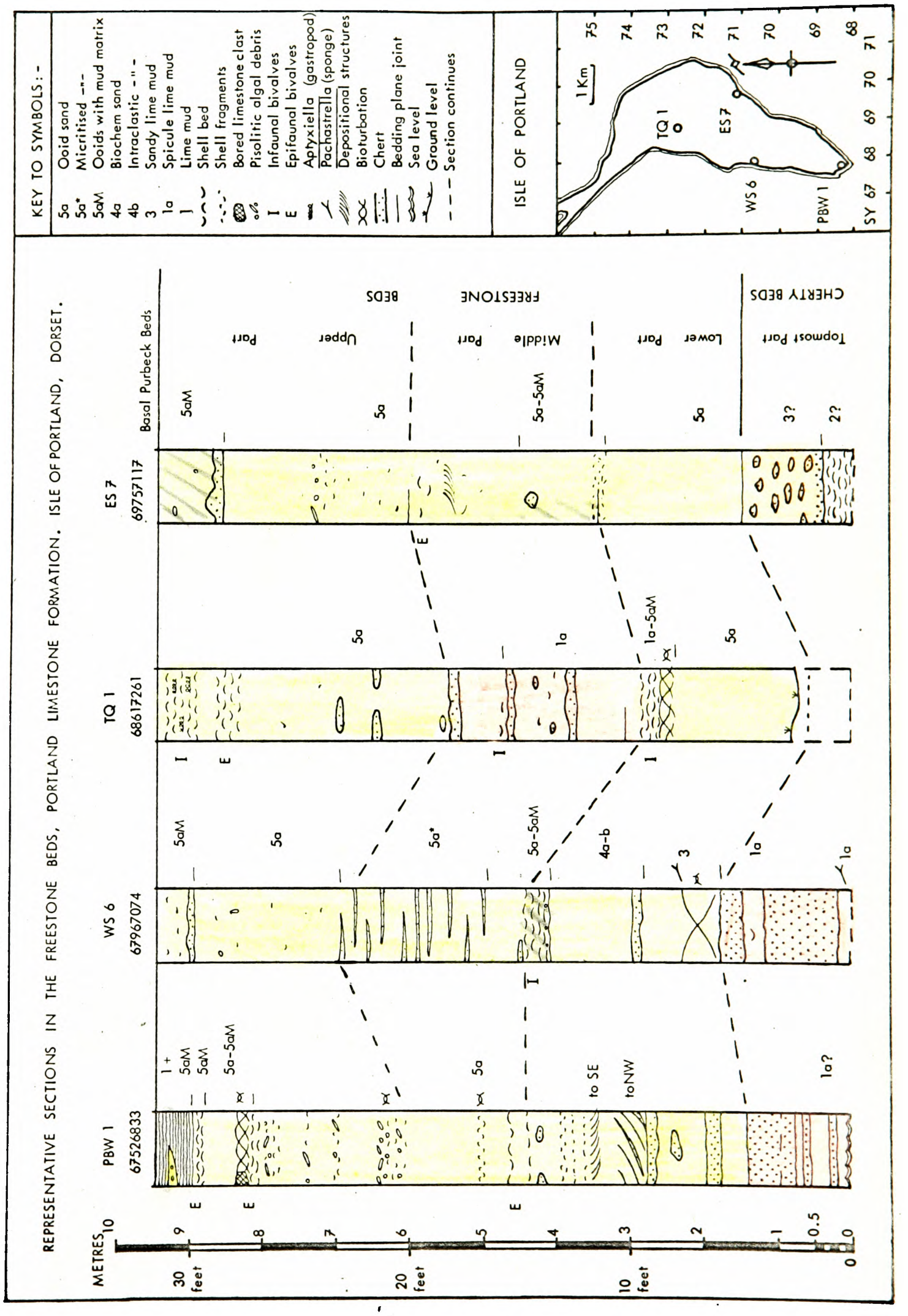

REPRESENTATIVE SECTIONS IN THE FREESTONE BEDS, PORTLAND LIMESTONE FORMATION. ISLE OF PORTLAND, DORSET.
KEY TO SYMBOLS:-
5a Ooid sand
5a* Micritised
5aM Ooids with mud matrix
4a Biochem sand
4b Intraclastic
3 Sandy lime mud
1a Spicule lime mud
Lime mud
Shell bed
Shell fragments
Bored limestone clast
Pisolitic algal debris
I Infaunal bivalves
E Epifaunal bivalves
Aphyxiella (gastropod)
Pachastrella (sponge)
Depositional structures
Bioturbation
Chert
Bedding plane joint
Sea level
Ground level
Section continues
ISLE OF PORTLAND
1 Km
TQ 1
ES 7
WS 6
PBW 1
SY 67 68 69 70 71
Basal Purbeck Beds
CHERTY BEDS
Topmost Part
FREESTONE BEDS
Lower Part
Middle Part
Upper Part
ES 7
69757117
TQ 1
68617261
WS 6
67967074
PBW 1
67526833
5aM
5a
5a-5aM
1a
1a-5aM
4a-b
1a?
3?
2?
3
1+
to SE
toNW
METRES
30 feet
20 feet
10 feet

FIG 66

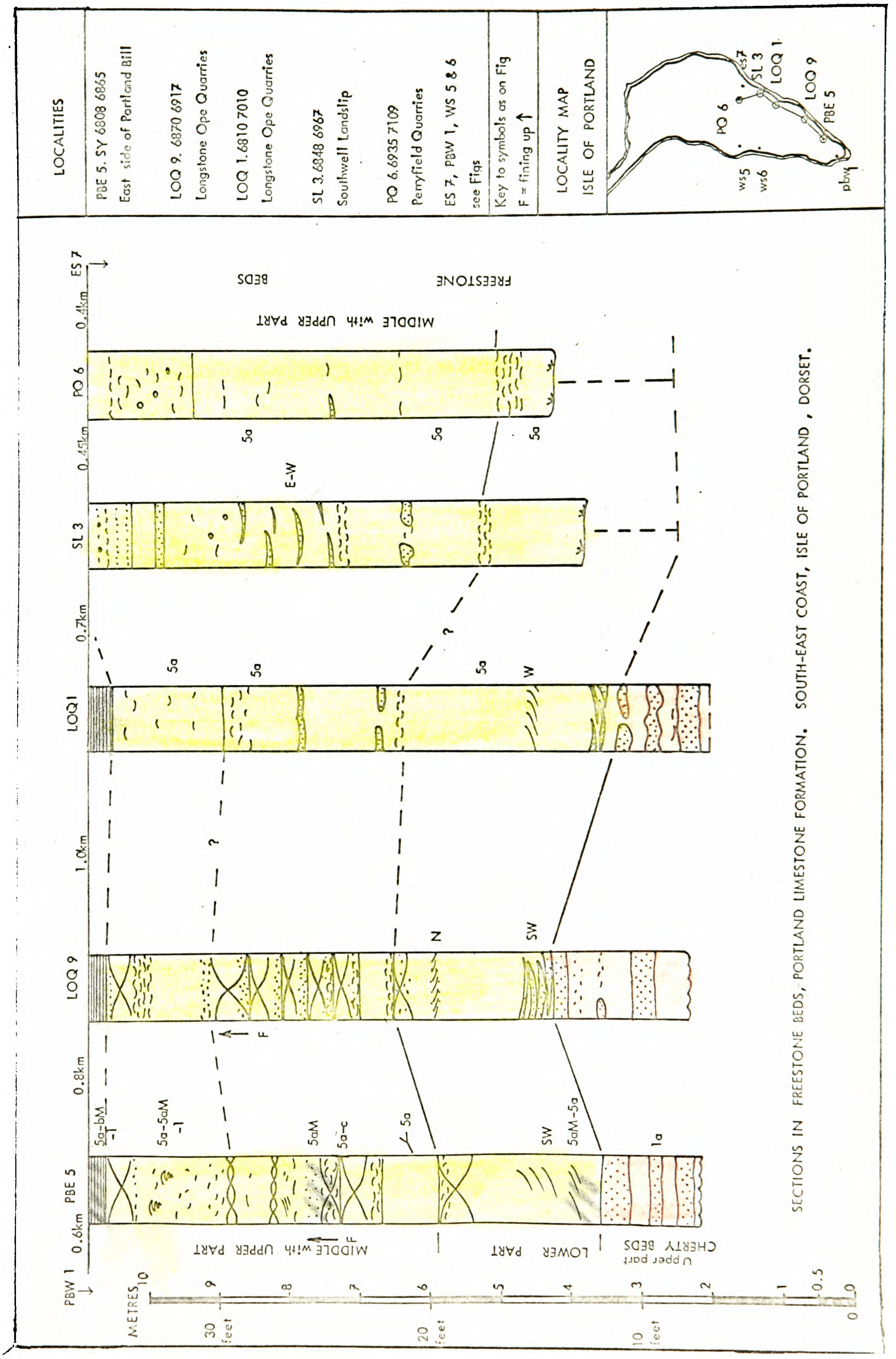

LOCALITIES
PBE 5. SY 6808 6865
East side of Portland Hill
LOQ 9. 6870 6917
Longstone Ope Quarries
LOQ 1. 6810 7010
Longstone Ope Quarries
SL 3. 6848 6967
Southwell Landslip
PO 6. 6935 7109
Perryfield Quarries
ES 7, PBW 1, WS 5 & 6
see Figs
Key to symbols as on Fig
F = fining up
LOCALITY MAP
ISLE OF PORTLAND
PBW 1
PBE 5
LOQ 1
LOQ 9
SL 3
PO 6
ES 7
ws5
ws6
0.6km
0.8km
1.0km
0.7km
0.45km
0.4km
FREESTONE BEDS
MIDDLE with UPPER PART
LOWER PART
CHERTY BEDS
Upper part
5a
5a-5aM -1
5a-bM -1
5aM
5a-c
5aM-5a
1a
N
SW
W
F
?
METRES
feet
SECTIONS IN FREESTONE BEDS, PORTLAND LIMESTONE FORMATION. SOUTH-EAST COAST, ISLE OF PORTLAND, DORSET.

FIG 67

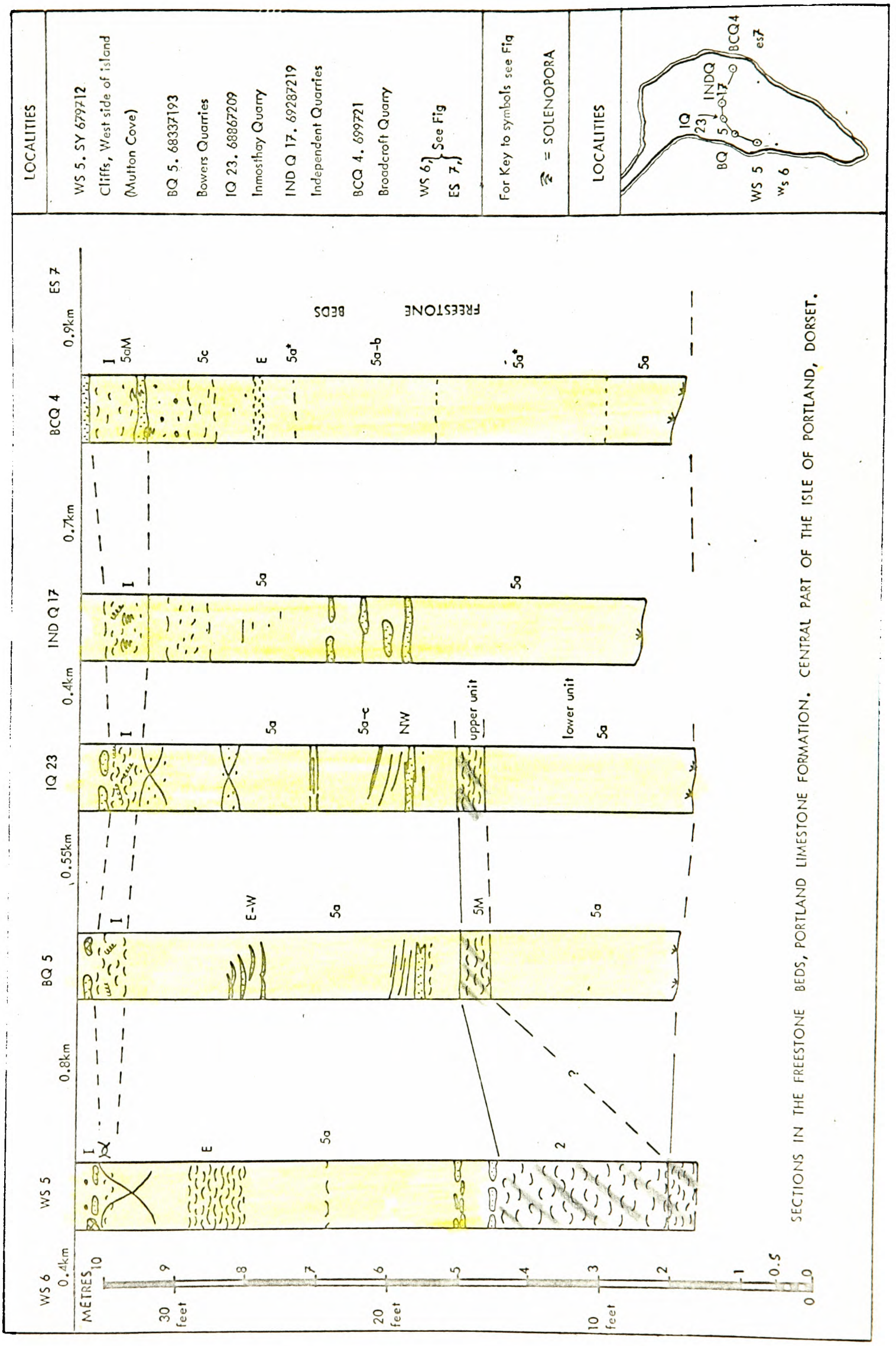
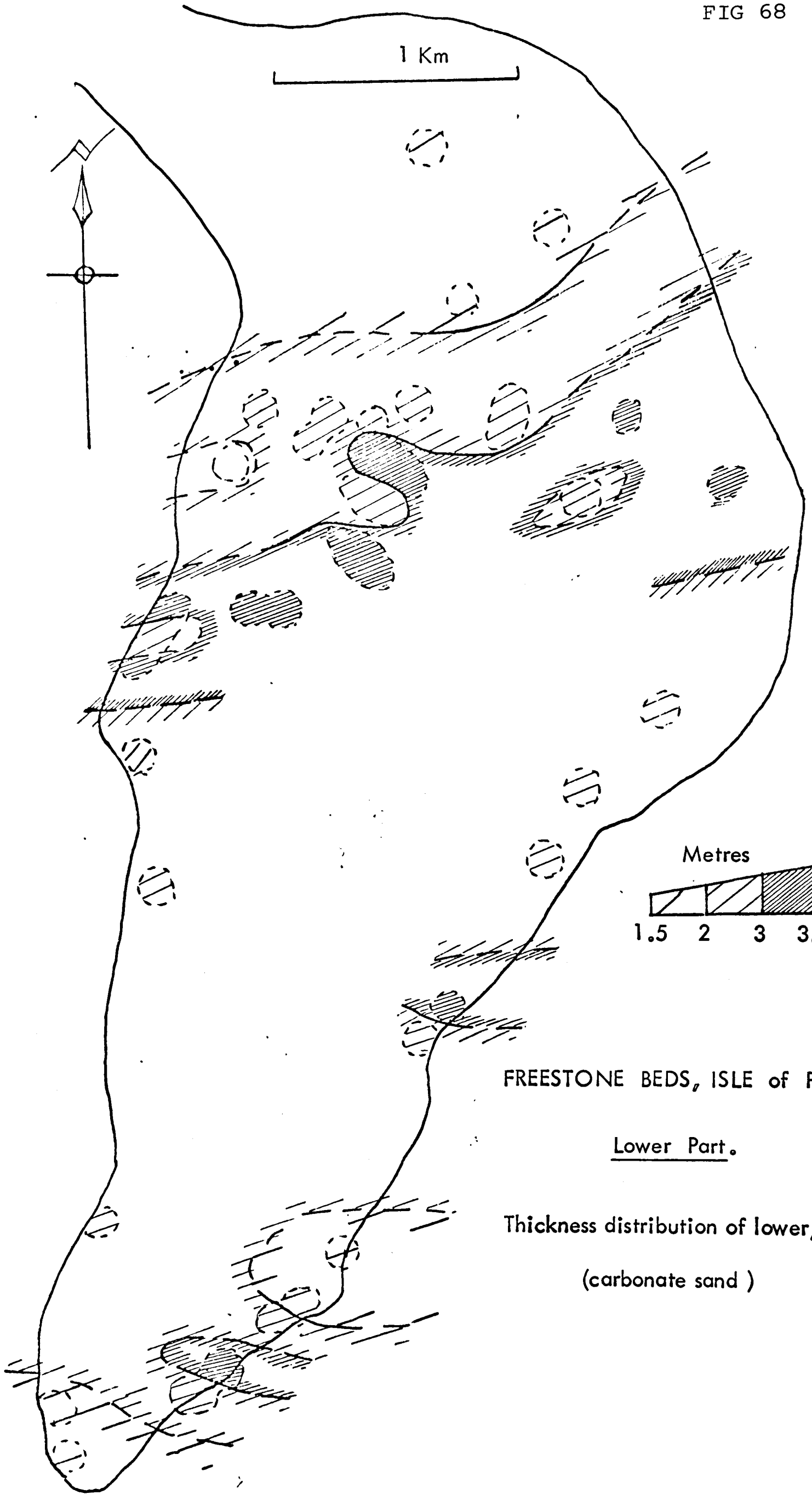

LOCALITIES
WS 5. SY 679712
Cliffs, West side of island
(Mutton Cove)
BQ 5. 68337193
Bowers Quarries
IQ 23. 68867209
Inmosthay Quarry
IND Q 17. 69287219
Independent Quarries
BCQ 4. 699721
Broadcroft Quarry
WS 6, ES 7 } See Fig
For Key to symbols see Fig
= SOLENOPORA
LOCALITIES
IQ 23
5
IND Q 17
BQ
BCQ 4
ES 7
WS 5
WS 6
FREESTONE BEDS
IND Q 17
BCQ 4
ES 7
0.9km
0.7km
0.4km
I
5aM
5c
E
5a*
5a-b
5a
5a*
5a
WS 6
WS 5
BQ 5
IQ 23
0.4km
0.8km
0.55km
0.4km
I
E
5a
E-W
5a
5a-c
NW
upper unit
lower unit
5a
5M
5a
2
?
METRES
30 feet
20 feet
10 feet
SECTIONS IN THE FREESTONE BEDS, PORTLAND LIMESTONE FORMATION. CENTRAL PART OF THE ISLE OF PORTLAND, DORSET.

FIG 68



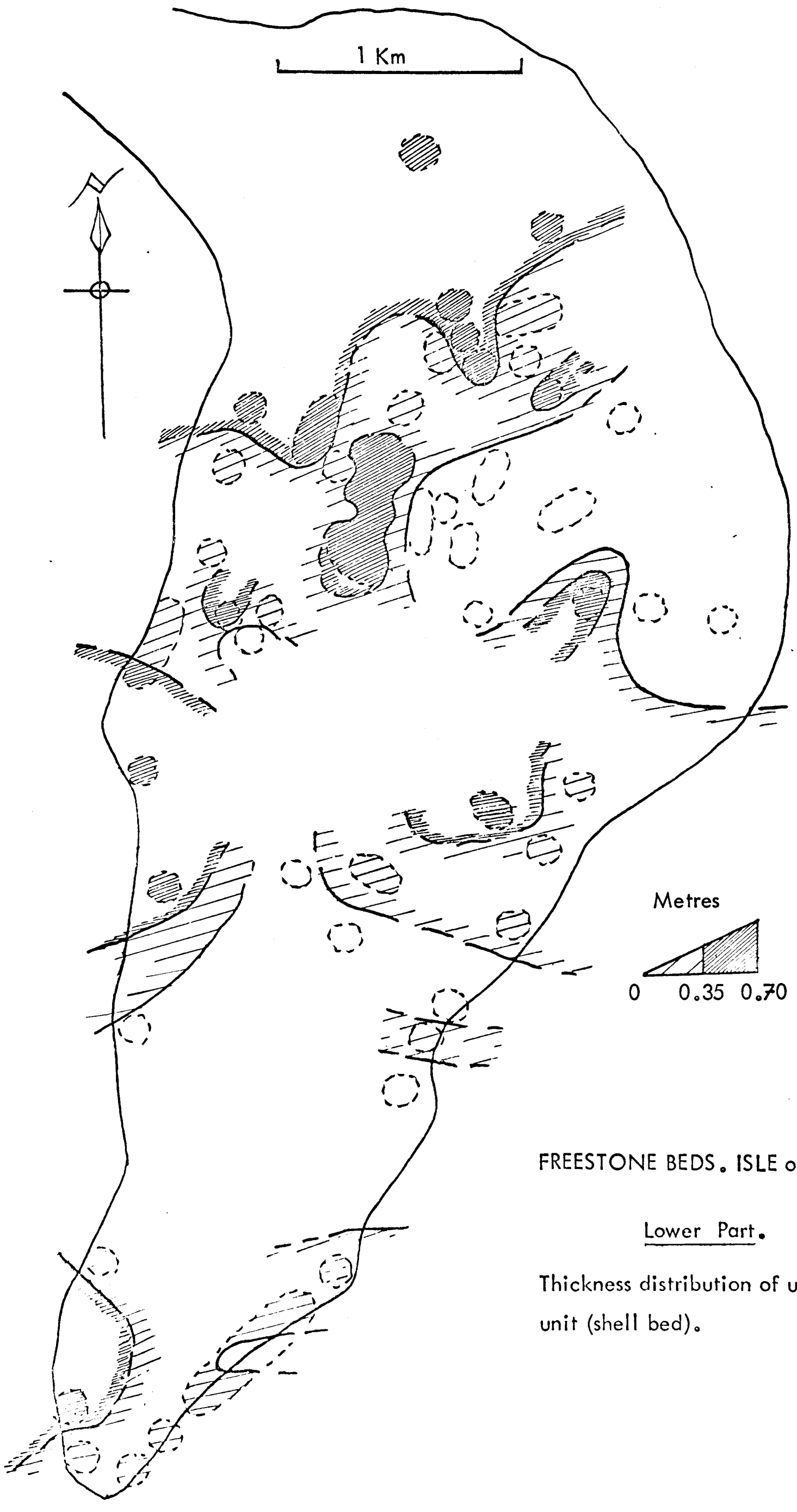
FREESTONE BEDS, ISLE of PORTLAND.

Lower Part.

Thickness distribution of lower, main, unit.

(carbonate sand)

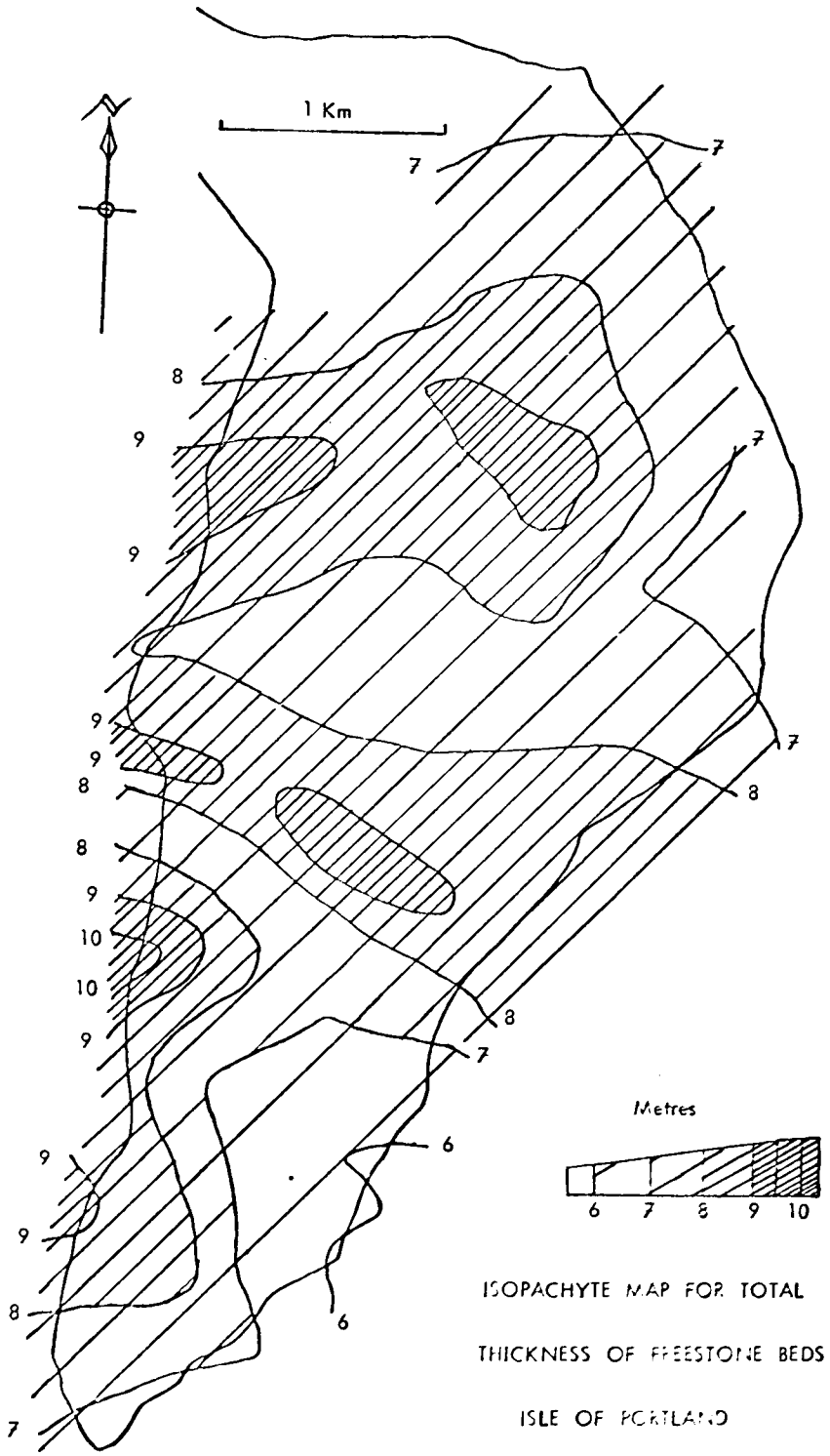
FIG 69



FREESTONE BEDS. ISLE of PORTLAND.

