THE DEVONIAN SYSTEM IN SOUTH DEVONSHIRE

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I. INTRODUCTION

NOT least amongst the many important geological features of Devonshire are the formations known as the Devonian system. This confusing and seemingly confused group of rocks occupies a large part of the geological map of South-West England and, in its array of widely different rock types and geological structures, is perhaps one of the most problematic in England. The two major outcrop areas of Devonian rocks, North Devon and West Somerset, and South Devon and North Cornwall, are separated by the Culm Measures (Carboniferous) outcrop of Central Devon. They reveal two quite different suites of rocks, and problems of correlation between the two are by no means easy to resolve. Study of these formations has a two-fold importance. In the first and more important instance the Devonian rocks here record part of a major geological phase in the evolution of North-West Europe, and secondly they lie within the "type-area" of the Devonian system. The rocks of South Devon and Cornwall are more diverse in character than those to the north and in many ways are more important in the broader aspects of the geological evolution of the region. This paper gives some account of their position in the stratigraphical column and mentions recent research and discoveries.

In his "Report on the Geology of Cornwall, Devon and West Somerset"—the first memoir of the Geological Survey (1839)—H. T. De la Beche was naturally concerned with the known palaeozoic strata and fossils in Devon. De la Beche followed previous authors in designating the pre-Carboniferous ("pre-Carbonaceous") rocks as the Grauwacké Group. It included the metamorphic rocks of the Lizard and Start promontories as well as the sedimentary formations. Sedgwick and Murchison had in 1834 correlated the Grauwacké rocks of North Devon with some of the Carboniferous formations elsewhere. In 1837, however, they pointed out that the pre-Carboniferous rocks of North Devon and South Devon were contemporaneous and probably equivalent to the upper and middle parts of Sedgwick's Cambrian System (i.e. to the Lower Silurian of modern usage). Their recognition of these rocks as being distinct from both

Carboniferous and Silurian and the use of the name Devonian came in their paper to the Geological Society that year (published 1839). In some respects it is unfortunate that these rocks were investigated by Sedgwick and Murchison so early in the development of our stratigraphical column, for the term "Devonian" is now given to all formations lying between the Silurian and Carboniferous systems the world over. As will be seen below, the rocks in Devon are almost impossible to use as a standard with which to correlate and compare rocks elsewhere, and beds bridging the Silurian-Carboniferous gap in Belgium and Germany serve better to do this. Sedgwick and Murchison's Devonian rocks had previously been known by a variety of names and were now determined as equivalent in position and age to the Old Red Sandstone of Wales, the Welsh Borderlands and Scotland. Their decision to set up a new system of rocks under this name was largely influenced by Lonsdale's critical study of fossils obtained from these beds.

Thus, the Devonian System is a large fundamental stratigraphical unit based upon the rocks of Devonshire which, as Sedgwick and Murchison recorded, are distinguishable without much argument as a lithological group, with fossils distinct from those of the already established Silurian and Carboniferous systems. The division of this large thickness of rocks into acceptable smaller units has been more difficult. Clearly the definition of all these rock divisions by physical criteria such as lithology and fossils demands that such criteria be readily distinguishable in the type areas. Shortly after Sedgwick and Murchison had established their system, work on the continent and in North America showed that the sub-division of the Devonian into series and stages could be made more readily there than in Devon. In consequence the stages within the system are today based upon sections in Belgium and Western Germany. The series have remained as Lower, Middle and Upper Devonian, though the Middle Devonian has also been called Eifelian by some authors.

II. SUBDIVISION OF THE DEVONIAN SYSTEM IN EUROPE

Each geological formation which serves as a standard of reference within the stratigraphical column should be known in as much detail as possible, for several important characteristics are required of it. Usually it is named after some distinct feature or character, an index or typical fossil or a locality. Each of these may present difficulties; distinctive physical characters at one place may not be discernible elsewhere, fossils may be only sporadically distributed throughout the formation and often the palaeontologist has seen fit to change the name of a fossil after that name has been used by the stratigrapher to label his formation. Since by far the greater part of the fossiliferous section of the geological record is made up of shallow-water marine sediments, formations which are taken as reference units should be of this kind and possess a distinctive fossil assemblage. At the place chosen as the type locality the formation should be typically developed, well-exposed and accessible and should yield characteristic fossils. Ideally the strata should not be contorted or broken by faults nor have suffered metamorphism, and the unit's relationships with formations stratigraphically above and below it should be seen. The Devonian rocks of South Devonshire fall sadly short of these requirements. They are for the most part poorly exposed, save on the coast, and in the Armorican orogeny suffered dislocation and