Lower Part.

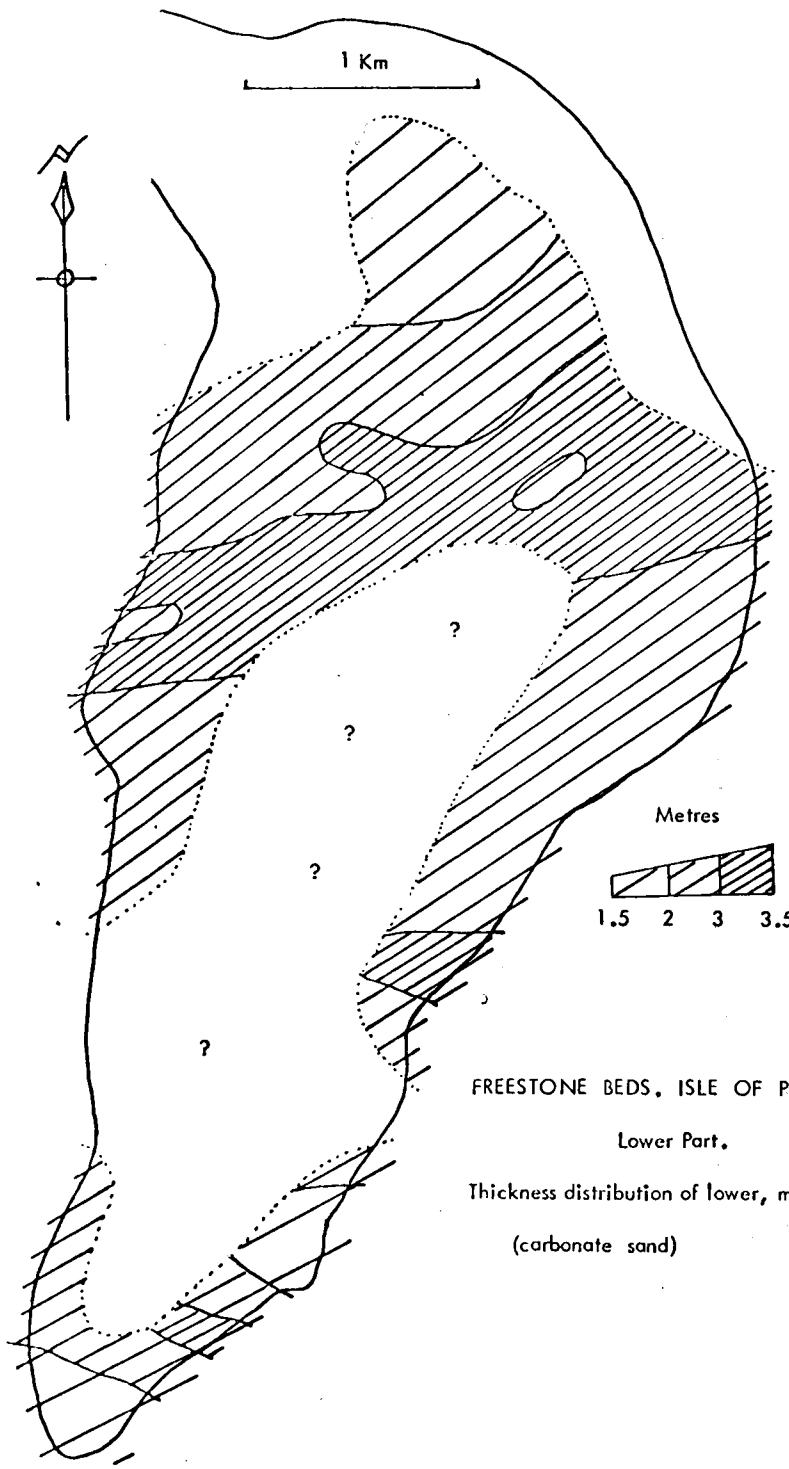
Thickness distribution of upper, minor, unit (shell bed).



ISOPACHYTE MAP FOR TOTAL

THICKNESS OF FREESTONE BEDS

ISLE OF PORTLAND

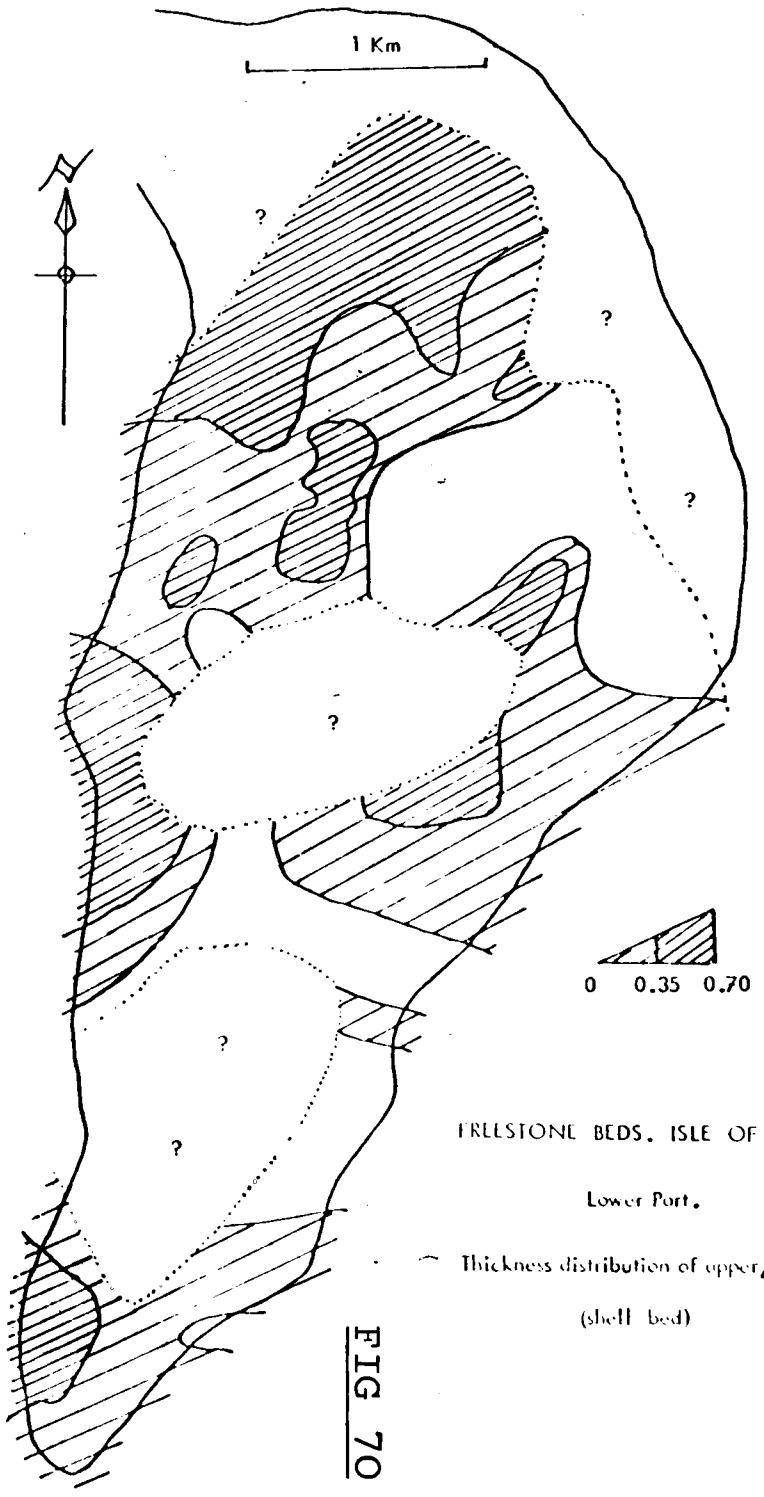


FREESTONE BEDS. ISLE OF PORTLAND.

Lower Part.

Thickness distribution of lower, main, unit

(carbonate sand)



FREESTONE BEDS. ISLE OF PORTLAN

Lower Part.

Thickness distribution of upper, minor, un

(shell bed)

FIG 70

merely the first of many shell beds up from the base of the Freestone Beds and as it does not occur everywhere (Figs. 63, 69) the separation of Whit Bed from Base Bed is not practicable. The Roach is the topmost shell bed and is not always present (Figs 64,). It is characterised in the north by the presence of a cerithiid gastropod (Aptyxiella portlandica) (Fig. 74). In places this top bed is lime mud facies which also varies in distribution and thickness (Figs 74). Two types of small patch reef occur in the upper part of the Freestone Beds; these are oyster reefs and algal-oyster-bryozoan reefs. The distribution of these and the pebble and sand grade debris derived from them is shown in Fig. 75.

Rather than attempting a long account of all the measured sections on Portland, the facies present are described and four representative sections show that facies vary within quite a short distance (Figs 64-67). Other diagrams show special local features but in spite of the multitude of sections available these afford only tantalizing glimpses of the three-dimensional picture.

In spite of the above remarks, it is convenient to make a rough division of the Freestone Beds into lower, middle and upper parts, although these units are not always distinguishable (Fig. 63). The thickness distribution for each part is given in Figs. 70, 73).

(A) Lower Part: This consists of one or two units. The lower main unit ("Base or Best Bed") varies from 1.5-3.5m thick, the original sediment of which was mostly carbonate sand. The upper, minor, unit ("Base Bed Roach") is a shell bed which varies from 0-0.7m thick. The overlying sediment of the Middle Part can be either lime mud facies or carbonate sand facies. Its contact with the Lower Part is easy to recognise when it is a change from sand to mud, with or without the shell bed. If the sediment above is still sand facies, however, it is very difficult, and sometimes impossible, to locate the division accurately when the shell bed is thin or absent (see Figs. 66, 67).

The lowermost unit varies in thickness as is depicted in Fig. 68. It is thickest (3-3.5m) in a belt across the centre of the island, thins rapidly to the north (1-1.5m) and more slowly

to the south (1-1.5m).

Most of the original sediment of the lower, main unit was ooid sand, although locally, thick shell beds or biochem sand occur instead, e.g. WS 5 & 6. The topmost facies of the underlying Cherty Beds is always shelly sponge-spicule lime mud. The basal 0.5-1.0m of the lower part of the Freestone Beds is often a mixture of sand and mud-grade carbonate; i.e. ooids or biochem grains in a mud matrix (wackestone-packstone), e.g. WS 2 (facies 5aM and WS 6 (facies 3) Fig. 59 . In both cases the upper part of the bed is mud free, having a grainstone texture.

The thick shell accumulation at WS 5 (Mutton Cove) (Plate 54) is a solid mass of shells and coarse fragments, some of which may be algal. Concentrations of whole shells are present containing large oysters, trigoniids Camptonectes, Isognomon, Pleurotomaria and Pholodomya (?). Also present are serpulids and partially silicified colonies of the coral Isastrea up to 0.2m across, bored by Lithophaga. (This locality, and that at the top of the Cherty Beds at WS 9 is the only place where this coral has been found by the author.) Discrete bioturbation is sometimes visible in the finer material and probably exists throughout the shell bed. The shells are sometimes seen to be imbricated and at a distance appear current bedded on a large scale (Plate 54). The total thickness (including part of the Cherty Beds) is about 4.5m and that assigned to the Freestone Beds is about 2.5m. The vertical variation in the size of whole and fragmented shells and various horizons of bioturbation suggest that the accumulation took place in many stages over a period of time, rather than representing a single period of sedimentation. The nearest sections are about half a kilometre to the north and south and are shell free (Figs. 59, 64). It is not easy to see the lateral changes in the inaccessible cliffs but the shell bed appears to be an accumulation at the south end of an ooid sand mass (Fig. 64). This may also be true for the east side of the island (Fig. 60) where the lower part of the Freestone Beds thickens southwards from NS 1 & 2 and becomes very shelly at ES 5. The shells include large oysters, trigoniids, Camptonectes and Isognomon; the infaunal and epifaunal bivalves

occur in approximately the same proportions.

The majority of the exposures in the lower unit show the beds to be composed of ooid sand facies. In some of the exposures the lower 1.5 to 2m is seen to be cross-stratified in planar sets (Figs. 65, 66) (Plate 55) and this, together with the thickness, suggests straight-crested, submarine sand ridges, with a wavelength of perhaps 100 to 500 metres (Fig. 81, 86) Sometimes the sets are graded (avalanche foresets) and often silicified in the form of chert containing a lot of spicules of the sponge Pachastrella. There are very few exposures suitable for measurements of foreset dip, but of the seven exposures in the cliffs of the south-east coast, all but one show a SW-SSW direction; the exception, which is at the Bill itself, dips to the NW. In all the other exposures the beds are massive and homogeneous. The grains are usually well sorted and this makes it difficult to detect depositional structures. Straight, high angle burrows are quite common as well as general bioturbation. It is obvious that burrowing animals have been responsible for destruction of the majority of depositional structures. This is more evident in the higher part of the Freestone Beds when there is some lime mud mixed with the sand; the burrows are more distinct due to biogenic segregation of the sand and mud. In sections where the beds of the lower unit are not totally massive throughout, the upper levels contain thin "strings" of bivalves (usually epifaunal) which demarcate beds of shell fragments and ooid sand, 0.1-0.5m thick. These thinner beds sometimes show small-scale depositional structures such as ripples and small-scale planar cross strata. trending NE-SW (Fig. 65, PBW1). It is thought that the large scale dunes moved only during rare high energy conditions and became colonised during the longer periods of relative quiet. Ripples and megaripples modified the surface producing the thinner, shelly beds.

The upper, minor, unit is a shell bed dominantly composed of disarticulated trigoniids, generally preserved as empty moulds. The matrix is a mixture of the sediment above and below, with the addition of some shell fragments; (thus it can be either a

carbonate sand grainstone or a sandy lime mud wackestone.) The basal contact is always burrowed, and mud-lined tubes often extend approximately 0.25m into the sand. The trigoniid valves are oriented in any direction, including vertical, and this is undoubtedly due to bioturbation.

It is probable that the bivalves colonised the sand body during a long period of stabilisation. Quieter water conditions ensued and lime mud was deposited in the north of the Isle of Portland. Some of the bivalves lived in the mixture of sand and mud. In some places the shells are concentrated at the base of the bed and fragments decrease is size upwards which implies current disturbance before bioturbation.

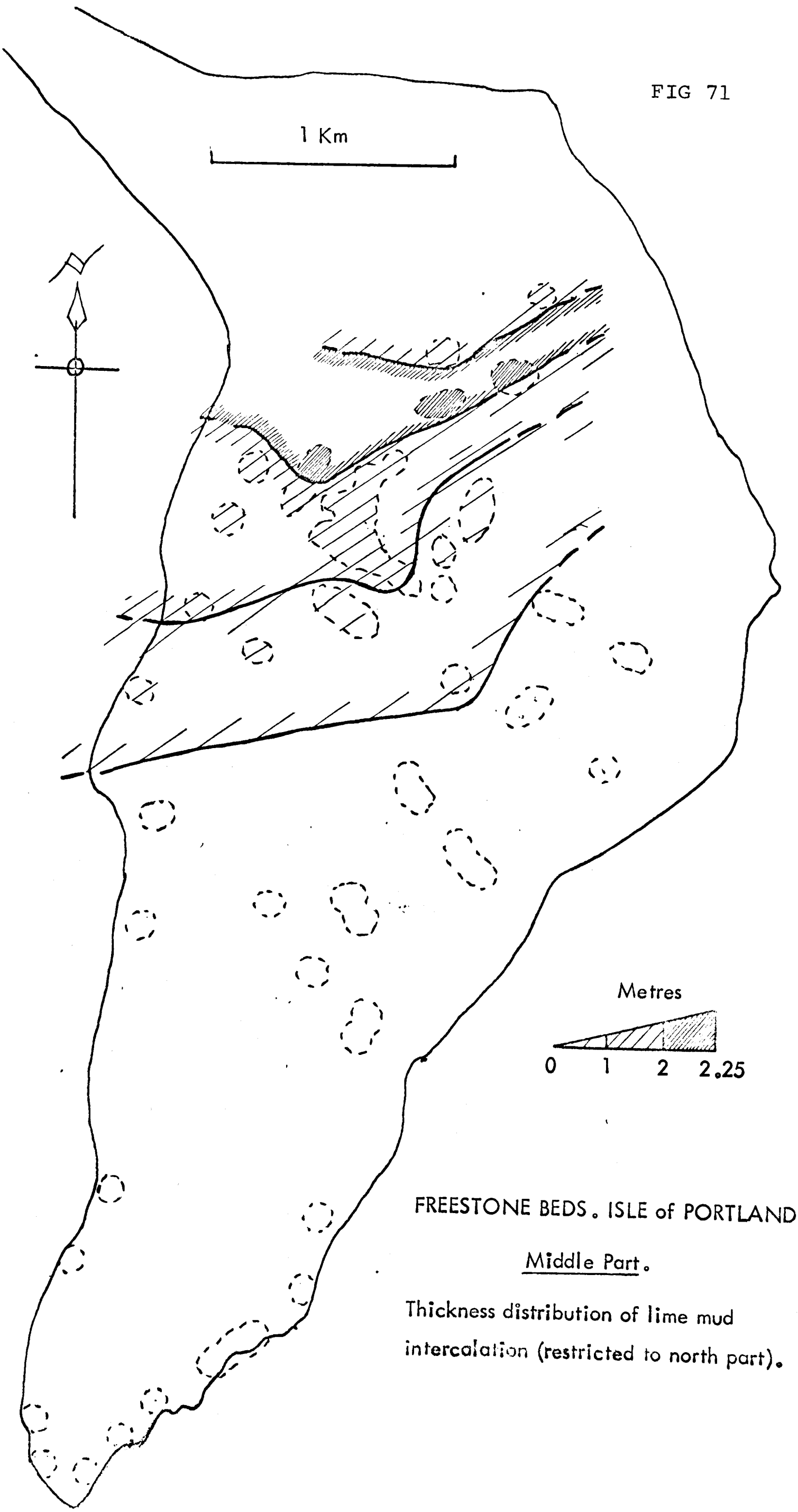
The distribution and thickness of this shell bed is given in Fig. 69 . To a certain extent, the thickness belts are parallel to those for the unit below, and have an inverse relationship in that the shell bed thickens to the north whilst the unit below thins in the same direction. The coincidence, however, is by no means exact.

(b) The Middle Part: Although an attempt has been made to divide the succession into three parts everywhere on Portland, it is not applicable in those areas without the lime mud intercalation, for reasons given above. The description for the beds above the Lower Part of the Freestone Beds will be as follows:-

Area with lime mud - (North Area): Middle Part; Upper Part.
Area with sand throughout - (Central and South Area): Middle with Upper Part as one continuous unit. (Fig 63)

North Area, Middle Part: The base is taken at the facies change from carbonate sand to lime mud with or without a shell bed. The top is taken at the facies change back to carbonate sand in the Upper Part. The Middle Part, thus defined, varies in thickness from 2.25m in some of the northerly exposures to zero, 1-1.5km to the south (Fig. 71). The thickness belts are approximately parallel to those of the units of the Lower Part of the Freestone Beds, and there is a general inverse relationship with the thick, lower, main unit. The sediment of the Middle Part was originally

FIG 71



FREESTONE BEDS. ISLE of PORTLAND.

Middle Part.

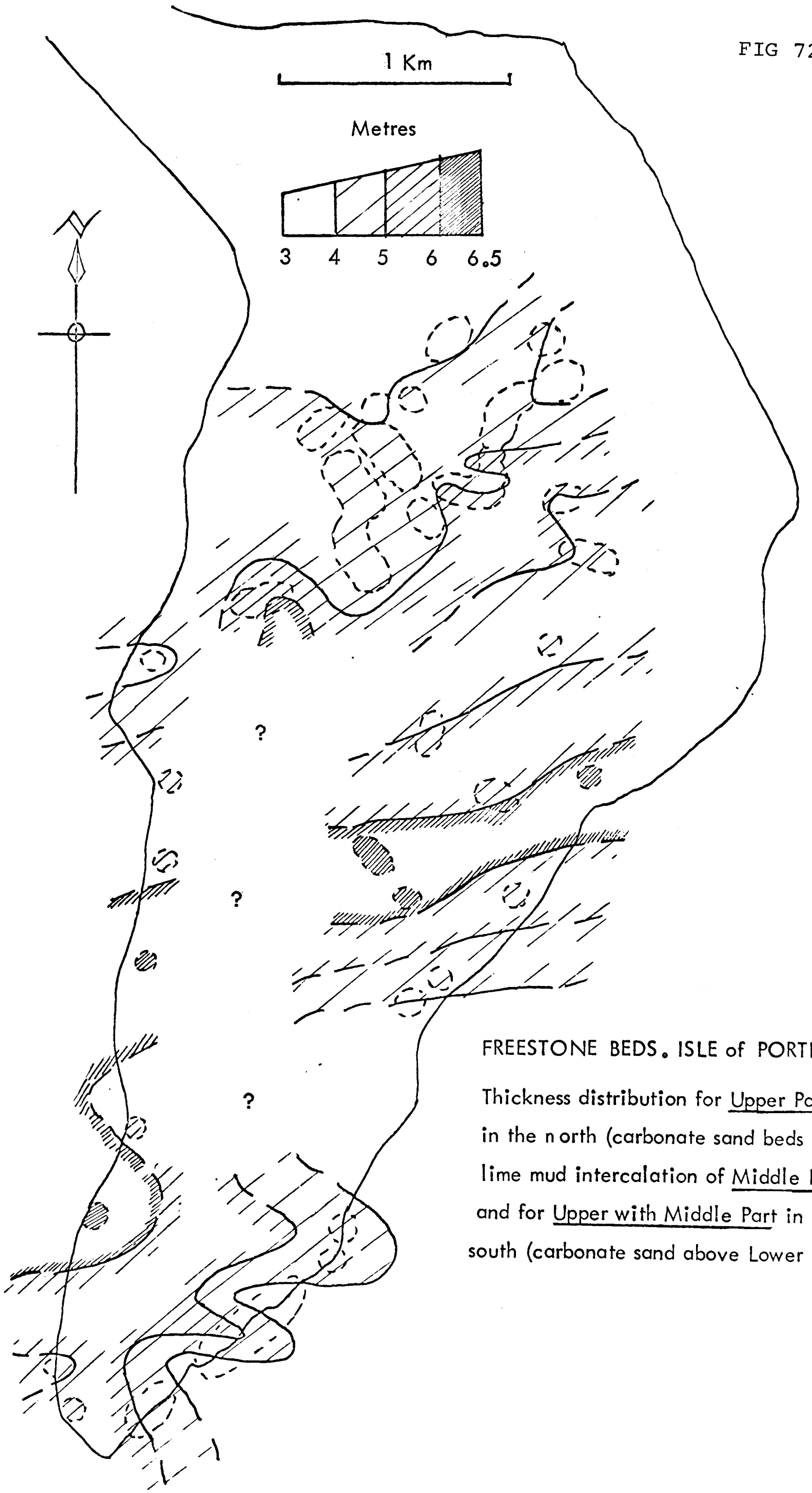
Thickness distribution of lime mud intercalation (restricted to north part).

lime mud with a varying proportion of biochem sand and often more than 10% Rhaxella spicules (facies 1a) ("Curf"). Occasionally single moulds of closed and open articulated valves of trigoniids are found, as well as single valves. Occasional shell surfaces and large ammonites are seen, as well as large and minute gastropods, and Callianassa fragments, but there are no thick shell beds.

In the area where this division thins and is not always underlain by the shell bed, the original sediment had an increased proportion of biochem sand (facies 3) and passed southwards into a spicule rich mixture of biochem and ooid sand, now cherty cross-stratified limestone (Fig. 64, WS3 to WS6). This compares with the Pachastrella-rich facies 3 & 4 intercalation in the in the Freestone Beds of the Isle of Purbeck East, the Freestone Chert Bed, 0-1m thick. The Middle Part always contains grey or black chert in the form of nodules and sheets ("Flinty Bed") which vary from <0.05- 0.25m in thickness. The thin seams of chert often follow shell "strings", and are generally parallel to the bedding. Some exposures show thin sheets of "transgressive" chert which superficially resemble those produced by silicification along foresets, as seen in the Lower and Upper parts of the Freestone Beds. However, on close examination there is no evidence for such a control and it seems that the silicification took place much later, along curved joints in the homogeneous fine-grained limestone. This is the same origin as proposed for the high-angle chert sheets in the Cherty Beds of Portland and the Isle of Purbeck West (Gad Cliff).

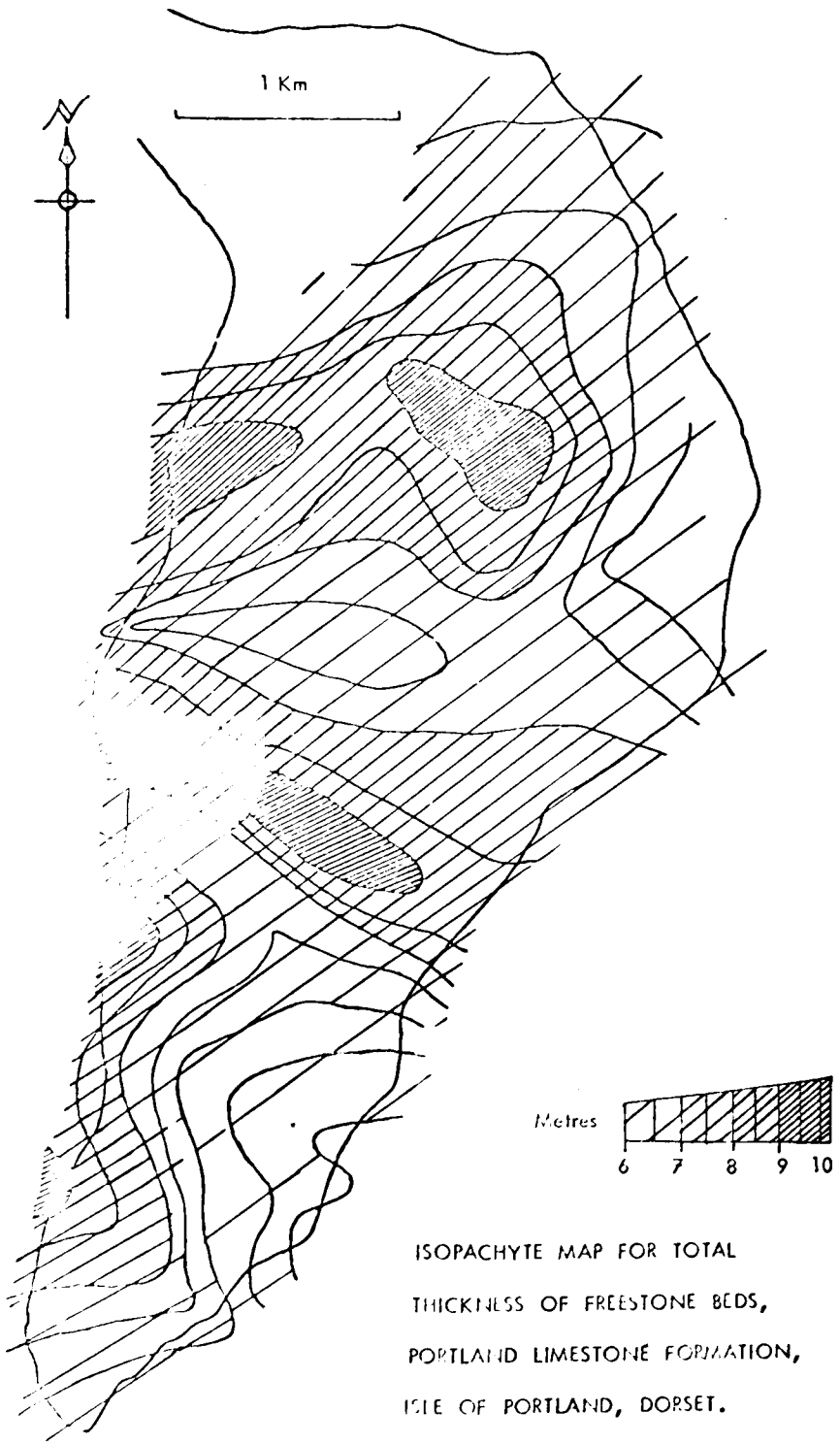
This fine-grained incursion of the Middle Part, into a generally sand-grade succession must represent a phase of quiet water conditions probably similar to those in which the sponge mud facies of the Cherty Beds was deposited. If a model may be briefly introduced here it seems that there was a shallow water area over a linear swell where ooid sand accumulated, surrounded by deeper water in which lime mud was deposited. The ooid sand mass seems to have had an a xis trending NE/SW, and a steeper slope landwards, to the north-east. The lime mud intercalation

FIG 72

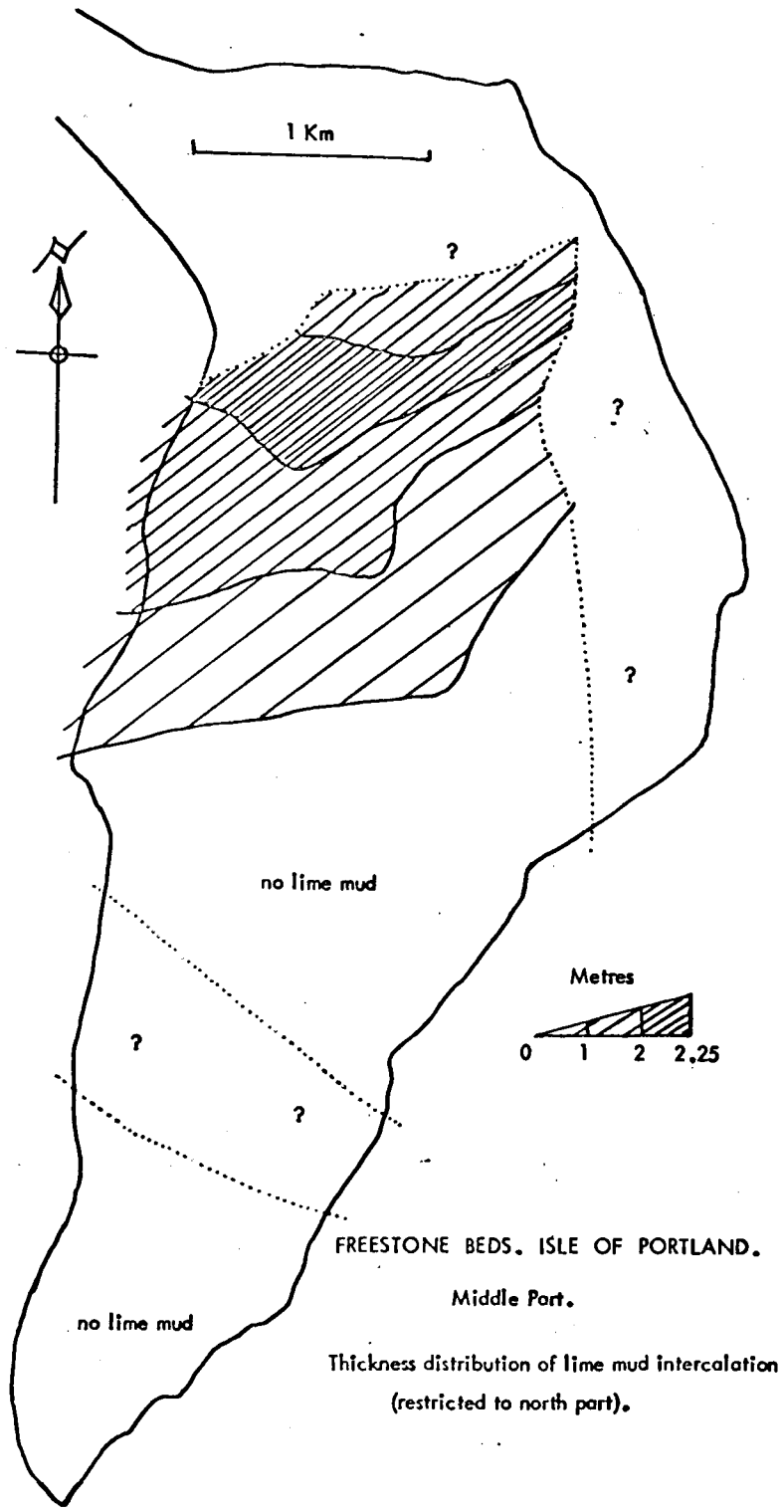


FREESTONE BEDS. ISLE of PORTLAND.

Thickness distribution for Upper Part in the north (carbonate sand beds above lime mud intercalation of Middle Part) and for Upper with Middle Part in the south (carbonate sand above Lower Part)



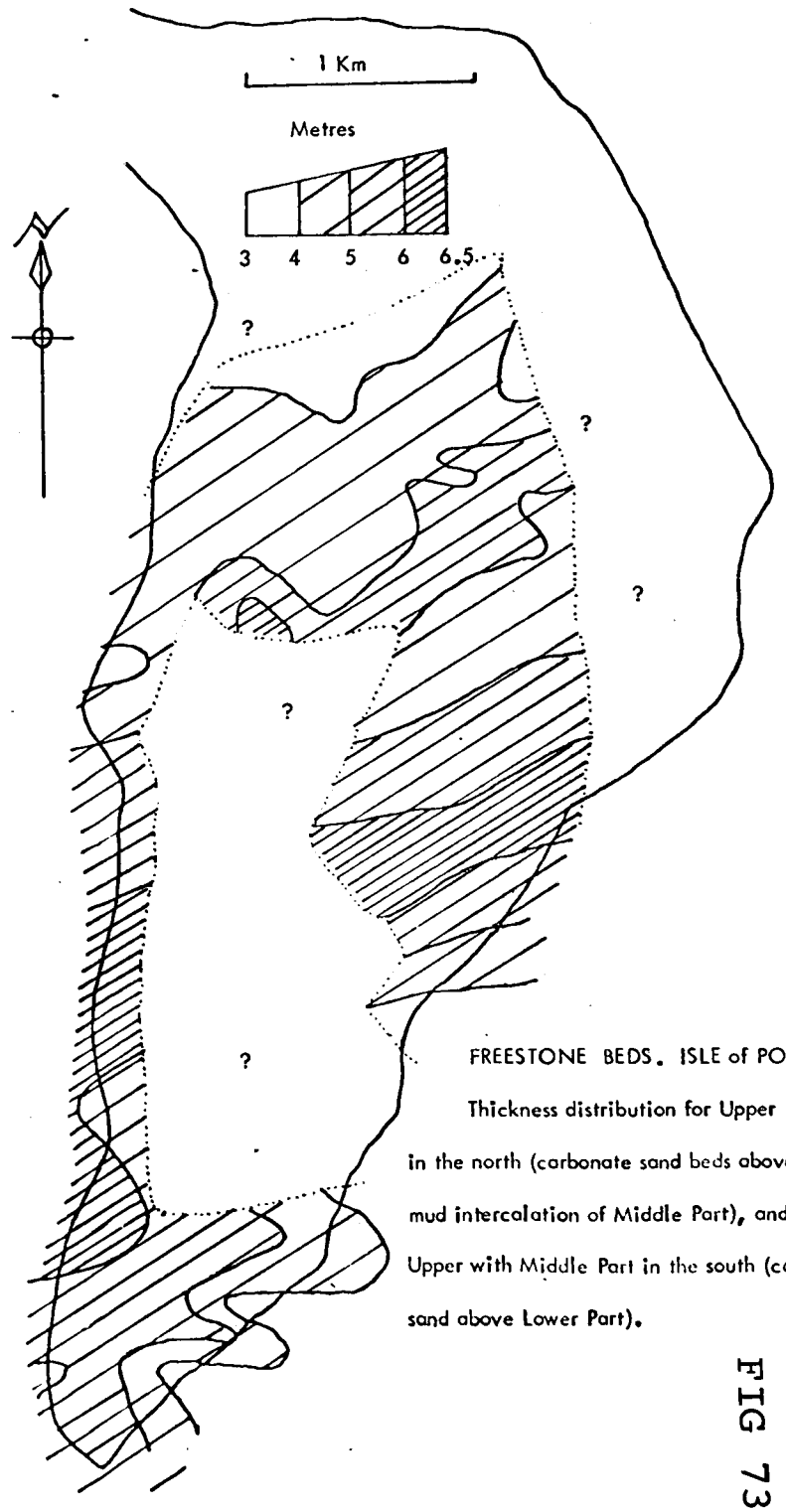
ISOPACHYTE MAP FOR TOTAL THICKNESS OF FREESTONE BEDS, PORTLAND LIMESTONE FORMATION, ISLE OF PORTLAND, DORSET.



FREESTONE BEDS. ISLE OF PORTLAND.

Middle Part.

Thickness distribution of lime mud intercalation (restricted to north part).



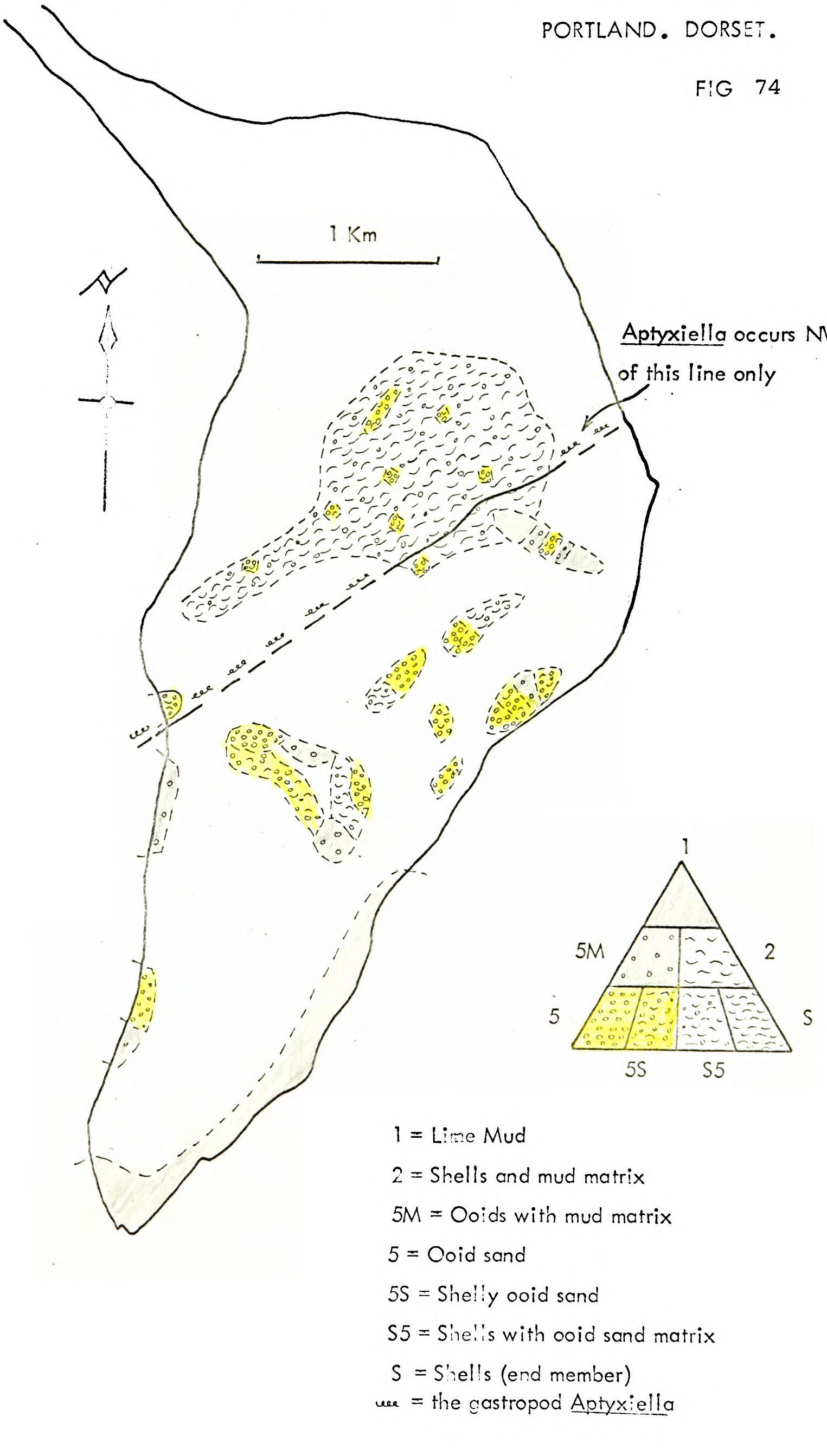
FREESTONE BEDS. ISLE of PORTLAND.

Thickness distribution for Upper Part in the north (carbonate sand beds above lime mud intercalation of Middle Part), and for Upper with Middle Part in the south (carbonate sand above Lower Part).

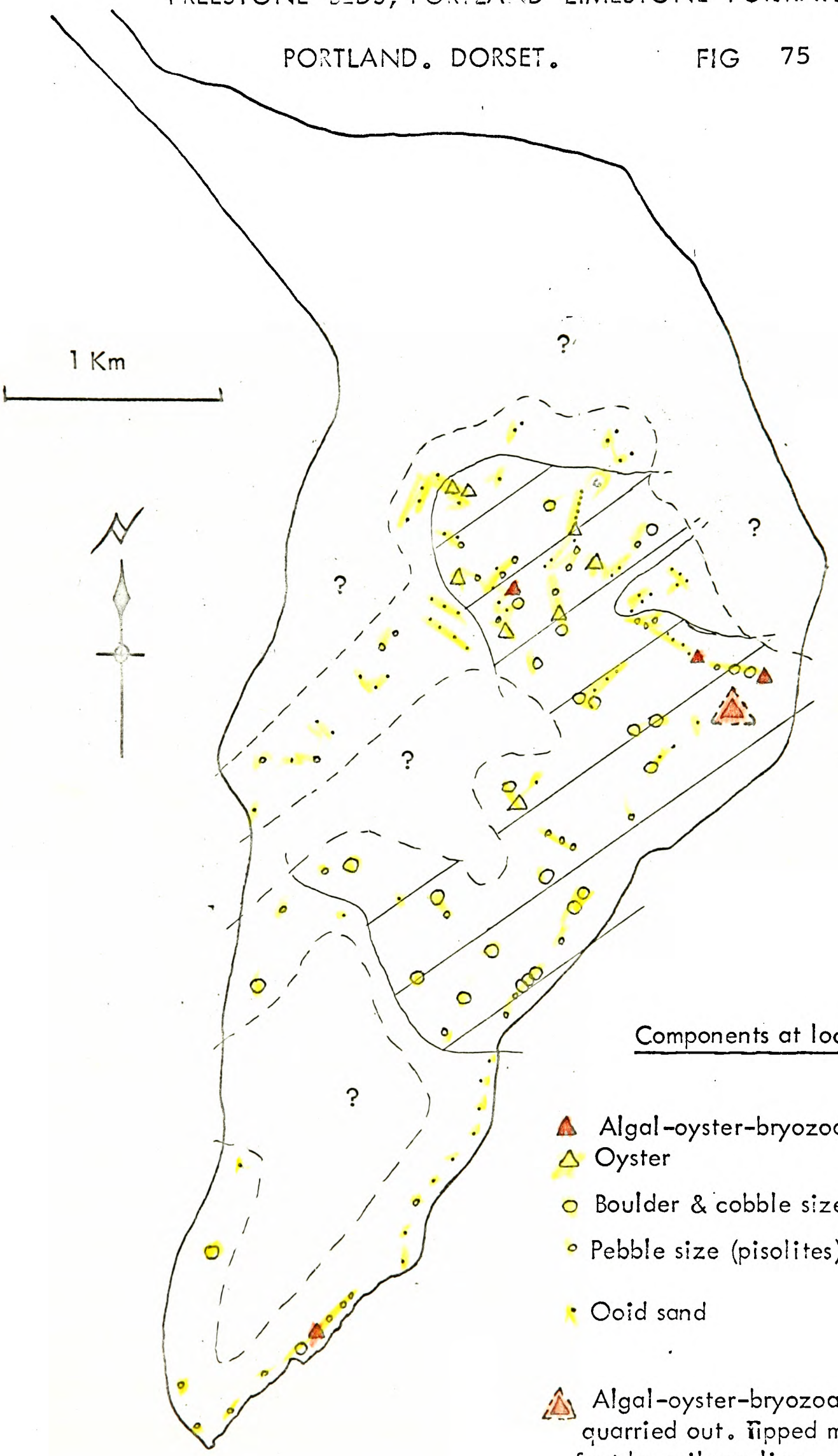
FIG 73

DISTRIBUTION OF FACIES FOR THE TOPMOST 0.5 - 1 METRE OF FREESTONE BEDS. PORTLAND LIMESTONE FORMATION. ISLE OF PORTLAND. DORSET.

FIG 74



DISTRIBUTION OF SMALL PATCH REEFS AND DEBRIS DERIVED FROM THEM, WITHIN THE OOID SAND FACIES OF THE UPPER PART OF THE FREESTONE BEDS, PORTLAND LIMESTONE FORMATION. ISLE OF PORTLAND. DORSET. FIG 75



Components at localities measured:

- Algal-oyster-bryozoan } Small Patch-reefs
- Oyster }
- Boulder & cobble size } Debris from the reefs + ooid sand
- Pebble size (pisolites) }
- Ooid sand

Algal-oyster-bryozoan reef complex quarried out. Tipped material at cliff foot by railway line.

No ornament indicates no information.

? = large area of no exposure

Area with the most "patch-reefs" and coarse debris.

is banked up against the steeper north side and does not extend far south of the axis. This suggests that the intercalation of mud came from the north west and represents a phase of quiet water deposition in the lee of the sand mass. This must represent a deepening of the water and a shift of the axis of sand deposition to the south. The gentler southern slope of the bank faced the open sea and mud deposition was not possible. The supposed equivalent sandy sediments to the south contain some mud, however, and the ooids are often micritised suggesting slow accumulation.

North Area, Upper Part: The base is defined as the top of the lime mud intercalation of the Middle Part in the north. The top is defined as the base of the Purbeck Beds. There is generally a very widespread and easily recognised facies change from shelly carbonate sand and mud of the Freestone Beds, to fine-grained stromatolitic algal sediments, with no macrofauna, of the lowest Purbeck Beds.

The known thickness of the Upper Part in the northern area varies from 3.6m in the far north to 6.0m one kilometre southwards; generally, it is between 4 and 5m (Fig.72,73). As in the case of the Lower Part, it can usually be divided into two units. The lower unit ("Whit Bed") mostly consists of 2-5m of ooid sand facies. The upper unit is very variable in thickness and lithology but is generally 1-2m thick and very shelly ("Roach"). The simplest and most typical sequence is described first (e.g. Fig. 65 TQ1) and some of the many local variations later.

Most of the original sediment of the lower unit was grain-supported ooid sand with subordinate mixtures of shells, fragments of shells and red algae, biochem sand, occasional Pachastrella sponge spicules and intraclasts of oomicrite. The ooids are usually well preserved but have been micritised to a variable degree and secondary porosity developed within some grains. Lime mud sometimes occurs as matrix and burrow linings.

The lowest 0.5-1.0m is often a mixture of sand and mud-grade carbonate, commonly with Pachastrella spicules and shell fragments. Depositional structures are not often seen as the sediment is

usually too well sorted for depositional surfaces to be distinguished, or too rapidly deposited for grading to have taken place. Most graded foresets which did exist were bioturbated and the structures destroyed. Also, most of the quarry sections are not clean or fresh enough for any details to be seen unless really coarse shell fragments weather out. Although none of the sections is washed by the sea, the best exposures are along the west-facing cliff tops and in the old, unsheltered quarries high in the north and the working quarries in the east. Even in the latter, many faces have a coating of dripstone which prevents the details of deposition from being disclosed.

Such depositional structures that are visible are of two types: erosional planar cross strata with sets 0.5-1.0m thick, and trough cross strata with sets 0.1-0.2m thick. Both types vary in orientation but the observed directions are too few to be particularly significant; the larger sets dip mainly to the south-west but occasionally to the north-west and south-west. The basal parts are often poorly sorted with shell fragments and sponge spicules delineating foresets. Solution and precipitation of the silica of the spicules resulted in partial silicification of the foresets in some cases, as in the Lower Part of the Freestone Beds. More common are lines of chert nodules 0.05-0.1m thick which follow discontinuity horizons, and which probably represent the base of foresets in a bioturbated or better sorted sediment. The trough cross strata are more variable in direction and trends have been observed in a N-S, NE-SW and NW-SE direction, in any one section. A section in the lower unit can show trough cross strata overlying the planar beds or be trough bedded throughout.