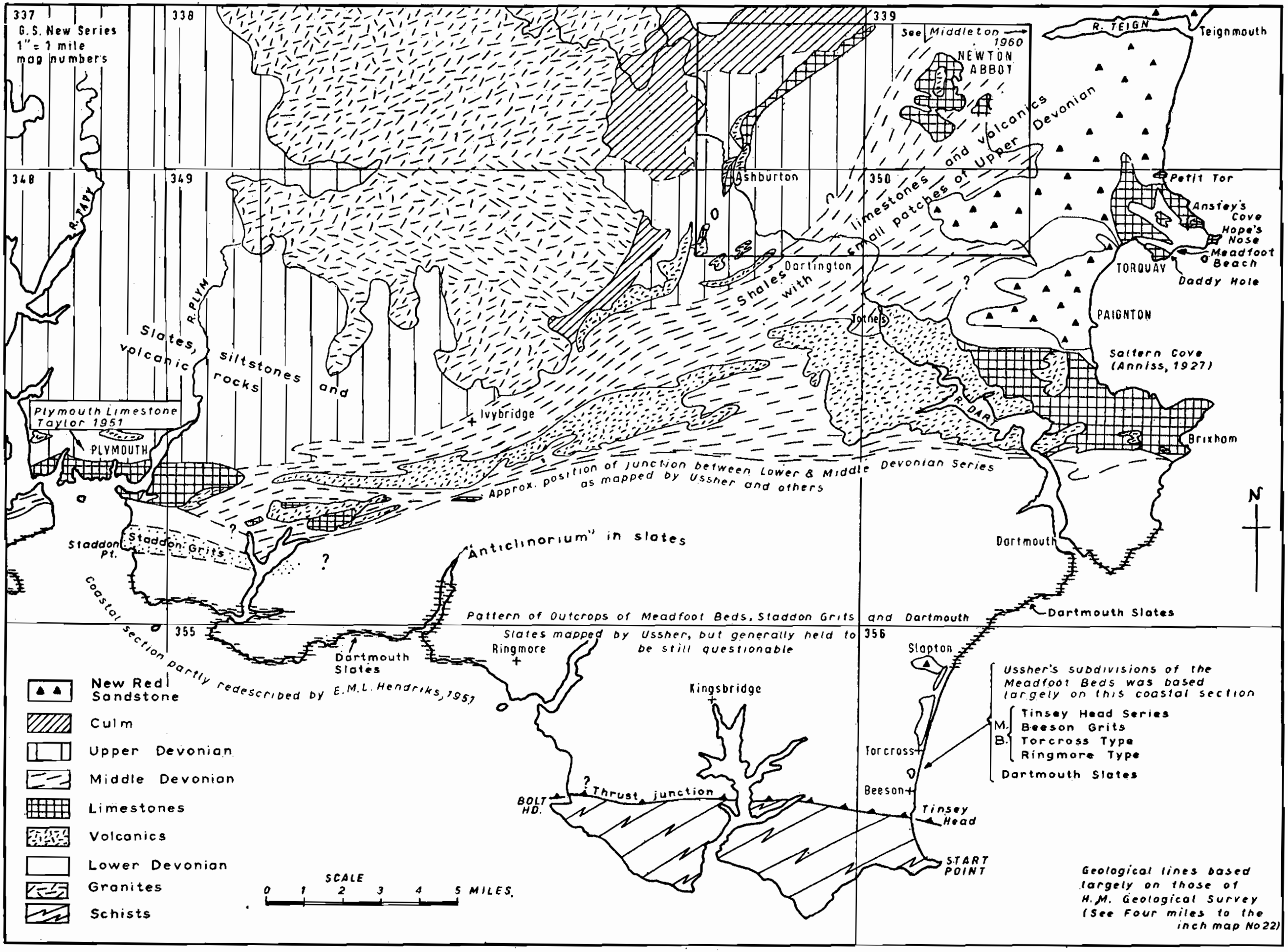

FIG. 1.
Generalized sketch map showing major geological features of South Devon.

contortion which violently interrupt their normal succession. Moreover, they have been subjected to metamorphism sufficient to distort and destroy many of the fossils by which correlation might be made. The different rock types appear to interfinger and merge gradually with one another both laterally (across country) and vertically. Lateral change of lithology is often accompanied by change in the faunal characters, making correlation difficult. However, on the grounds of precedence if nothing else, the name Devonian has been retained, though as early as 1847 G. and F. von Sandberger demonstrated that in the Ardenne and Rhineland areas a much more easily understood and fossiliferous sequence of beds could serve as a standard so much better. Since H. A. Dumont and other Belgian and German geologists began their investigations into the rocks there in the early years of last century, the number of formation and time-rock subdivisions erected for the local Devonian is almost legion.

The stages now generally accepted are based upon distinctive lithological units with characteristic fossils (see Table 1). The Devonian fossils proving most useful in this respect, and similarly for the recognition of the smallest paleontological divisions, zones, are the brachiopods, rugose corals, ammonoids, trilobites, conodonts. The pioneer work on the distribution of all these forms in the Devonian was, after the British start, carried on in continental Europe—later the British Devonian faunas were grouped and compared on the lines of standards erected across the Channel. In the non-marine beds the ostracoderm fishes are proving stratigraphically important, largely as a result of the work of E. I. White. Fortunately the British and the continental faunas are in most respects essentially similar, and even zonal schemes devised in the one region appear usually to be applicable also to the other. The British and the European Devonian rocks were deposited in different parts of a continuous province—the Gornubian-Rhenish Geosyncline.