The Upper unit is characteristically very shelly. The most common constituents are Laevitrigonia, Isognomon, Aptyxiella and Solenopora. Typically this topmost shell bed consists almost entirely of Laevitrigonia and Aptyxiella in an ooid sand matrix. The aragonite shells have been dissolved leaving external and internal moulds with a void between. Generally, the shells occur throughout this unit but in places they are concentrated into two

or three current deposited horizons with shell-free ooid sand facies between. (Fig. 65 TQ1). The long, high-spired gastropods are usually unbroken, even at their tips and, apart from lying horizontally, do not point in any obvious direction. The trigoniids are usually disarticulated but not broken and sometimes open, articulated valves are seen on bedding planes. As with the gastropods, no preferred orientation of the bivalves is obvious, apart from being horizontal. The mixing of the disarticulated, shallow infaunal bivalves with the epifaunal gastropods indicates disturbance and the general horizontal attitude indicates that this was generally due to current activity rather than bioturbation, but is some places burrows can be seen (e.g. INDQ5).

The topmost 0.1-0.5m is often coarse grained with intraclasts of lime mud and sometimes bored clasts occur, up to 0.05m across. This topmost part is often partly silicified in the form of nodules and sheets of dark brown chert in which the details of the sediment and structure are preserved exceptionally well. The silicification preceded solution of aragonite shells and thus the shell structure of the trigoniids and the laminations of ooid grains are preserved. This shell bed at the top of the succession is widespread over the northern area and constitutes a "veneer" over the more varied beds below.

Local variations from this simplified description of the Upper Part of the Freestone Beds in the north area are common, mainly affecting the upper part of the lower unit but influencing in detail the shell bed above. The variations occur in the Upper part of the Freestone Beds throughout the island and are described following a generalised account of the Middle with Upper Part in the rest of the area.

Middle with Upper Part (Rest of the Island)

The base is taken as the top of the upper, minor unit (shell bed) of the Lower Part where present. When absent a layer of shell fragments can usually be traced. (Figs. 65, 67) The thickness distribution is similar to that for the Freestone Beds as a whole (Figs. 73). The Middle with Upper Part reaches a known maximum of 6.7m in the thick east-west belt across the centre of the

island. The beds are also thick in the south-west but thin to 4.0m in places along the south-east coast (Fig.72).

It is not practical to divide these beds because in the field it is not possible to trace bedding planes over the whole area for use as lithostratigraphic boundaries. However, they can be described in terms of a lower portion, generally without shell beds, and an upper portion which is often shell-rich. It seems probable that the lower portion is in part equivalent to the Middle Part in the north, whilst the upper portion seems to correspond to the Upper Part.

In order to synthesise descriptions of 95 measured sections in the Middle with Upper beds, generalised accounts are given for the following main areas:-

(i) Central Area: west and east. This area includes the west coast half a kilometre north and south of Mutton Cove (WS4-6), Bowers Quarries, the south faces of Inmosthay and Independent Quarries, Higher Headlands Quarries, Long Acre, France, Broadcroft (including Yeolands), Siltlake, Chalklands, Cottonfields, Bottom Coombe and Wakeham East Quarries; also ES6 and 7 (Rufus Castle).

(ii) South-east Area: This includes Perryfield Quarries, Southwell Landslip, Suckthumb Quarry (includes Grangecroft and Coombefield), Duncecroft, Freshwater and Breston Quarries as far south along the south-east coast as Sand Holes.

(iii) Far South Area. This includes the coastal Longstone Ope, Butts and Bill Quarries and the sea cliffs between.

Grid References for these localities are given in Fig.61 .

(i) Central Area

On the west side of the island for about 1.5km south of the lime mud intercalation in the north, the lower portion of these beds is chert-rich. This cherty part thins from 2.5m on the west coast, to zero on the east side of the island (Fig. 65, c.f. WS6 & ES7). The original sediment was a mixture of Pachastrella spicules, shell fragments, biochem and ooid sand.

The ooids are generally very micritised. Depositional structures are usually obscured, but planar cross strata with erosional, but tangential bases are sometimes visible, with sets up to 1.0m thick. Foresets dip in NW, W, SW, S and E directions but there are not enough suitable exposures for significant data to be recorded. The fore and bottom sets are often silicified and when seen in the field in cross section, appear as thin, light grey chert lenses up to 0.05m thick and 1-3m across. A good example is at locality WS6, on the west coast (Fig.65) where there are about ten sets, each approximately 0.25m thick. The thick development at this point is probably related to the massive shell bed of the Lower Part of the Freestone Beds about 0.5km to the north, over which the cherty facies thins and at locality WS5 is only 0.6m thick (Fig. 67).

The upper portion in this western part of the Central Area is generally homogeneous ooid sand facies which thickens eastwards at the expense of the siliceous sediment below. At WS5 there is 5.0m of massive oolite, interrupted by a single thin layer of shell fragments and a shell bed (calcitic bivalves) 0.8m thick (Fig.67, WS5). To the east of this the cherty sediment at the base is 0.5-1.0m thick but a similar bed about 0.5m appears 1-2.0m above. The latter, higher silicified cross strata are seen only in cross section; the trend of foreset dip is E-W and NE-SW. Above this the sediment is still generally pure ooid sand but beds with shell fragments occur (Fig. 67, BQ5, IQ23). The topmost 0.5-1.5m below the Purbeck Beds, is the same as in the north area; that is, a shell bed, rich in trigoniids and Aptyxiella, with chert, coarse ooids and occasional micrite clasts in the top 0.5m (Fig. 67).

When the lower portion is traced eastwards in this Central Area the cherty horizons eventually disappear and the beds consist of massive oolite with bedding plane joints two to three metres apart (Fig.67, BCQ4, Fig. 65, ES7). Shell "strings" and fragments are rare. In these massive successions, where it is difficult to distinguish even the Lower Part of the Freestone Beds, there is a slight change in facies in the middle of the whole succession.

The ooids are more micritised than above and below, there is a slight increase in the proportion of intraclast sand and lime mud may appear (i.e. the facies may change from 5a to 5b or 5M). In places the upper portion (1-3m) is very shelly and cherty or becomes a lime mud facies. These local variations are described later. The topmost 0.5-1.5m is nearly always shelly but without Aptyxiella (Fig.74)

(ii) South-east Area

Southwards from the east end of the thick central belt, the Middle with Upper Part is less massive and less homogeneous. It is 6.0m thick at ES7 (Rufus Castle) (Fig.65) and approximately the same at Perryfield Quarries 0.5km west. However, at the latter the lower portion contains one or two layers of chert nodules and the upper, shelly, portion is 1.5m thick (Fig.66 PQ6). The beds are 6.25m thick in the north side of Suckthumb Quarry, about 1km WSW of WS7. The original sediment of the lower portion was micritised ooid sand. The upper, shelly, portion varies from 1.5-3.0m and contains massive patch silicification of the shell beds in places. The original sediment of the upper portion was basically ooid sand but with an appreciable amount of intraclasts and lime mud mixed with the shells. The topmost 1.0m contains chert but is more variable than to the north. The sediment was shell-free coarse ooid sand usually with lime mud, and some shell fragments. It is either a typical trigoniid shell bed, but without Aptyxiella, or a bed of oysters and other bivalves. In the south faces of Suckthumb Quarry the lower portion is chert-free and so massive that the junction with the Lower Part of the Freestone Beds is not always detectable. The upper, shelly portion varies in thickness from 2.25-3.25m.

South-south-west from ES7, along the coast, the Middle with Upper Beds thin from 6.0m at the north end of Southwell Landslip, to 5.5m at the south end (SL3) and 4.5m at Freshwater Quarries (LOQ1) (Fig.66). The beds between ES7 and LOQ1 are variable, but generally become thinner bedded with more shell horizons, some silicified cross strata (foresets dip E-W) and some horizons of chert nodules (Fig.66). Along Southwell

Landslip there are shells in the middle rather than in the upper portion, the latter of which was composed originally of fine to coarse ooids and coarse shell sand. Further south, in Duncecroft Quarries (above ES8), the lower portion is again massive and the upper shelly portion varies from 1.0-3.0m. From here to the southernmost exposures at Portland Bill, the topmost 0.5m consists of laminated lime mud facies (Figs 66, 74).

From Freshwater Quarries (Fig. 66, LOQ1) to Sand Holes, about 0.6km south-west, only the upper 2.5-6.0m of the Freestone Beds are exposed and the junction with the Lower Part is not usually seen. The lower portion of the Middle with Upper Part is massive bedded ooid sand facies with only scattered shell fragments. The upper portion is 1.0-1.5m thick and consists of an upper 0.5m of laminated lime mud resting on a shell bed of either trigoniids or calcite-shelled bivalves. The contact is noticeably bioturbated and discrete mud-filled irregular burrows (crustacean?) penetrate the ooid sand to a maximum observed depth of 0.8m. (Plate 57) The shell bed matrix is a mixture of ooid sand and lime mud (i.e. facies 5M). Thin lenses of ooid sand occur above the shell bed with a capping of laminated lime mud completing the sequence.

(iii) Far South Area

South-west along the coast from Sand Holes to Portland Bill there is a continuous exposure in the upper part of the sea cliffs and in the disused clifftop quarries. From Sand Holes to Butts Quarries, about 0.8km, the Middle with Upper Part varies from 4.25-4.0m thick. From here to the Bill, about 1km, it fluctuates in thickness from 4-5m (Fig. 71 & 65, PBW1).

The succession above the Lower Part of the Freestone Beds contrasts with that in the other areas in that it is relatively thinly bedded, consisting of about ten units which average 0.5m in thickness (Fig. 66, LOQ9 & PBE5). Each unit has an upward-fining basal shell or shell fragment layer, with or without algal debris. Only rarely is cross stratification visible in the coarser part (in one example this was to the east) and usually the unit has been bioturbated throughout. (Fig. 66). The burrows

are easiest to recognise when the sediment is a mixture of lime mud and sand. Thalassinoides is often seen on weathered bedding planes and has tubes 10-15mm in diameter with coarser material inside. In vertical section mud-lined unbranched, horizontal, inclined and vertical tubes are seen, about 10mm in diameter. (Plate 56). The sediment was basicly ooid sand but became mixed with biochem sand in the lower part of each unit and often with lime mud in the upper part; thus facies 5a was modified to 5c and 5aM (Fig. 66, PBE5).

These units differ up the succession slightly. In the lower portion of the Lower with Middle Part they are about 0.3m thick with more shell fragments than shells and no algal debris, whereas in the upper 3-3.5m they reach 1m in thickness, contain more shells and whole and broken algae are common. On the west side of the Bill the amount of shells in each unit increases throughout and in section PBW2 (Fig. 64) shell beds comprise 45% of the whole Middle with Upper Part, the upper portion of which is mostly shell bed. The topmost 0.25-0.5m of the Freestone Beds is laminated lime mud facies sometimes with starved ripples of coarse ooid sand and bored clasts of micrite. (Fig. 65, PBW1).

(iv) Local variations from the generalised sequences in the Freestone Beds on the Isle of Portland

Variation 1

Oyster "patch reefs" and associated debris

Massive accumulation of shells occurs in the Upper Part of the Freestone Beds, in the north, and in the upper portion of the Upper with Middle Part elsewhere on the island (Figs. 75). Close examination of these shell beds in the rare, clean exposures reveals that they are often composed of blocks of oyster bound-stone. The blocks vary from 0.05m to at least 0.50m across and consist predominantly of oysters, with subordinate Plicatula and sometimes the red alga Solenopora (O. expansa, P. lamellosa, S. c.f. jurassica). The bivalves cement each other together and multilamellar encrusting bryozoa occur in places, binding the shells and red algae more firmly, whilst carbonate sand and mud

fill the smaller interstices. The blocks are bored by Lithophaga, sponges, algae and annelids (Plate 59).

This debris was derived from local oyster "Patch reefs", but as it is not always easy to distinguish between derived and in situ material in an exposure, only a few isolated examples of the "reefs" in place are known. Oyster "pathh reefs" also existed in a lime mud facies and this is described in the context of the third local variation.

These "patch reefs" are thought to have developed on stabilised ooid sand dune surfaces during quiet periods and eroded during storms. The sand between the "reefs" was colonised by infaunal trigoniids and epifaunal pteriioids (Camptonectes, Isognomon) and gastropods (Aptyxiella). These now form the typical, widespread, shell beds within the ooid sand facies, as already described.

Other small "patch reefs" which occur, are algal dominated and consist of Solenopora with encrusting oysters and bryozoa which bound the red algae together (Figs 75, 81, Plates 61, 64). (local variety 2). Small Solenopora are found in the oyster-dominant debris and pebbles, or "pisolitic grains", of the alga are common in the sand-grade sediment.

The original distribution of the sessile, epifaunal "reef" organisms and the mobile epifauna and infauna on the sea bed has given rise to an "association" of faunas which are easily recognised in the field. Once can distinguish:-

(i) Laevitrigonia - Aptyxiella association, with subordinate red algae.

(ii) Ostrea - Solenopora association with subordinate trigoniids. Pteriioids are accessory constituents of both associations.

These are not completely mutually exclusive but a bed with mixed components is probably indicative of a higher level than is usual for the energy event which disturbed the organisms, and/or indicates that it was effective for a longer time. Some exposures show that the beds of shells and "reef" blocks were current deposited. Rounded and bored blocks occur mixed with the shells and fragments; Solenopora colonies occur upside down and the whole mass can sometimes be seen to be cross stratified

on a large scale.

Examples

1. Oyster "reef" in situ

(a) Railway cutting and quarry, east side of Inmosthay Quarries, Easton, Portland. SY 69137235.

It is not easy to see the relationships between the "reef" material and the lateral sand facies. The "reef" is 2m high and consists of apparently in situ Ostrea, Plicatula, Solenopora, Lithophaga with associated naticid gastropods and Pleurotomaria. It is about 20m wide and silicified in places with large grey chert nodules 3m long and 0.3m thick. The details are shown in Fig. 76. The interpreted history is as follows:

(i) Lowest part of section in Upper Part, Freestone Beds. The Chert at the base results from silicification of the bottom sets of a sand body which thickens to the S and SW. The oyster "reef" began to colonise the N and NE part.

(ii) Middle part of section. The Oyster "reef" increased in size and spread laterally. Debris from it spread westwards (IQ6); elsewhere there was ooid sand with fine shell fragments.

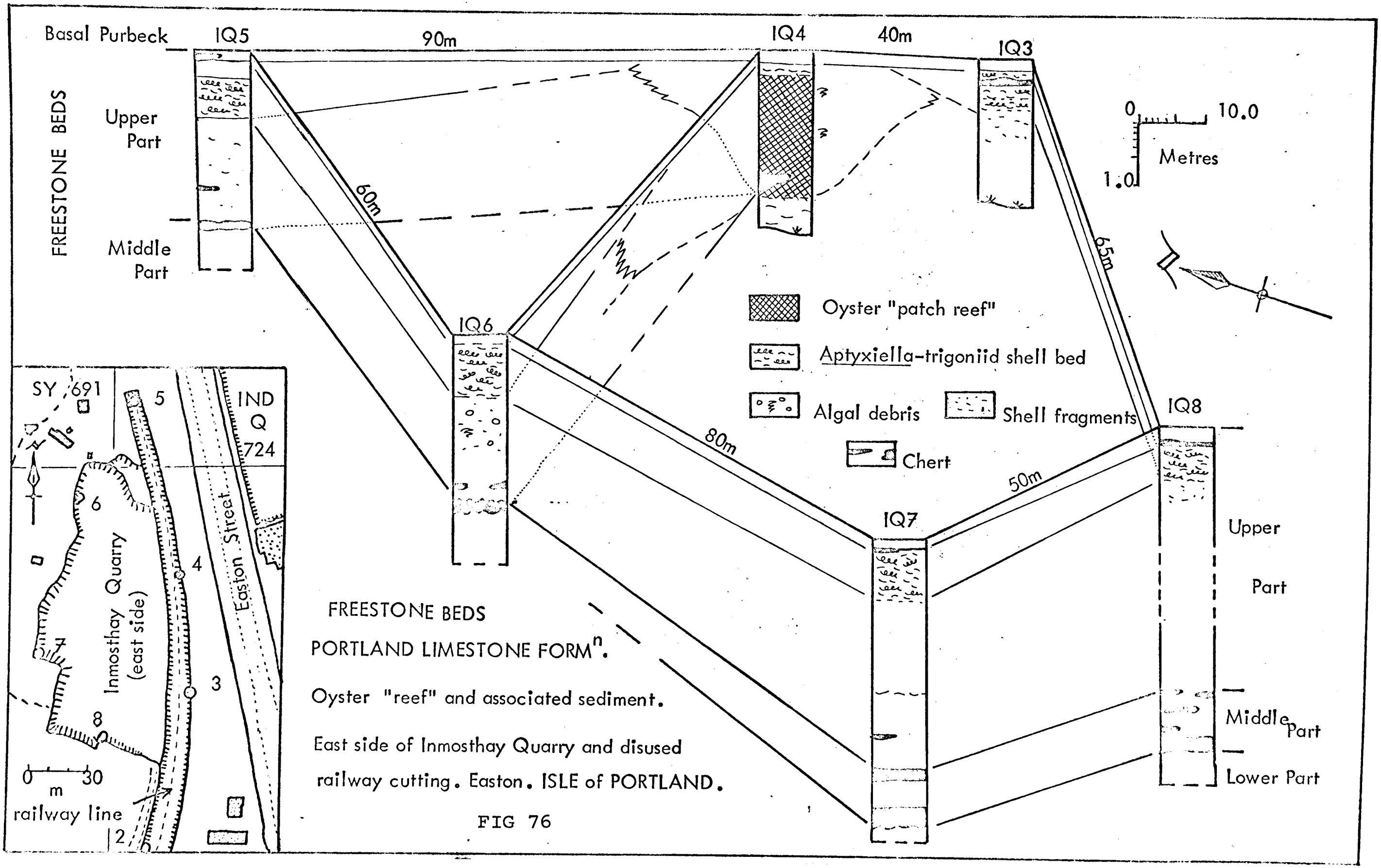
(iii) Higher part of section. The "reef" was still in existence, protruding above the sea bed. Around it, the top of the sand was colonised by infaunal trigoniids, epifaunal gastropods and burrowing animals.

(iv) A thin layer of coarse ooid sand formed a uniform cover over the whole area and then the blue-green algal sediments of the basal Purbeck were deposited.

(b) Railway cutting in land-slip on the east coast, just north of ES6, SY 70087151. The oyster "reef" here is seen to have formed an obvious positive feature on the sea bed.

2. Oyster and algal "reef" debris in current deposited shell beds (Figs 76-79)

As might be expected, there are many more localities exposing debris from "reefs" than those showing a "reef" preserved. Localities are shown in Fig. 75, but are too numerous to list



FREESTONE BEDS

PORTLAND LIMESTONE FORM^{n}.

Oyster "reef" and associated sediment.

East side of Inmosthay Quarry and disused railway cutting. Easton. ISLE of PORTLAND.

FIG 76

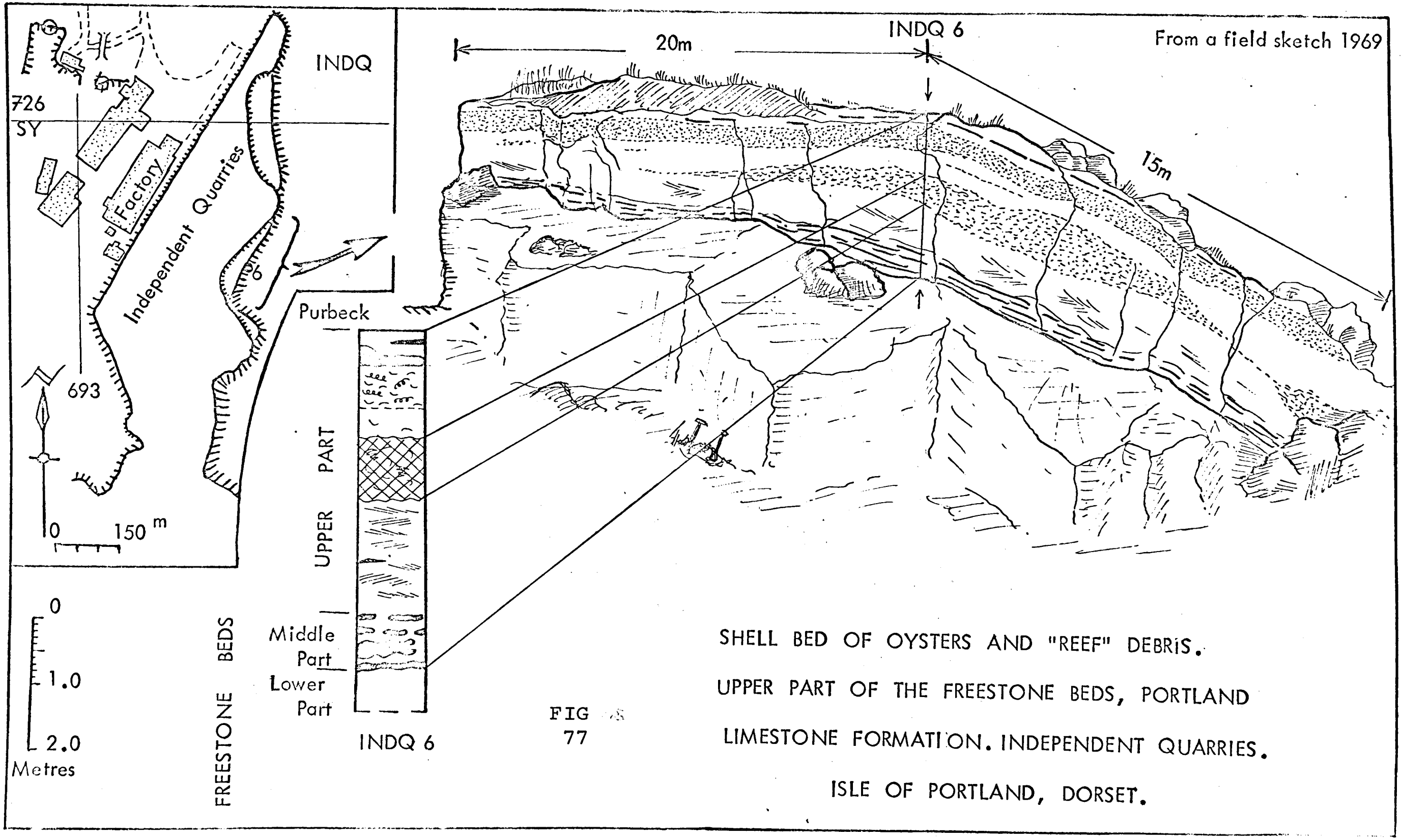
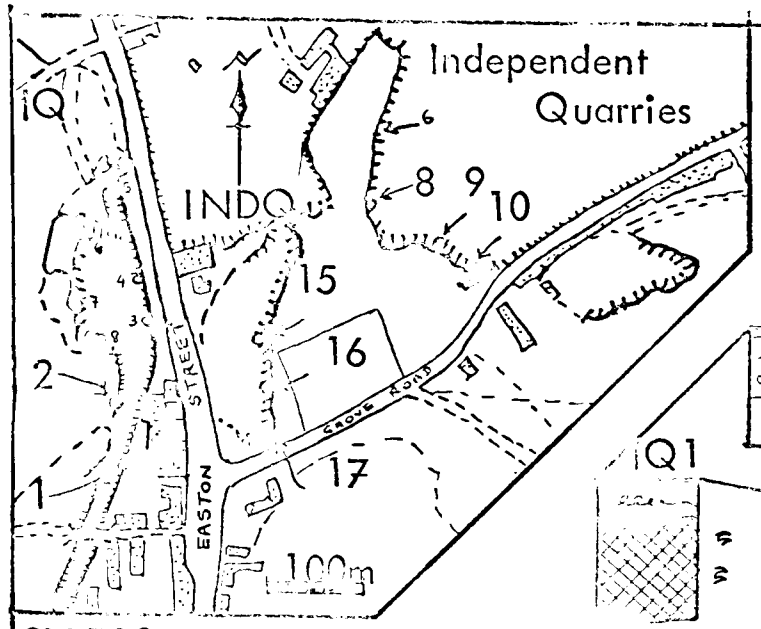


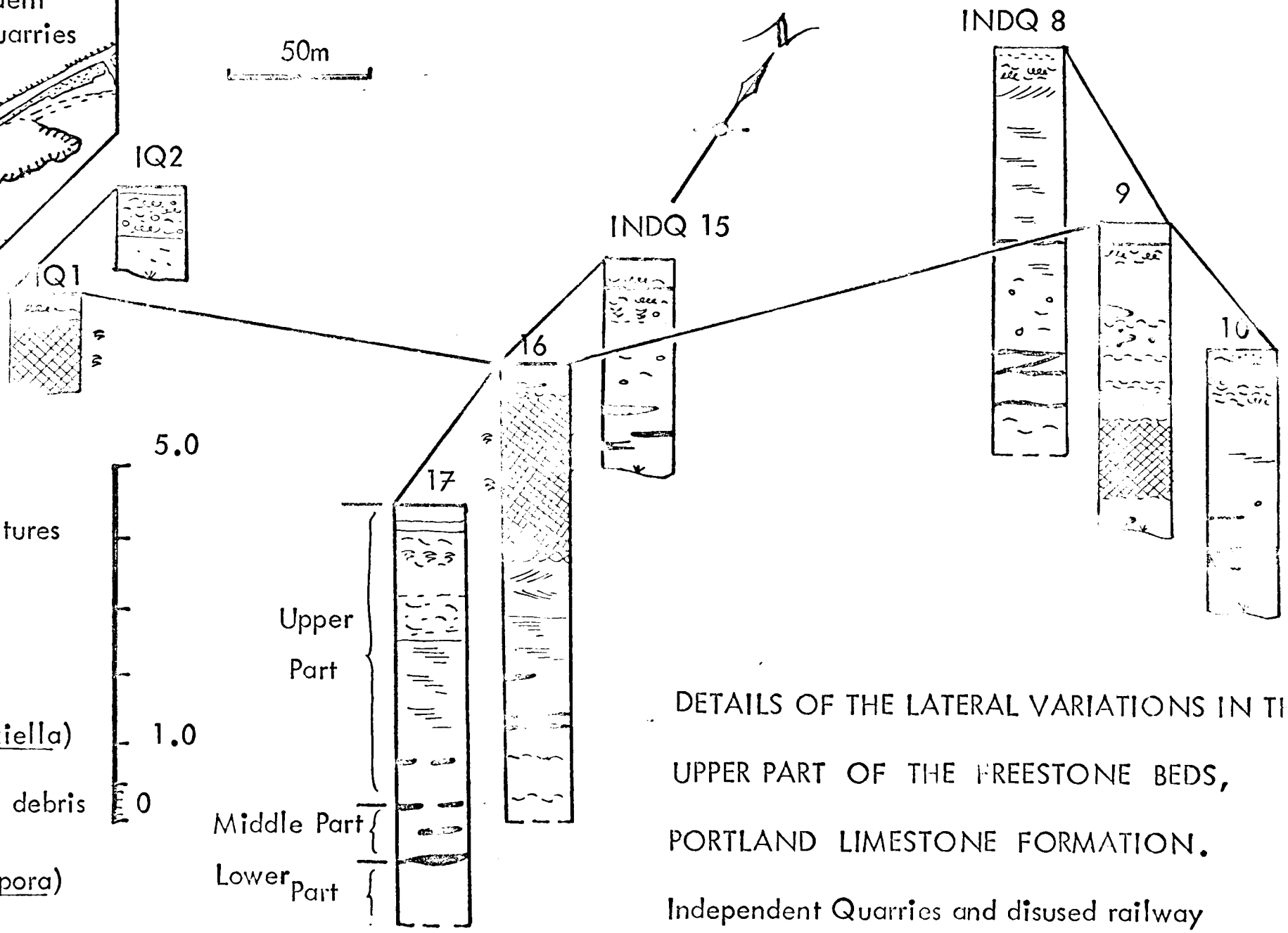
FIG 77

SHELL BED OF OYSTERS AND "REEF" DEBRIS.
UPPER PART OF THE FREESTONE BEDS, PORTLAND LIMESTONE FORMATION. INDEPENDENT QUARRIES.
ISLE OF PORTLAND, DORSET.



SY 720

50m



ooid sand facies

depositional structures

bivalves

shell fragments

gastropods (Aptyxiella)

oysters and "reef" debris

red algae (Solenopora)

algal pebbles and "pisoliths"

chert

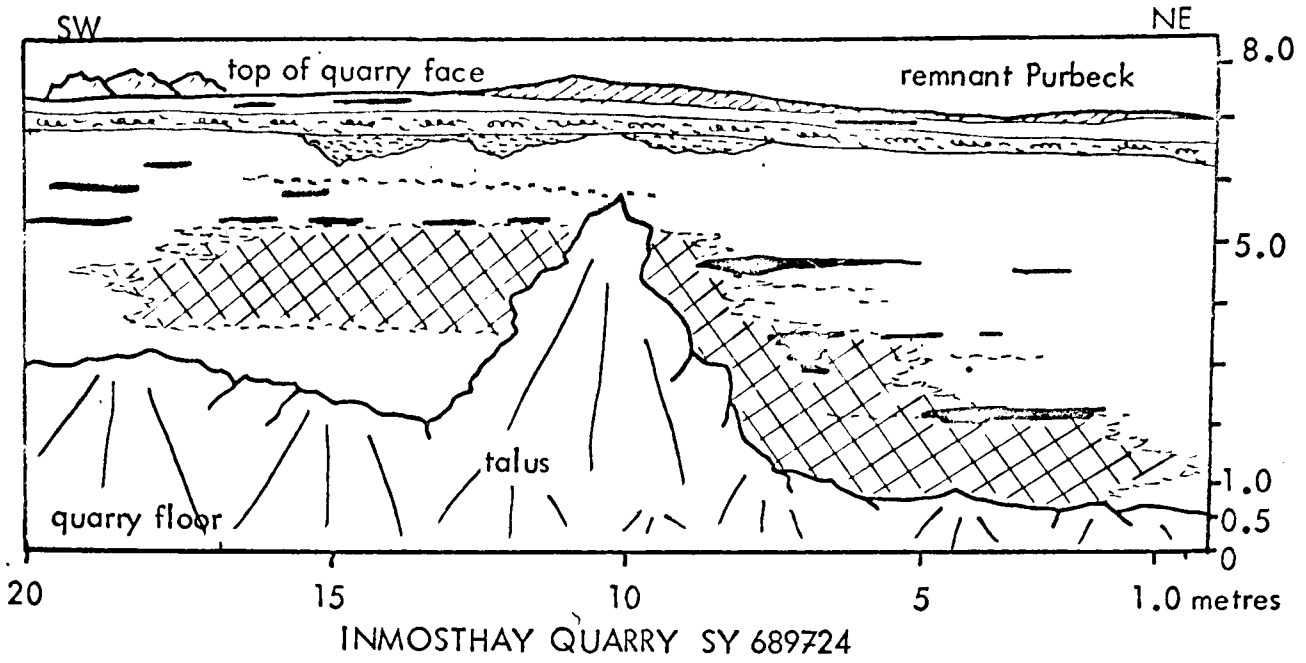
DETAILS OF THE LATERAL VARIATIONS IN THE UPPER PART OF THE FREESTONE BEDS, PORTLAND LIMESTONE FORMATION.

Independent Quarries and disused railway cutting in Inmosthay Quarries. Easton.

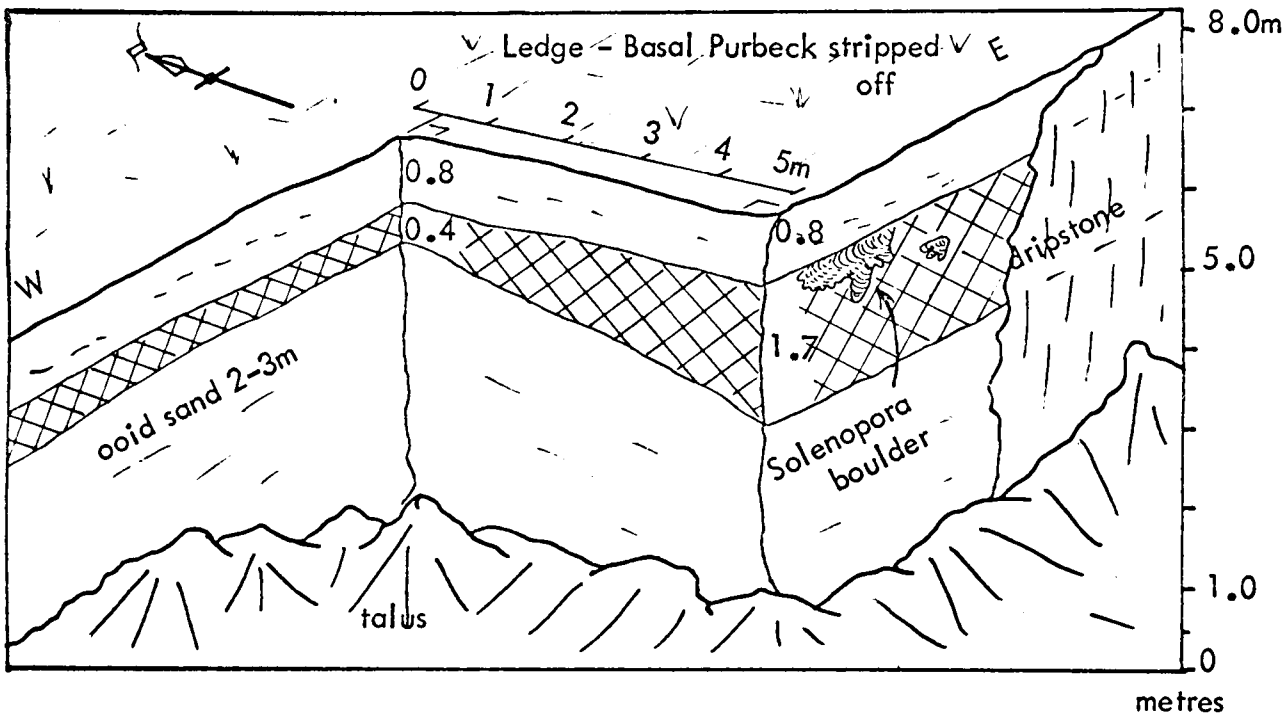
FIG 78 ISLE OF PORTLAND, DORSET.

SHELL BEDS IN THE UPPER PART OF THE FREESTONE BEDS, PORTLAND LIMESTONE FORMATION, ISLE OF PORTLAND.

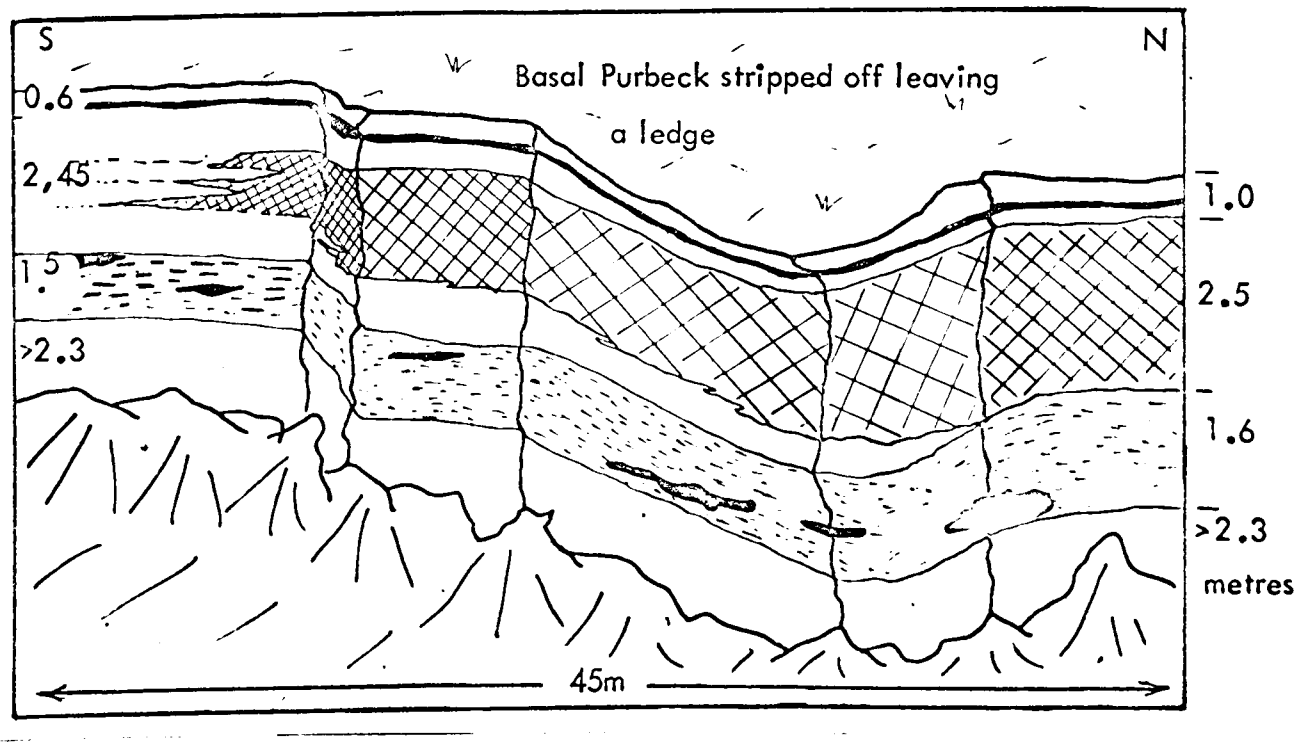
FIG 79



INMOSTHAY QUARRY SY 689724



CHALKLANDS QUARRY SY 698715



COTTONFIELDS QUARRY SY 692714

specifically. They can be summarised by giving the following general locations and examples:

(a) Admiralty and Withies Croft Quarries (SY 6972). There is an exposure in the south "wall" of the former which continues as the west "wall" of the latter. The association (a) shell bed (approximately 1m thick) at the top of the Freestone passes laterally south-westwards into a bed of current deposited oysters and "reef" debris. There is a mixed area for approximately 150m and then approximately 600m of thick association (b), before reverting to the "normal" gastropod-rich facies.

(b) Independent Quarries (Fig. 75) (SY 6972). The above "wall" passes south and patches of oyster debris up to 6m across occur at the horizon of the top shell bed of the Freestone. Below this level, in the more massive, cross-stratified ooid sand facies there is a lenticular bed of oyster debris approximately 35m wide and up to 1m thick (Fig. 77). The margins are gradational and the deposit probably represents foreset accumulation of shells on the southward facing steep slope of a dune which had a crest line exposed in longitudinal section.

In the far south-east corner of Independent quarries a development of chert-rich shell beds is exposed in the topmost 2m of the Upper Part, below which there is a bed of oyster and "reef" debris, approximately 1.3m thick and 10-15m across. There is a considerable amount of chert in these shell beds at this locality in the form of large grey patches (Fig. 78 INDQ9). Laterally equivalent to this is cross stratified ooid sand facies with algal debris.

In the far south corner of the Independent Quarries, near the junction ofEaston Street and Grove Road, the quarry face exposes a bed of oysters and "reef" debris up to 2.3m thick and approximately 30m across. (Fig. 78 INDQ16). This is laterally equivalent to ooid sand facies with algae up to 0.03m across, and finer algal debris.

(c) In Inmosthay Quarries, on the east side (SY 691723) there is a railway cutting which exposes up to 0.9m of a similar bed

to that in INDQ16, at the same horizon (Fig. 78, IQ2). On the east side of the actively quarried remnant "island" of Freestone Beds, west of the old railway, is another shell bed approximately 20m wide and up to 4m thick (Fig. 79). This is interpreted as representing the accumulation of shells on fore- and bottom-sets of several dunes transporting material in a SW direction. This section is considered to be a "dip-section", in contrast to the "strike" or horizontal sections in Fig. 77 .

(d) Chalkland Quarry (SY 698715). In the north face, above 2-3m of ooid sand facies there is a bed of oysters, algae and "reef" debris which thickens southwards from 0.4m to 1.7m in a distance of 5m, and which is at least 10m wide in an east-west direction (Fig. 79). The bed contains large Solenopora on their sides and upside down; one example is 1m long in direction of growth, and at least 0.6m wide, with fairly delicate "fingers" still intact. The fragments have an east-west lineation which might suggest that the material was transported from the north and the algal and oyster "reef" boulders tumbled down a southward facing slope.

The upper part of the succession consists of 0.8m of ooid sand, with scattered bivalves, resting on an erosion surface at the top of the shell bed.

(e) Cottonfields Quarry (SY 692714)

Near the base of the succession, above 2-3m of ooid sand facies, there is a bed, 1.4m thick, composed almost entirely of Isognomon with a matrix of lime mud and ooid sand (Fig. 79). Above this is a shell bed up to 2.5m thick with blocks of bored algal and oyster "reef" mixed with pteriioids and general shell debris. At some points, the reef blocks are 0.5m-1.0m across and when these are not obviously disorientated it is difficult to tell if they are, in fact, in position of growth. It is probable that transported material was still alive and capable of continuing growth when redeposited. The bed passes laterally southwards into ooid sand facies and t[illegible] the shell bed has an overall appearance of having been current deposited. Above, there is a thin, uniform ooid sand horizon which rests on an

erosion surface at the top of the shell bed.

The origin of these shell beds is not completely indisputable but they are obviously current deposited. At the margins of these lenticular bodies the shells pass into ooid sand, often with a "string" of shells and fragments. The margin of a bed is seen to consist of several shell units grading in this way and these appear to be separate dunes with ooid sand being replaced by shells. Thus, a massive shell bed, approximately 2m thick, is usually a composite phenomenon accumulating over a period with several high energy events, during which several dunes, perhaps 0.3m thick, deposited shells in the same area.

3. Dunes of shells, shell fragments and biochem sand.

There is apparently only one locality where the upper bands of the Freestone Beds were composed of entirely pebble and sand grade biochemical material; this is on the west coast at WS7 (Fig 57) ~~(Plate——)~~. The succession is in the Middle with Upper Part of the Freestone Beds and consists of 2.5m of tangential cross stratified ooid sand facies (5a) with silicified top and bottom fore-sets. These dip S-SW and are overlain by 2-2.5m of cross stratified bivalve and algal sand, and pebbles with fore-sets dipping to the SW. Irregular intraclasts of biochems in lime mud and of pellet mud occur sometimes to a proportion which changes facies 4a to 4b. In places above this, is a bed 0.75m thick, of coarse intraclast and biochem sand (facies 6c) mixed with lime mud. ~~(Fig.——)~~ (Plate 61). The sediment is very poorly sorted and shells and fragments are in places imbricated on foresets. Thin seams of lime mud (approximately 0.05m thick) sometimes occur between sets and there are burrowed contacts with mud clasts mixed with the sand grade sediment. There is a micro-stalactitic cement to this sediment similar to that described by Taylor & Illing (1969) and Purser (1969a) which indicates early subaerial cementation by aragonite (high inter-tidal to supratidal).* The top of the succession is a thin carbonaceous bed ("Dirt Bed") at the base of a typical stromato-litic algal limestone of the Purbeck Beds, 0.8m thick. This is

*see Plate 61

overlain by the thick "Great Dirt Bed" in which trees are rooted at various localities in the northern part of the Isle of Portland.

Variation 2

(i) Algal-oyster-bryozoan "reefs"

These are well exposed in only two areas on the Isle of Portland, but judging from the widespread occurrence of algal debris in the Freestone Beds these "reefs" were quite widely distributed. Further information has been obtained by examining the walls of buildings where this material has been used, cut and sometimes polished, for decorative facing, as, for example, in certain buildings in Oxford.

The two areas in Portland are: (a) East side of Broadcroft Quarry; and (b) Sea cliffs on the south-east coast. In the former area the "reefs" occur where the Upper Part of the Freestone Beds thins between two east-west trending thicker belts (Figs.73,75). On the south-east coast the "reefs" occur where the Freestone Beds are thinner than to the west (Figs.73,75). It is thought that these thickness variations reflect sea-floor topography and that the "reefs" existed in slightly deeper water; perhaps a depth of 2-3m.

(a) East side of Broadcroft Quarries (Yeolands Quarry). This "locality" is a collection of blocks of Freestone which were considered unsuitable as building stone and tipped over the east cliff. They came to rest on the railway line (now disused) which runs from Easton village along the east coast, to Portland Harbour (Fig.55). Numerous blocks up to 4m cubed, display "patch reefs" of red algae bound by bryozoa, with oysters and Plicatula occurring only as subordinate constituents. These "patch reefs" are seen to reach 3m across and 1m high, with erosion surfaces at the top. The blocks are from the uppermost 2-3m of the Freestone Beds, and the bedding plane marking the junction with the Purbeck Beds can be recognised by the typical presence of a thin brown carbonaceous layer and chert. At least two successive stages of growth and erosion of "reefs" are seen in the top two metres of

the Freestone Beds ~~(Fig.)~~. The "reefs" can be described in terms of constructive and destructive elements.

Constructive: Each "patch reef" is a composite structure with several algae growing at different levels, although some continued to grow throughout and reached a metre high. Encrusting oysters grew between the algae and both were coated by bryozoa (Plates 64,64). Lime mud and some sand filled the remaining cavities. The Solenopora grew with quite delicate "fingers" in places, and these are bound by multi-lamellar encrusting bryozoa and serpulids. The algae responded to the latter by growing round and enclosing them. (Plate 67)

Destructive: Other annelids perforated the calcareous skeleton of the algae and small tubes, up to 2mm across (probably algae or sponges) riddle the outer fringe of the "reefs", including the oysters and bryozoa. Lithophaga bored the entire structure and many are preserved inside their crypts in differing growth stages (Plate 61). Although the "composite reefs" consist of more than one stage of constructive organic growth, they also often contain more than one destructive stage. The sediment between the "reefs" is the normal shelly, ooid sand facies of the Freestone Beds, with trigoniids and pteriioids. The sand with shells lapped the "reefs" as they grew. The tops of the latter are flat, horizontal erosion surfaces truncating all the organic framework, including Lithophaga, and overlain by shell-free ooid sand, forming a distinctive contrast ~~(Fig.)~~.

Blocks of the "reefs", as described under variety 1, are bored on all surfaces and examples of these occur with the in situ material at this locality. Also found are bored blocks, approximately 0.25m across, which are not derived from the "reefs". The skeletal material in these is not in position of life but obviously current deposited, containing fragmented epifaunal and infaunal bivalves, gastropods and rounded algal pebbles. This must be sea-floor cemented sediment from between the "patch-reefs". No obvious bored hard-grounds have been found in situ anywhere in the Portland Group in Dorset and it is suggested that, as in the case of the "reefs", the areas of Lithophaga-bored hard substrate

were restricted to patches only a few metres across. The "reefs" may have required patches of such cemented sea bed for colonisation to commence.

(b) Sea cliffs on the south-east coast. There are two localities where algal-oyster-bryozoan "reefs" can be seen on bedding planes in the topmost 1-2m of the Freestone Beds. Both are on the raised wave-cut platform which has been quarried in places along the south-east coast. Localities are at: PBE1a SY 68505 68950 and PBE4 SY 68225 68700.

The "reefs" are approximately oval patches which measure about 1 x 1-1.5m (Plate 62). The height reaches about 0.25m but this is after penecontemporaneous erosion which truncated the skeletal components. It is probable that the height during life was up to double this. The structure is composed of oysters in life position, with a few interspersed Plicatula set in a white, fine grained micritic matrix. Solenopora occur scattered throughout but are not so dominant as at locality (a), reaching only 0.1m across. Bryozoa again occur as a binding agent but the components are more closely bound by the fine grained matrix which appears to be lime mud, probably baffled by the organic framework and possibly lithified soon after. It may have been algal in origin and the fact that it is a significant contributor to the "patch-reef" structure (Plates 61, 62) is the reason for including these examples under variety 2. In both localities in area (b), the overlying sediment is bioturbated ooid sand facies, 0.4-0.7m thick, overlain by 0.1m of small bivalve moulds, passing up into a topmost capping of laminated pellet lime mud facies, 0.3-0.5m thick. At locality PBE5 (Fig. 66) 175m SWW of PBE4, the succession is similar and Solenopora colonies up to 0.5m across and 0.25m high occur at the same level as the "patch-reefs". These are apparently in position of growth but with some bored material in the surrounding matrix.

(ii) Debris from these "reefs"

This has been largely described under variation 1, Examples 2 and 3. Fragments of Solenopora are common in many horizons in

the Upper Part of the Freestone Beds in the north, and Upper with Middle Parts in the rest of the Isle of Portland. The separation of lower portion from upper portion in the latter is based on the presence of algal debris in the higher beds. The Solenopora fragments range from whole colonies down to pisolith and ooid grain size (Plate 63). It has long been noted that the Freestone in places contains white patches but their origin has not been recorded before. Edmunds and Schaffer (1932) comment that "Stone is found with included pellets of chalky material up to one inch in diameter." Polished sections show the banded growth structure and thin sections confirm that these "pellets" are eroded Solenopora fragments. The distribution of such boulder, cobble and pebble size debris is shown in Fig. 75. The relationship of the "reef" debris to the other sediments is shown in Fig. 81 .

Variation 3 Facies change from ooid sand to lime mud, Upper Part of the Freestone Beds; Long Acre, Broadcroft and Yeolands Quarries.

The excavation of the Freestone Beds ceased in the north face of the quarries due to a lateral change, northwards, from the ooid sand facies used as building stone, to uneconomical lime mud. There is a series of exposures in abandoned quarry cuts, from the far eastern sections in Yeolands Quarry (above the cliffs over the railway track), through Broadcroft Quarry, west north-westwards into Long Acre Quarries. Many of the exposures show the nature of this facies change which strikes in a WNW-ESE direction and is exposed for 0.6km. The change is such that one section shows 4.0m of typical ooid sand facies with shells below the Purbeck Beds, whereas only 20m to the north-east, at the same horizon, there is 3.5m of lime mud with ooid sand facies below. The base of the Purbeck is a horizontal datum which can be traced between all the sections. In quarries 200m to the north and 350m to the NE (Higher Headlands Quarry, SY 696723, 699724) there is no lime mud facies, nor is it seen if the strike is traced west-north-westwards into Independent Quarries (Figs. 55, 61). The change is thought to be due to lime mud filling a submarine sand

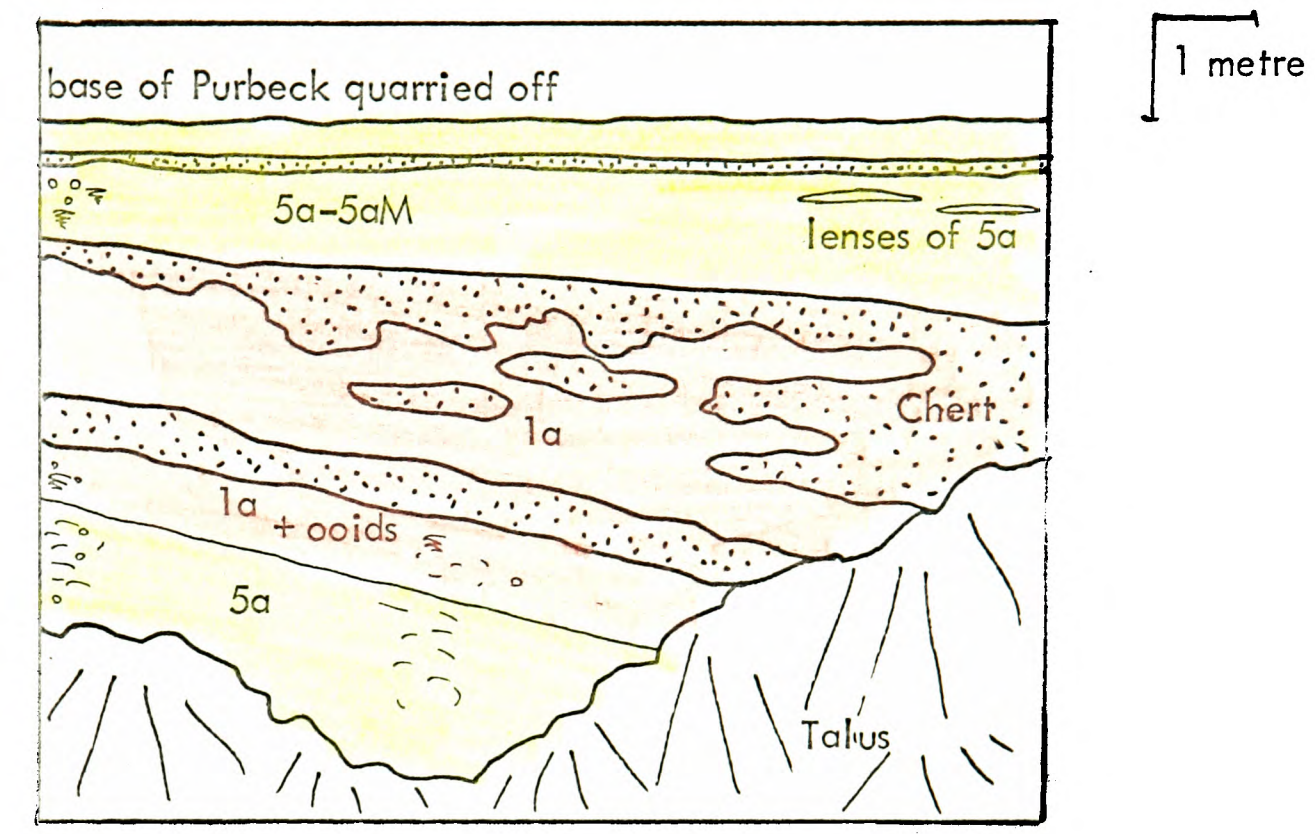
dune topography accentuated by erosion. Features of this are described under two headings:-

(a) North-east face of Yeolands Quarry and WNW to Broadcroft Quarry. The quarry face here is only a few metres north of where the laterally equivalent blocks containing algal "reefs were excavated (Variation 2 (i) (a). There is almost a continuous section for 150m ESE to WNW. The far eastern end shows nearly 2.5m of compacted, current-deposited ooid sand facies at the base of the section, with imbricated shells in places in the upper 0.5m. Above, is 0.35-0.4m of lime mud with Rhaxella spicules and scattered ooids (facies 1a), overlain by 2.0m of laminated lime mud containing oyster "patch-reefs".

These "reefs" are up to 1.0m high and the width varies from half to equal the height. Oysters are in vertical life position and very closely cemented, with small Solenopora only at the bases and round the sides (Plate 70). Plicatula and bryozoa are not obvious components but Lithophaga and other indeterminable boring organisms are fairly common. (See Chapter 2) Above is 0.5m of ooid-rich lime mud facies with a burrowed basal contact. Its top is the Purbeck junction with chert and a thin, brown carbonaceous horizon containing micrite intraclasts. The lime mud enveloping the oyster "reef" consists of laminations 1-5mm thick which are usually burrowed by small, straight, branched "twig-like" tubes 1-2mm in diameter (Plate 71,72). The lime mud was stiff enough at the time of burrowing for the tubes to remain open. Often these burrows were soon filled by ooids or later by sparry calcite, but some still remain empty. Thin lenses (average 5mm x 50mm) of ooids in a mud matrix occur within the laminations and represent isolated ripples which drifted over the mud surface of the sea bed, filling the open burrows as they passed.

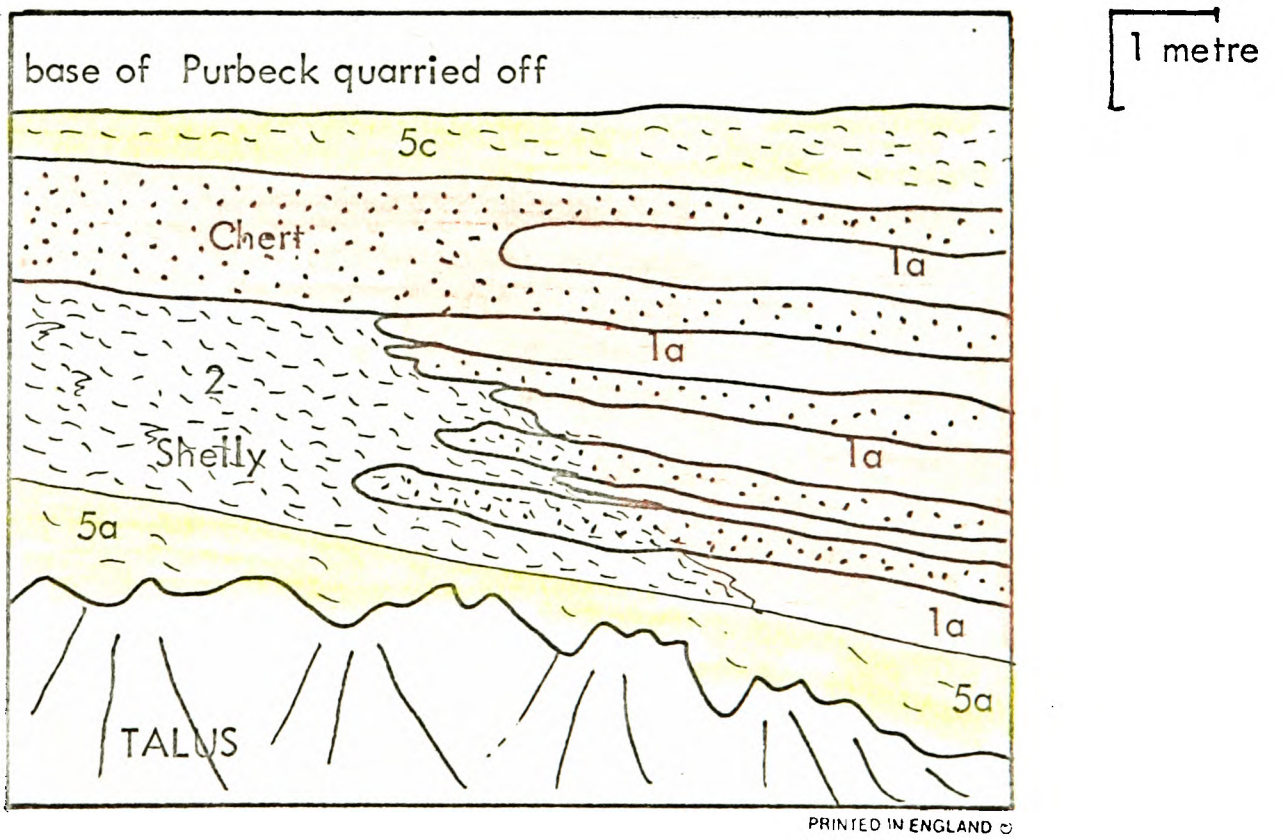
The oyster "reefs" seem to have maintained growth during the period of being "silted up" by the lime mud, giving the high pinnacled shape. The mud does not drape the whole "reef" as it would if it had been deposited after growth was complete. The "reefs" must have acted as "baffles" at times, influencing

FIG 80



NORTH FACE OF BROADCROFT QUARRY, PORTLAND

S N



NORTH FACE LONG ACRE QUARRIES, PORTLAND

MICRITE FILLING EROSION SURFACE ON OOLITE SAND BODY

UPPER PART OF THE FREESTONE BEDS. NORTH PORTLAND

SUGGESTED ORIGIN OF CARBONATE SEDIMENTS IN THE UPPER FREESTONE BEDS OF THE ISLE OF PORTLAND. FIG 81

① Lime mud. Mudstone. Calcilutite. Micrite.

② Ooid & skeletal sand. Packstone & grainstone. Calcarenite.

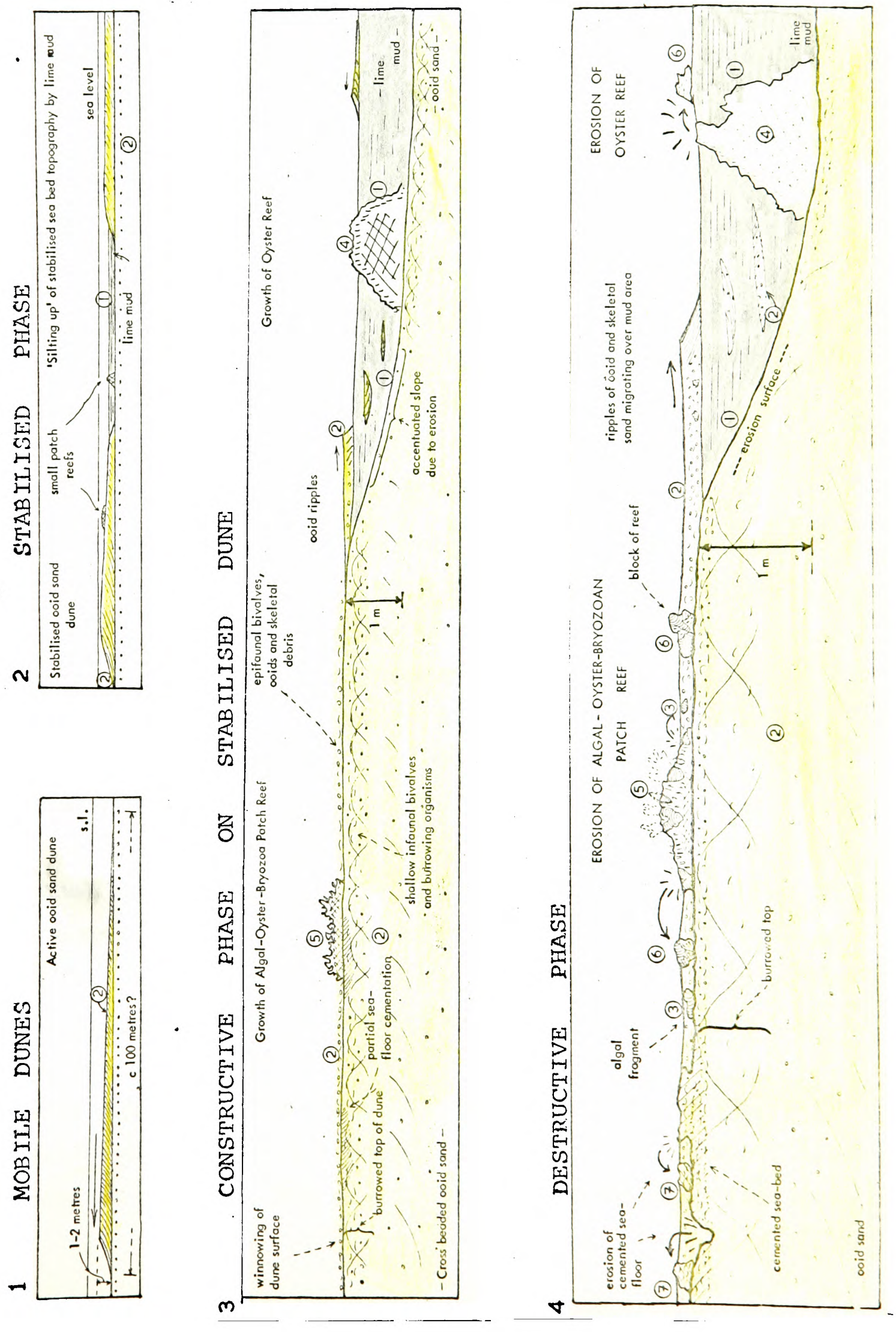
③ Shell & Algal debris. Packstone & grainstone. Calcirudit & calcarenite.

④ Oyster patch reefs. Boundstones.

⑤ Algal-Oyster-Bryozoa patch reefs. Boundstones

⑥ Eroded blocks of 4 & 5 Calcirudites.

⑦ Eroded blocks of sea-floor cemented 2 & 3. Calcirudites.



the position of drifted shell debris and ooid sand.

About 100m westwards, the face consists of laminated lime mud with ooid sand lenses (Plate 71) resting on 1.4m of shelly ooid sand with Solenopora debris and some patches of chert. There is an appreciable amount of ooid sand in the lower part of the mud facies in the form of isolated ripples and small dunes (megaripples) up to 4m across and 0.2m high with internal foreset laminae dipping approximately NW and SE. The bases of these ripples are often burrowed by shallow tubes 3-10mm across which are always sand filled, and the upper surfaces are draped by laminated lime mud with smaller burrows.

About 50m west, the exposed succession consists of 2m of ooid sand (facies 5a) overlain by 1m of partly cross stratified shelly ooid sand (facies 5c) with numerous eroded blocks from algal and oyster "reefs". The overlying topmost 1m of the succession consists of ooid sand with a mud matrix (facies 5aM) containing chert nodules with Pachastrella spicules. Within a few metres to the west the succession consists of ooid sand throughout, with a high proportion of shells, algal debris and "reef" blocks on the upper 2-2.5m (Fig. BCQ4).

(b) North face of Broadcroft Quarries and west north-westwards to Long Acre Quarries. About 150m WNW of the section just described, the relationship between these different facies can be seen (Fig. 80). Here, and in several disused quarry faces to the WNW, the top of the ooid sand facies in the lower part of the section is seen to be an inclined surface (Plate 68). This surface has a gradient which varies from 1 in 10 to 1 in 3 and cuts the internal structure of the beds below. This is therefore an erosional phenomenon and not a stabilised foreset slope. The greatest thickness of lime mud facies exposed is 3.5m and, if most of this represents the amount of down-cutting through an ooid sand sea-bed, then it seems possible that the slope is perhaps a channel side.

In this area (b), the lime mud facies is rich in Rhaxella sponge spicules (facies 1a) (Plate 69) and is silicified in large patches and as beds of grey chert up to 2.5m thick. Crustacean

fragments (Callianassa?) and ammonites occur in the lime mud (as they do in the Middle Part of the Freestone Beds) and thick shell beds of oysters and pteriioids occur laterally (Fig.8o). The bed immediately above the erosion surface contains algal and oyster debris, and ooids mixed with the sponge spicule lime mud facies.

This complex described as Variation 3 may have been formed by storm erosion. The channel-like longitudinal depressinn was filled by lime mud with current deposited shells at the margins, and with sponges and oyster "reefs" further out. The laminated lime mud may represent sub- and inter-tidal stromatolites with ooid sand ripples and small dunes migrating along the axis of the "channel". The area of the sand surrounding this feature was colonised by oyster and algal "reefs" in water probably, on average, only about a couple of metres deep. Storm action eroded the "reefs" contributing large blocks to the shell beds laterally equivalent to the lime mud "channel" deposits which accumulated in water which was slightly deeper and quieter. A generalised interpretation of the relationships between the lime mud, "reefs" and ooid sand dunes is given in Fig. 8\ 1-4).

7. Fauna Recorded from the Portland Limestone Formation of Dorset

Freestone Beds

The White Micrite Beds (Isle of Purbeck)

Common: *Laevitrigonia gibbosa* Sowerby
Myophorella incurva Benett
Protocardia dissimilis Sowerby
Camptonectes lamellosus Sowerby
Isognomon bouchardi Oppel
Pleuromya tellina Agassiz

Euspira ceres de Loriol
Procerithium sp.
"*Titanites*" sp.

Less Common: *Isocyprina* sp.

Chenopus beaugrandi de Loriol
Excelissa aff. *septemplicata* Roemer
?*Odostomia* sp.

Paracraspedites sp. (*fide* Casey 1962)

Rhaxella spicules
Solenopora fragments
Bryozoa fragments

The Thin Chert at the Junction of the Freestone Beds and Purbeck Beds on the Isle of Portland

Common: *Eodonax dukei* Morris and Lycett
Eodonax pellati Cox
Eodonax ovum Cox
Eocallista pulchella de Loriol
Eocallista intermedia de Loriol
Eocallista socialis d'Orbigny

Less Common: *Corbicellopsis lorioli* Cox
Corbicellopsis portlandica Morris and Lycett
Pseudoisocardia (?) *rotunda* Cox
Quenstedia portlandica Cox
?*Corbula dammariensis* Buvignier

Pleuromya tellina Agassiz

"Mytilus" (vel Modiolus) pallidus Sowerby

Mucula lorioli Cox

The Topmost Shell Bed of the Freestone Beds on the Isle of Portland

Common: Laevitrigonia gibbosa Sowerby

Aptyxiella portlandica Sowerby

Plicatula lamellosa Cox

Ostrea sp.

Less Common: Bodonax dukei Morris and Lycett

Corbicellopsis portlandica Morris and Lycett

Lucina portlandica Sowerby

Quenstedia portlandica Cox

Parallelodon dorsetensis Cox

Arca sp.

Pleurotomaria sp.

The Carbonate Sand Facies of the Freestone Beds in all the Areas (shell beds)

Common: Laevitrigonia gibbosa Sowerby

Myophorella incurva Benett

Isognomon bouchardi Oppel

Camptonectes lamellosus Sowerby

Plagiostoma rustica Sowerby

Less Common: Ostrea expansa Sowerby

Exogyra nana Sowerby

Exogyra thurmanni Etallon

Plicatula boisdini de Loriol

Protocardia dissimilis Sowerby

Pholadomya rustica Phillips

Protocardia sp.

Corbula saltens Blake

Pleurotomaria sp.

Natica sp.

Glomerula gordialis Schlotheim

Serpula sp.

"Titanites" sp.

Pachastrella spicules

Also, on Portland: Solenopora c.f. jurassica

Diastoporidian bryozoa

Upper Cherty Beds (All Areas)

Common: (only in the upper part on Portland)
- Laevitrigonia gibbosa Sowerby
- Myophorella incurva Benett
- Camptonectes lamellosis Sowerby
- Isognomon bouchardi Oppel
- Exogyra nana Sowerby
- Glomerula gordialis Schlotheim
- spicules of Rhaxella and Pachastrella

Less Common:
- Lithophaga portlandica Morris and Lycett
- Isastrea portlandica Edwards and Haime
- Pleurotomaria sp.
- Natica sp.
- "Behemoth" sp.

Lower Cherty Beds (Limestone facies)

Isle of Purbeck Topmost shell bed (Arkell's Bed J')

Common:
- Laevitrigonia gibbosa Sowerby
- Exogyra nana Sowerby
- Glomerula gordialis Schlotheim
- Thalassinoides

Less Common:
- Glaucolithites sp.
- Rhaxella spicules

Beds below only
- Glomerula gordialis Schlotheim
- Rhaxella spicules
- Thalassinoides

Isle of Portland Basal Shell Bed (abundance after Cox 1925)

Common:
- Barbatia cavata de Loriol
- Ostrea expansa Sowerby
- Exogyra nana Sowerby
- Laevitrigonia gibbosa Sowerby

"Trigonia" portlandensis Cox (Myophorella?)

"Trigonia" radiata Benett

Camptonectes lamellosis Sowerby

Plagiostoma rustica Sowerby

Musculus autissiodorensis Cotteau

Euromya tellina Agassiz

Glomerula gordialis Schlotheim

Pleurotomaria rugata Benett

Oolitica cunningtoni Cox

Euspira ceres de Loriol

Less Common: Nucula lorioli Cox

Isognomon bouchardi Oppel

Ostrea blakei Cox

Myophorella incurva Benett

Plicatula boisdini de Loriol

Myoconcha portlandica Blake

Falcimytilus suprajurensis Cox

Modiolus hudlestoni Cox

Isocyprina pringlei Cox

Isocyprina elongata Cox

Anisocardia buckmani Cox

Mactromya verioti Buvignier

Eocallista pulchella de Loriol

Eocallista courcellensis de Loriol

Pleurotomaria rozeti de Loriol

Proconulus foucardi de Loriol

Delphinula portlandensis Cox

Nododelphinula vivauxea Buvignier

Calliomphalus nodosus Cox

Chenopus beaugrandi de Loriol

Pterocoma richardsoni Cox

Pseudomelania chatwini Cox

Zygopleura portlandica Cox

Procerithium mansellii de Loriol

Uchauxia quadrigranosa Cox

Vanikoro fittoni Cox

Actaeonina insularis Cox

	Nucleolites brodiei Wright
	Tetragramma sp.
	Trochotiara sp.
	Hemicidaris (?) spines
	Elaphora cervina Lang
	Berenicea damnatorum Lang
	Serpula sp.
	Asteroid ossicles (indet)
	Glaucolithites gorei Salfeld
	"Kerberites" portlandensis Cox
	"Behemoth" sp.
Rare:	Nuculana dammariensis Buvignier
	Parallelodon dorsetensis Cox
	Inoceramus cunningtoni Cox
	"Trigonia" c.f. concentrica Agassiz
	Camptonectes suprajurensis Buvignier
	"Mytilus" (vel Modiolus) pallidus Sowerby
	Isocyprina compressa Cox
	Isocyprina obesa Cox
	Eocallista cunningtoni Cox
	Corbula c.f. bayani de Loriol
	Eumargarita durui de Loriol
	Natica sp.
Vertebrate remains	Cimoliosaurus portlandicus Owen
	Lepidotus tooths

8. Synthesis

The setting for the deposition of the Portland Limestone Formation was already established during Portland Sand Formation times and the presence of East and West Basins separated by a swell persisted. The overall regression continued until the sea bed became subaerially exposed in places during deposition of the topmost beds of the Portland Group and the basal strata of the Purbeck Beds. The swell maintained its position, and its influence on local water depth and facies distribution is even more marked in the shallower water deposits.

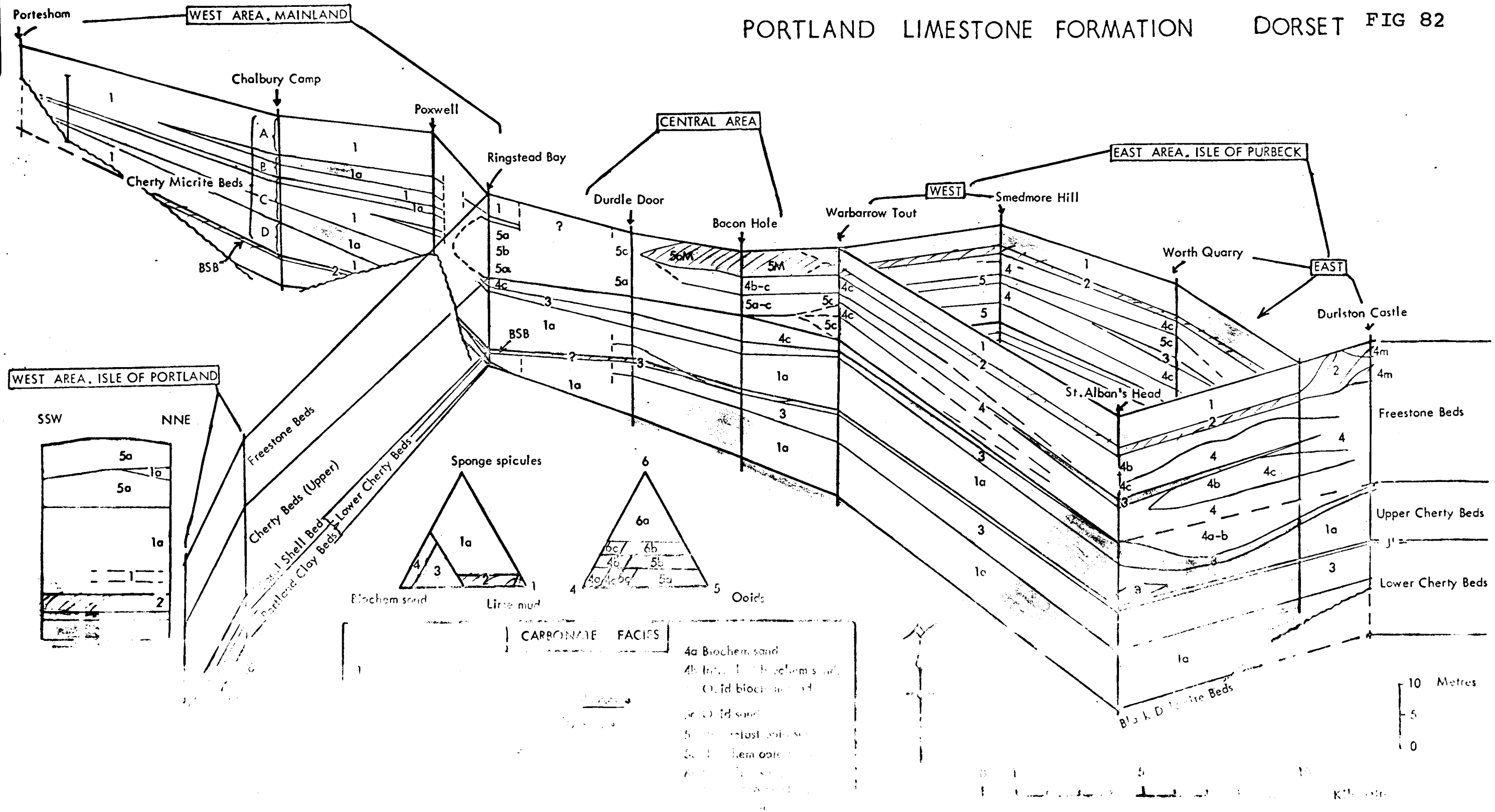
Time correlation within the Portland Limestone Formation must be speculative but an attempt is made here using the events of minor changes in water depth superimposed on the general shallowing. The one horizon which is regarded as the nearest to a time place ever possible is the top of the Lower Cherty Beds, Arkell's Bed J' in the East and Central Areas and the top of the Basal Shell Bed in the West Area. This horizon separates the second phase of Portland Group sedimentation from the third. The former laid down the Cast Beds, the Black Dolomite Beds and the Lower Cherty Beds, culminating in a virtual cessation of deposition which resulted in the widespread condensed Basal Shell Bed - J' horizon.

The third phase started in slightly deeper water and laid down the Upper Cherty Beds, Freestone Beds and the basal Purbeck Beds. Time correlation within this third phase is uncertain but suggestions are made as follows:-

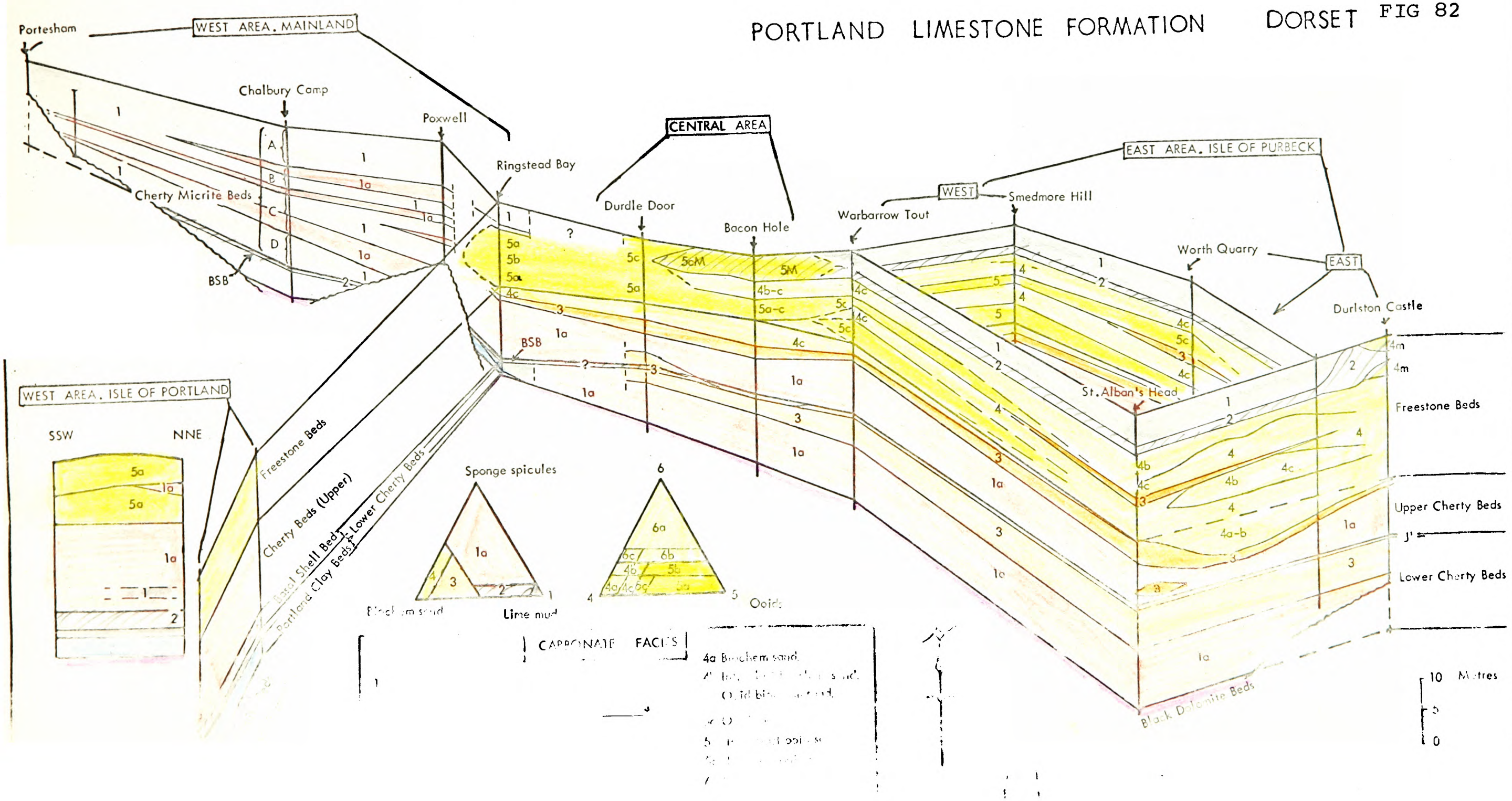
(i) The Lower Cherty Beds (Fig. 82, Fig. 83 A, B, C).

The maximum thickness is in the East Basin where they thin westwards from c.14m in the Isle of Purbeck and at Smedmore Hill to 12.5m at Warbarrow Tout. In the Central Area the Lower Cherty Beds thin from 7.5-6.0m in a distance of 1.78km, indicating the proximity of the swell to the west. At Ringstead Bay the equivalent beds are only 2.75m but these thicken again to c.4.5m in the West Basin and to the Isle of Portland where they vary from 6.75 - c8.75m.

PORTLAND LIMESTONE FORMATION DORSET FIG 82

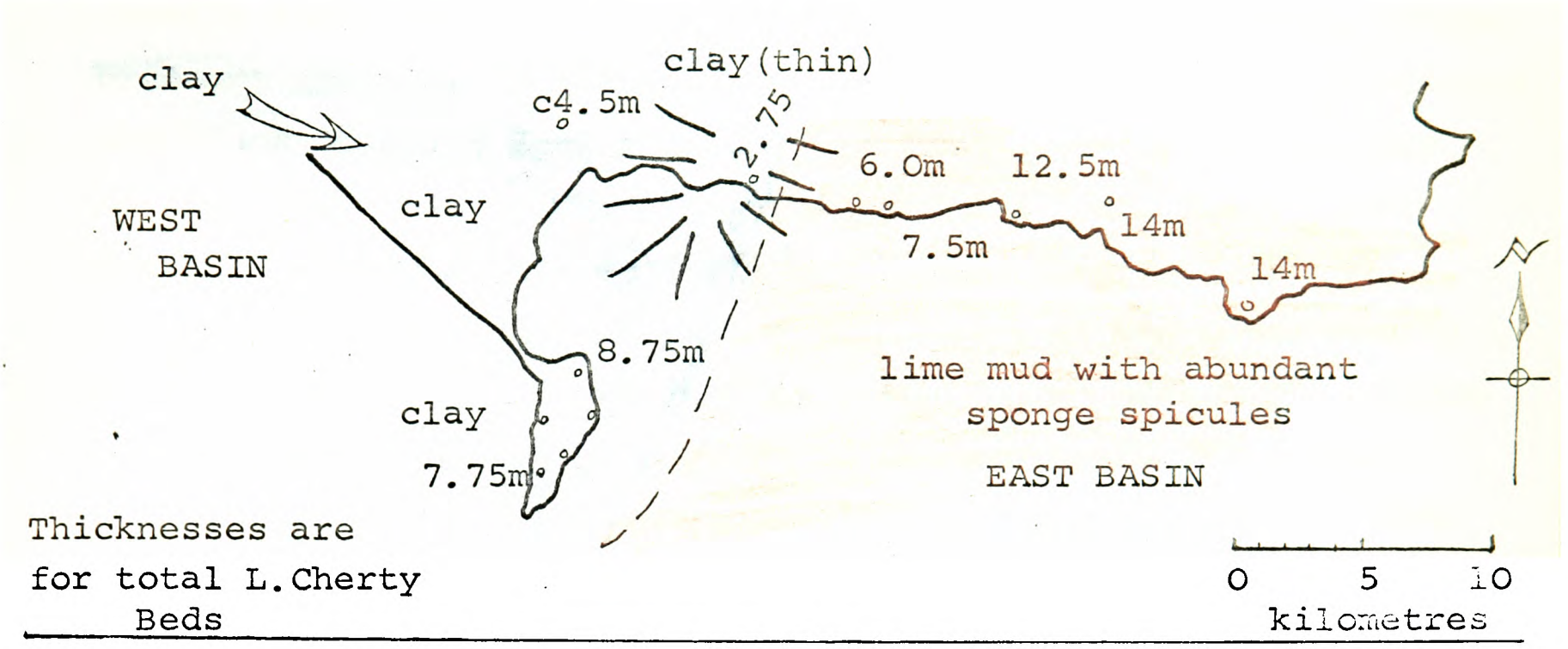


PORTLAND LIMESTONE FORMATION DORSET FIG 82

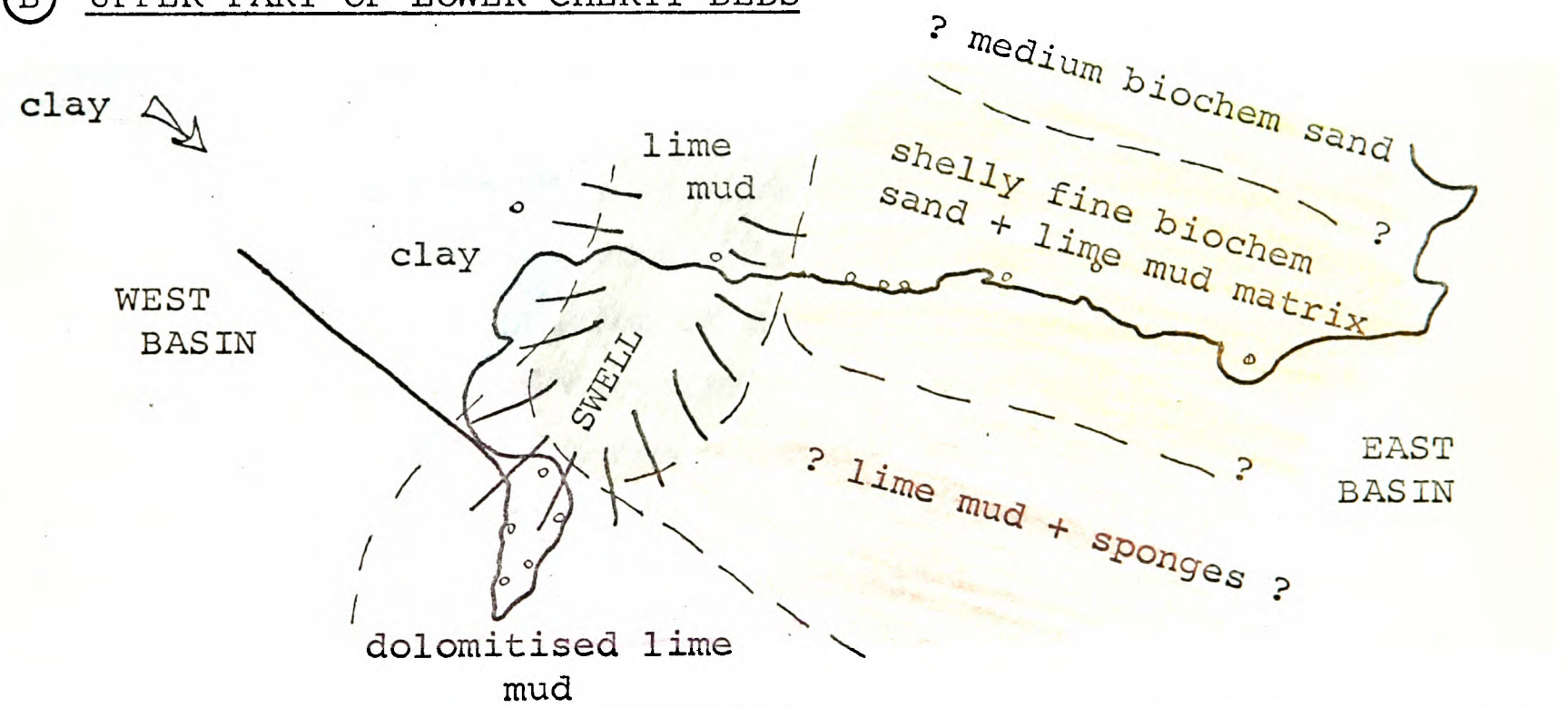


GENERAL FACIES DISTRIBUTION DURING THE DEPOSITION OF THE LOWER CHERTY BEDS, PORTLAND LIMESTONE FORMATION. FIG 83

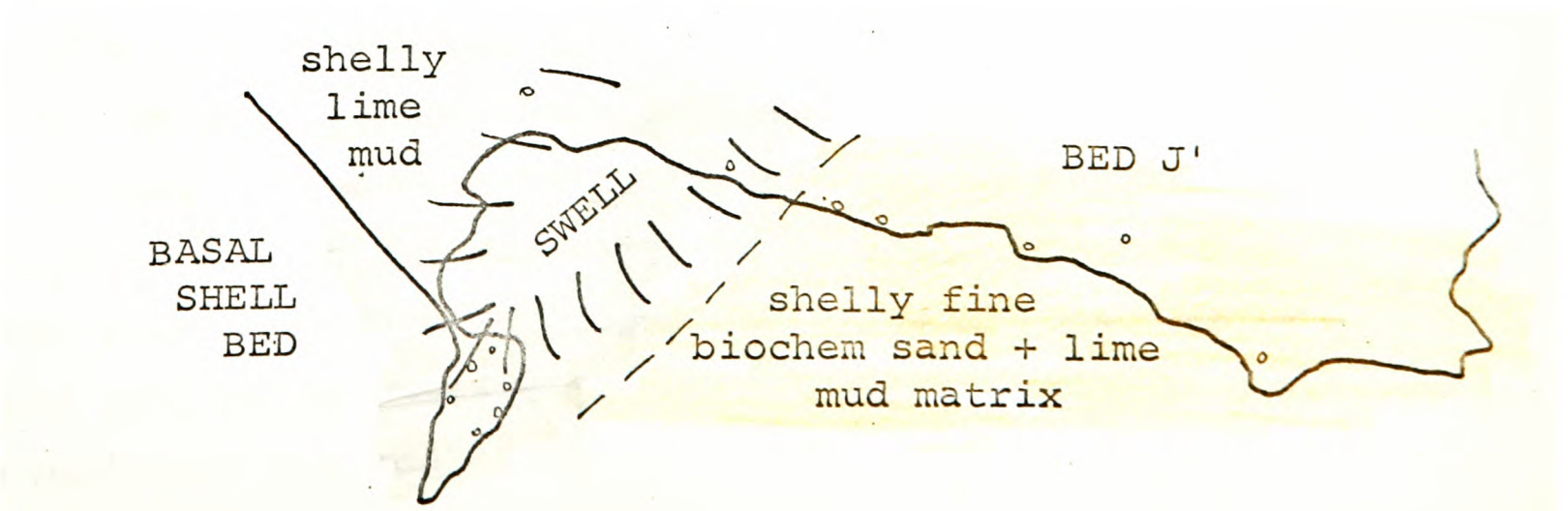
(A) LOWER PART OF LOWER CHERTY BEDS



(B) UPPER PART OF LOWER CHERTY BEDS



(C) TOP OF LOWER CHERTY BEDS (J')



In the East Basin the lower part of the Lower Cherty Beds differs from the underlying Black Dolomite Beds merely in that they are not dolomitised, they contain a high proportion of Rhaxella spicules and 1.5% fine quartz sand (Fig. 41). No other fossils apart from burrows and occasional ammonites occur. These beds are the same when traced westwards until the swell is reached, the Black Dolomite Beds then pass up into a few metres of clay. At Ringstead this clay is very thin and the Lower Cherty Beds are represented almost entirely by micrite (Fig.52).

The original sediment of the upper part of the Lower Cherty Beds in the East Basin was a fine biochem sand with a mud matrix which supported a prolific serpulid fauna. Apart from these animals there are only occasional bivalves and ammonites. When traced over the swell this passes into soft, bioturbated, chalky micrite which is barren except for scattered shell fragments. In the West Basin clay is still present but on Portland it is represented by dolomitised lime mud (Fig.83 B).

The topmost horizon of the Lower Cherty Beds in the East Basin is composed of fine biochem sand with a lime mud matrix and sometimes with an appreciable proportion of sponge spicules. It contains a concentration of encrusted ammonites, bivalves, serpulids, burrows and crustacean fragments which is due to slow deposition rather than a dense population at any one time. On the swell, in the West Basin and on Portland, the bed is a mixture of abundant shells and lime mud. In these areas the fossils are dominantly ammonites with a diverse bivalve fauna but gastropods are also common (partly a function of good preservation in micrite); no brachiopods or belemnites are known.

(ii) The lower part of the Upper Cherty Beds (Fig.84,B)

The total thickness of the Portland Limestone Formation above the Lower Cherty Beds in East Purbeck is 24m, on the swell it is 15m, in the West Basin it thickens to 20m and thins to an estimated 13m in the far west; on Portland it is 22m thick (Fig 84A). These remaining Portland Group sediments are the result of a third shallowing phase of deposition which commenced with a slight deepening of the sea.

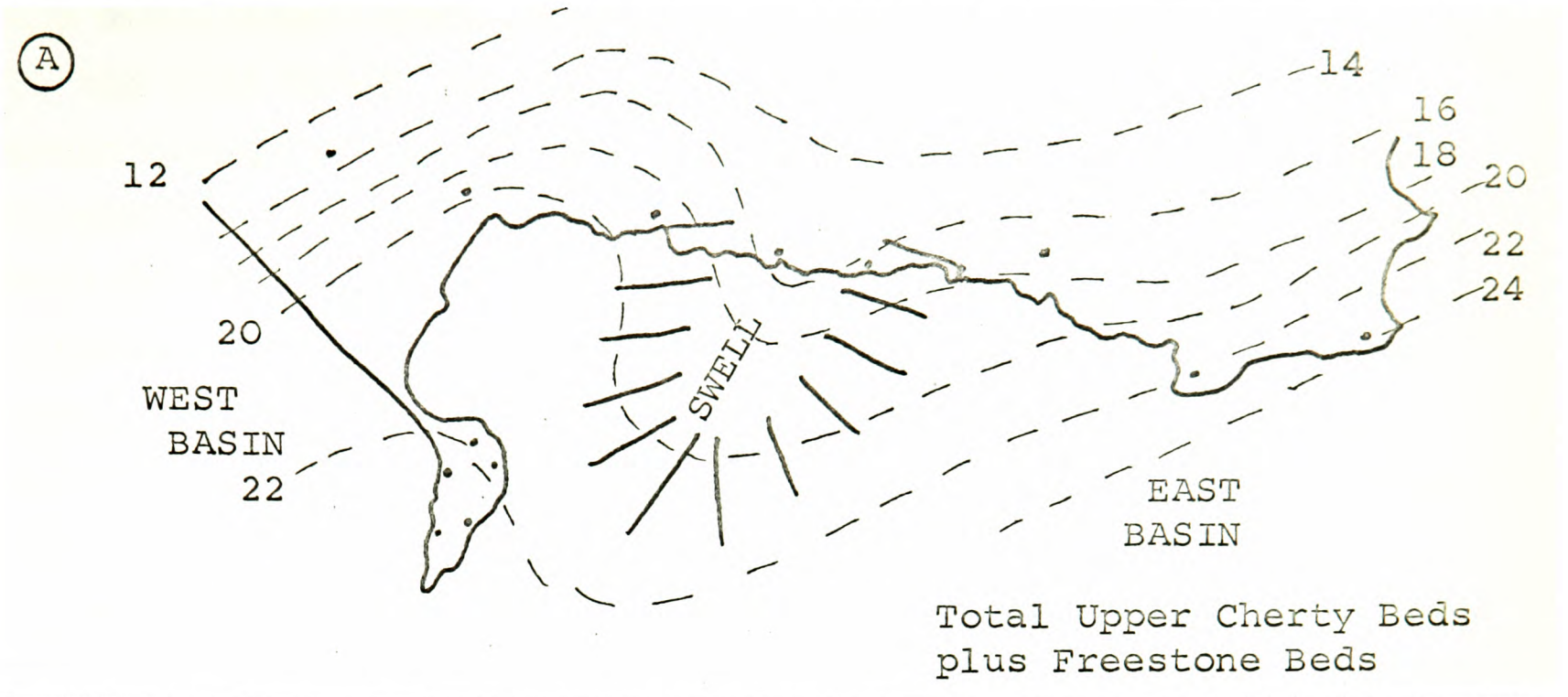
In the East Basin the lower part of the Upper Cherty Beds was deposited as sponge spicule lime mud, again with abundant serpulids and burrowing organisms (Fig.43). In the West Basin and on the swell this facies also occurs but with a lower proportion of spicules (Fig.52). In the far west the succession consists of alternations of lime mud with and without Rhaxella.

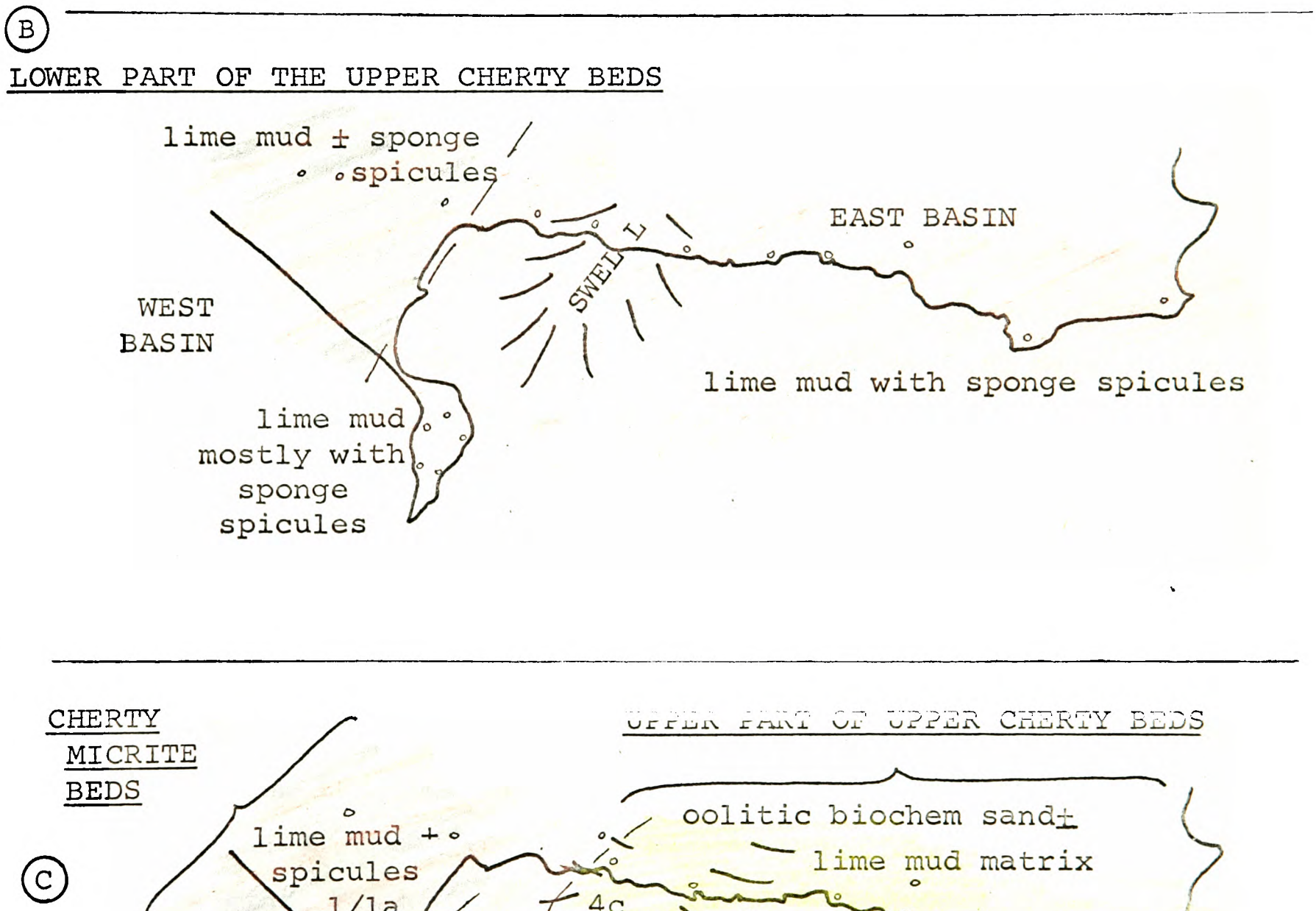
(iii) Following the lower part of the Upper Cherty Beds.

After the last stage the water shallowed to the extent that rapid lateral variation in sediment-type resulted and the swell began to have a pronounced influence on local water depth. The facies are no longer sufficiently thickly developed and widespread for Bed names to approximate to synchronous intervals of time. Thus, for example, the Lower Freestone Beds of the East Basin are thought to have been deposited at the same time as the upper part of the Upper Cherty Beds of Portland. Such "time-correlations" are based partly on thickness comparisons and partly on the way in which the model fits best below and above. This method runs the inevitable risk of leading to circular arguments where the model is derived from correlation and vice-versa. In the absence of an alternative method the following suggested sediment distribution patterns at successive times are given, whilst freely admitting the unconsolidated ground upon which they are based.

Following the sponge-rich muds of the lower part of the Upper Cherty Beds, the upper part in the East Basin consists of fine biochem sand with a mud matrix (as in the upper part of the Lower Cherty Beds), followed by medium-grained mud-free biochem sand with common Pachastrella spicules (Fig.84 C). Apart from these, the faunal density was low. In the Central Area and at Ringstead, on the swell, the biochem sand contains up to 25% ooids (change from facies 4a and 4b in East Purbeck to 4c westwards. Fig.82). Within 2.7km from Ringstead to Poxwell these carbonate sands disappear to be represented by lime mud, with or without spicules, which continues throughout the West Basin. On Portland the middle part of the Upper Cherty Beds is Rhaxella-rich lime mud facies with abundant serpulids at certain levels.

ISOPACHYTE MAP AND GENERAL FACIES DISTRIBUTION DURING DEPOSITION OF THE PORTLAND LIMESTONE FORMATION FIG 84





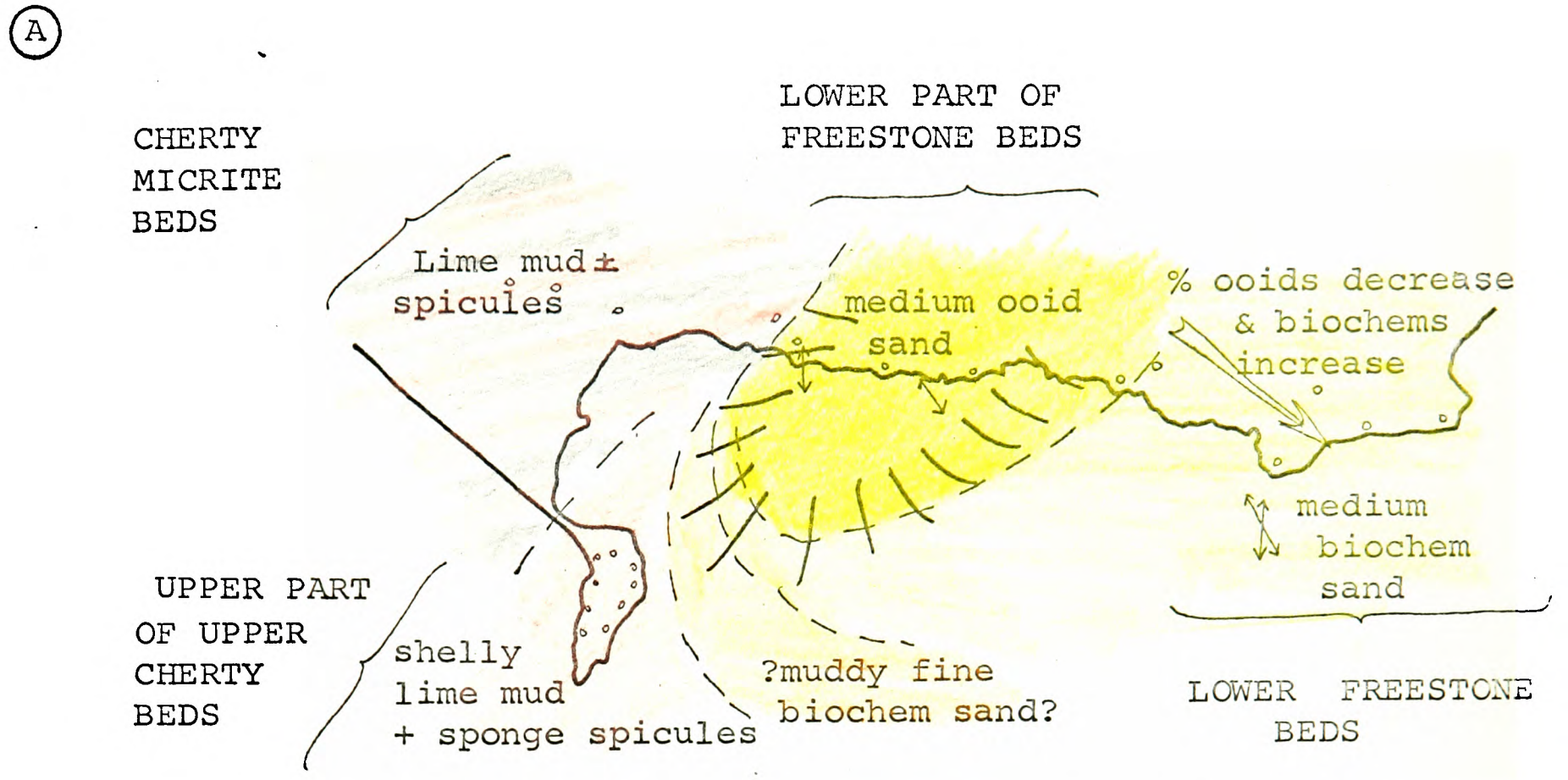
Following this, as the overall fall in sea level continued, the swell area became sufficiently shallow for ooids to form. In the East Basin, the Lower Freestone Beds are composed of grain-supported medium biochem sand which contains an increasing proportion of ooids towards the swell (facies 4 to 5a. Fig. 82). West of the swell the original sediment was lime mud with or without sponge spicules and on Portland the upper part of the Upper Cherty Beds is lime mud facies with common Pachastrella spicules as well as Rhaxella, and an abundant diverse and dense bivalve fauna when compared with beds below (Fig. 56). The suggested facies pattern is given in Fig. 85 A.

The overall shallowing continued and the area of turbulent water over the swell extended. During deposition of the Lower Shelly Freestone Beds in the East Area and the lower part of the Freestone Beds on Portland the facies pattern was as shown in Fig. 85 B. The major change from the previous pattern is only that the area of ooid sand included the Isle of Portland. The biochem sand in the Isle of Purbeck generally contained up to 25% ooids (facies 4b and 4c, Fig. 82), although in places the proportion was higher (Fig. 42).

A slight overall deepening of the sea ensued, indicated by a repetition of the facies change from 3 to 4 which took place in the upper part of the Upper Cherty Beds in the East Basin. The spicule-rich muddy biochem sand of the Freestone Chert Bed of the Isle of Purbeck and the lime mud intercalation in the middle part of the Freestone Beds of Portland are the result of a decrease in the mean level of water turbulence (Fig. 85 C). As the regression again proceeded, the facies pattern during the deposition of the upper part of the Freestone Beds in the Isles of Purbeck and Portland was identical to that during the lower parts (Fig. 85B can be used twice).

The final shallowing during the Portland Limestone Formation times resulted in the sediment distribution pattern of Fig. 85 E. The Top Grey Micrite Beds of the East Basin are thought to correlate with the oolites of the Central Area (Durdle Door, Dungy Head) because gradations between the two can be traced from the

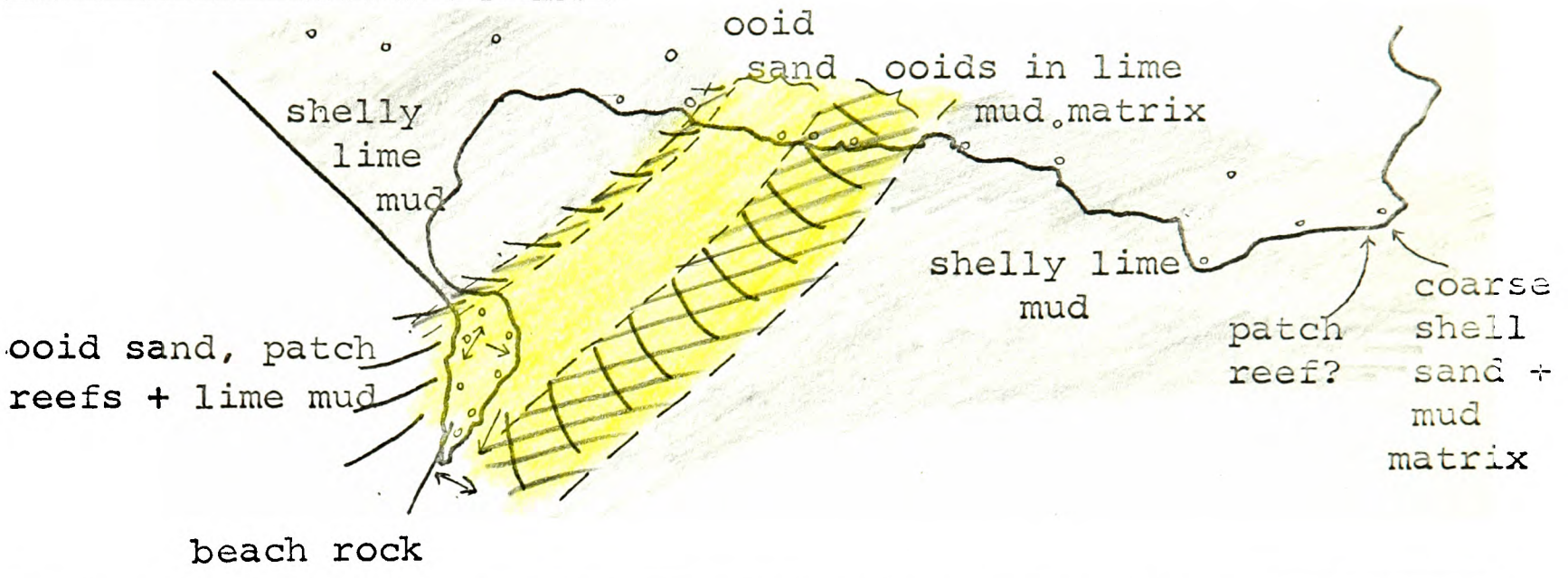
GENERAL FACIES DISTRIBUTION DURING DEPOSITION OF THE HIGHEST BEDS OF THE PORTLAND GROUP IN DORSET FIG 85



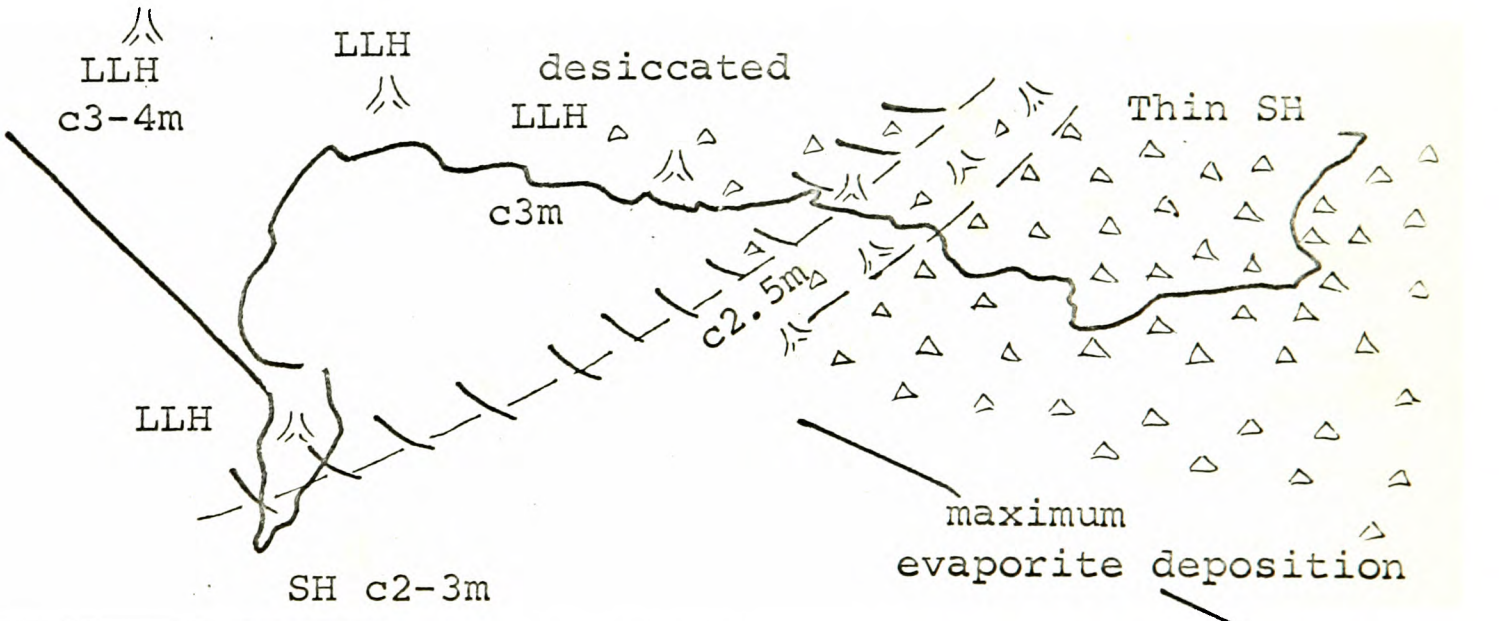
GENERAL FACIES DISTRIBUTION DURING DEPOSITION OF THE HIGHEST BEDS OF THE PORTLAND IN DORSET FIG 85 cont^d.

(D) UPPER PART OF THE FREESTONE BEDS ON PORTLAND AND ISLE OF PURBECK
Facies distribution as for (B)

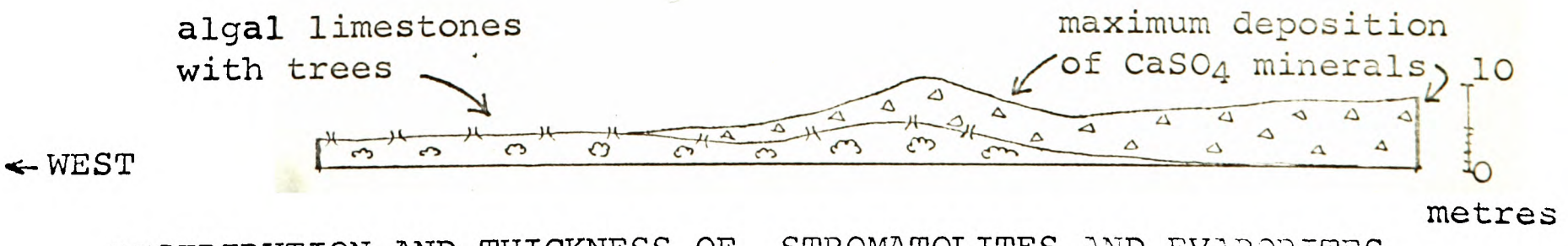
(E) UPPERMOST PART OF THE FREESTONE BEDS ON PORTLAND AND TOP GREY MICRITE IN ISLE OF PURBECK



(F) BASAL PURBECK BEDS



Stromatolitic Algae (After Pugh + own observations)
SH= stacked hemispheres
LLH= laterally linked hemispheres



DISTRIBUTION AND THICKNESS OF STROMATOLITES AND EVAPORITES IMMEDIATELY FOLLOWING THE PORTLAND LIMESTONE FORMATION.

tne west Isle of Purbeck where it is lime mud facies, through ooids in a mud matrix at the east end of the Central Area, to oolites at the west end (Fig. 48). This transition from mudstone, through wackestone, packstone to grainstone demonstrates that the difference between the Central and East Areas was one of water turbulence and not of age, as might be suggested. The lime mud of the East and West Basins contains a diverse molluscan fauna and the carbonate sands of Portland contain in detail a complex pattern of submarine sand dunes, patch reefs and lime mud areas, with emergence in places in the south-west of the Isle indicated by a stalactitic cement characteristic of beach rocks (Plate 60).

The overlying beds across the whole area of deposition are stromatolitic micrites but these vary in morphology and thickness, still indicating different water depths and rates of subsidence. Fig. 85 E shows that relatively thick algal limestones developed along the line of the swell and in the West Basin (which had by that time filled). These thin towards the East Basin and change in morphology indicating slightly deeper water (1-2m.) in that direction. (Pugh 1968, West in Torrens 1969). Trees grew on the surface of algal mounds but are not known east of Gad Cliff in West Purbeck (personal observations and West in Torrens 1969).

A restricted hypersaline, evaporite-depositing environment developed and thick beds of nodular anhydrite with gypsum occur in the East Basin, and these thin westwards. They are now replaced by calcite and are familiar as the "Broken Beds" of the Lower Purbeck. For up-to-date details of the stratigraphy following the Portland Limestone Formation and interpretations the reader is referred to the works of Brown (1961, 1963, 1964), Pugh (1968), West (1964, 1965, and in Torrens 1969) and Clements (in Torrens 1969).

9. Interpretation

By a study of the facies distributions through time derived from detailed descriptions of the rocks, the basic generalised model for the deposition of the Portland Limestone Formation

outlined in Chapter 3 can be discussed in more detail. This is best done by reference to different "energy levels".

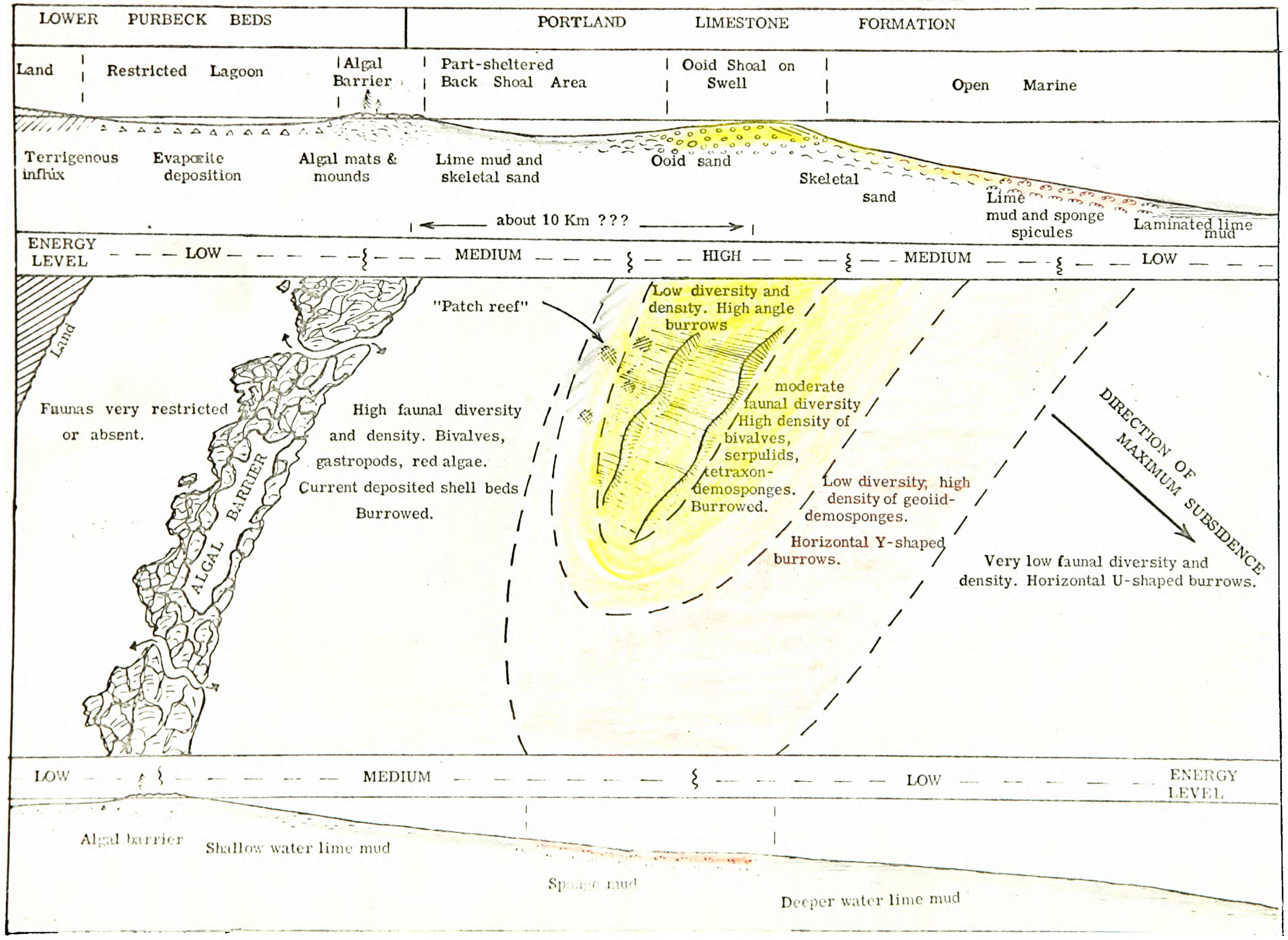
The surface of the sea is disturbed by the friction of air moving over its surface, producing wind-generated waves, and the depth to which the water is agitated is proportional to the strength of the wind. High energy events (e.g. hurricanes) are less frequent than low energy ones (i.e. normal winds), therefore unsheltered shallow water can be regarded as being always turbulent when compared with deep water. It is reasonable to suggest that zones of high, medium and low turbulence, or "energy", existed at different depths.

Shallow water need not be in a high energy zone as the presence of a barrier, producing even shallower water seawards, shelters the water behind, which then becomes a medium energy zone. The energy level controls the facies and the presence of a swell during Portland Group times had a profound local effect on water depth and hence on sediment and faunal distribution.

An idealised model is depicted in Fig.86, but this is not intended to be a representation to scale at any one time of the situation in Dorset. It merely shows, in an exaggerated fashion, how the facies are related to depth, energy level and the presence or absence of a swell.

In the deepest water depicted (free of terrigenous sediment), laminated lime mud was laid down below the critical level postulated in Chapter 3 and was thus dolomitised. Above this level lime mud was deposited and Rhaxella sponges were able to survive in water more likely, over a long period of time, to be agitated. The sea bed was soft, thus eliminating a bivalve population in the way described by Rhoads & Young (1970) and discussed in Chapter 2 of this thesis. The only bivalves present encrust ammonites which were the only form of hard substrate available.

When the water over the swell was shallow enough for it to be in a high-energy zone, it was warm, saturated with calcium carbonate and sufficiently frequently agitated for ooids to form. Recent shifting submarine ooid sand-dunes are normally biological deserts and the sediment is colonised only during



SUGGESTED GENERALISED ENVIRONMENTAL MODEL FOR DEPOSITION OF THE PORTLAND LIMESTONE FORMATION FIG 86

the periods of still-stand. The maximum density and diversity of fauna is on the seaward margin of Recent sand bodies where the water is turbulent enough to be well-oxygenated and for there to be a plentiful food supply, and where the substrate is more stable (Newell & Rigby 1957, Ball 1967).

The high energy carbonate sands and associated sediments which formed in the shallow water over the swell are best studied on the Isle of Portland, the only place where they are exposed in three dimensions. There was deeper water in the south and south-east of the island and ooid sand dunes were best developed in the north-west. These sand masses moved into the deeper water when affected by high energy events, became inactive and were colonised by epifaunal and infaunal bivalves as well as burrowing crustaceans. In the shallowest phase of deposition, patch reefs developed and the sea bed was lithified in places. Storm erosion cut stabilised sand dunes and the resulting accentuated topography was filled by lime mud. The stabilised dune tops became beaches which in places were subaerially cemented.

The slightly deeper fringing zone of the swell was the area of production of medium biochem sand (facies 4) and the source of the fine sand which is mixed with lime mud (facies 3) between this and the area of sponge-rich mud deposition (facies 1a). In the area of fine biochem sand mixed with lime mud, serpulids were common and the sponge Pachastrella was able to live, as well as Rhaxella, trigoniids and large pectinids.

Landward of the swell, and protected by it, the water was sufficiently shallow to be well-oxygenated, for food to be plentiful and for a diverse fauna to exist. It is likely that the lime mud of this area was rich in green and blue-green algae which stabilised the sea bed in the manner described by Scoffin (1970). The area was still subject to the effects of medium energy events as evidence by the presence of current-deposited shells in places, which is a contrast with the deep water lime mud facies where depositional laminations are preserved, except where burrowed. Bordering this zone on the landward margin was a belt of stromatolitic algal mounds, such as described by Logan et al, (1969),

which formed a barrier separating water of near-marine salinity from that sufficiently hypersaline for evaporites to form (West et al 1969).

In areas where the swell was not effective, the facies changed from barren deep water lime mud to fossiliferous shallow water mud with only an intermediate transitional facies belt inhabited by Rhaxella.