Brachiopods. Amongst the brachiopods the "*Spirifer*" and "*Rhynchonella*" groups are the most useful in erecting zones. The Devonian marks the acme of spiriferoid development and Table 1 shows a few of the typical spiriferoids present in the shelly faunas. The value of rhynchonelloids has recently been demonstrated in North American Devonian stratigraphy.

Rugose corals. Studied intensively in Germany by Wedekind and others, these fossils were incorporated by him in a set of zones for the Middle Devonian, which although subjected to some criticism and modification, has been found applicable in Britain by Taylor (1951) and Middleton (1959).

Trilobites. The work of R. and E. Richter in Germany has shown that trilobites are of stratigraphic value in the German Devonian, and the British Devonian faunas are now attracting attention. Stubblefield (1960) has reviewed the trilobites of south-west England and noted that the world-wide diminution of trilobite families at the close of the Middle Devonian and again at the end of the Frasnian is reflected in the faunas in Devon.

Ammonoids (Goniatites). The widespread pelagic ammonoids have been utilized stratigraphically in Germany by Wedekind, Schindewolf and Schmidt. House

Table 1. *Stages of the Devonian system erected in Western Europe*

	Stage	Type Locality	Lithologies	Index Fossils (Mostly Brachiopods)
UPPER	FAMENNIAN	LA FAMENNE, Belgium	Shales, sandstones and limestones (rare) buff to red in colour	*Productella togata*, *Leptodesma lepidum*, *L. alatum* *Cyrtospirifer verneuili*, *C. lonsdalei*, *C. archiaci* *Reticularia simplex*, *Tylothyris laminosa* *Ptychopteria damnoniensis*, *Posidonia venusta* *Phacops granulosus*
	FRASNIAN	FRASNES, Belgium	Shales with thick limestones, some reef developments	*Cyrtospirifer verneuili*, *C. orbeliamus* *Rhynchonella* (*Hypothyridina*) *cuboides* *Phacops latifrons*, *Cyphaspis ocellata* *Buchiola palmata*, *Lyropecten gilsoni*
MIDDLE	GIVETIAN	GIVET, France	Shales and limestones dark in colour	*Spirifer undiferus*, *S. mediotextus* *Stringocephalus burtini* *Uncites gryphus*
	COUVINIAN (Eifelian)	COUVIN, Belgium	Shales and limestones above Shales and sandstones below	*Spirifer cultrijugatus*, *S. ostiolatus*, *Acrospirifer speciosus* *Gypidula brevirostris*, *Atrypa desquamata* *Leptaena nodulosa*, *Strophonella anaglypha* *Reticularia concentrica*, *Calceola sandalina* *Asteropyge punctata*, *Scutellum fabelliferum*
LOWER	EMSIAN (Upper Coblencian)	EMS, Germany	Shales, sandstones	*Spirifer arduennensis*, *Acrospirifer pellico* (=*S. hercyniae*), *S. carinatus* *Athyris undata*, *A. concentrica* *Tropilodeptus rhenanus* *Phacops potieri*, *Treveropyge rotundifrons*
	SIEGENIAN (Lower Coblencian)	SIEGEN, Germany	Mostly shales and greywackés	*Spirifer hystericus*, *S. excavatus*, *Acrospirifer*, *L. primaevus* *Leptaena murchisoni* *Pterinea costata*, *Pleurodictyum problematicum* *Phacops ferdinandi*
	GEDINNIAN	GEDINNE, Belgium	Shales, sandstones and conglomerates	*Bellerophon trilobatus* *Spirifer sulcatus* *Loxonema* *S. mercouri*

(1949, 1958, 1959) and Selwood (1960) have identified ammonoid faunas in the limestones, cherts and even in cleaved shales in Cornwall and Devon, and House (1958) has provided a list of zones now recognized here.

Table 2. *Ammonoid zones in the European Devonian*

Age		Zones	
L. Carboniferous		Gattendorfia	x = recognized in S.W. England
Upper Devonian	Famennian	Wocklumeria	x
		Clymenia	x
		Platyclymenia	x
		Cheiloceras	?
	Frasnian	Manticoceras	x
Middle Devonian		Maeniceras	x
		Anarcestes	x
Lower Devonian		Mimosphinctes	–

Conodonts. The conodonts are tooth-like phosphatic microfossils, often extremely abundant in Devonian shales or limestones. During the last decade they have been intensively studied in America and Germany and have been pressed to stratigraphical use. Sannemann, Beckmann, and especially Bischoff and Ziegler have all divided various German Devonian (limestone) formations on the basis of conodont faunas. Rhodes and Dineley (1956, 1957) have discovered significant faunas, akin to the German, in the limestones of the Torquay area.

Ostracoderm fishes. Often fragmental, distorted and difficult to extract from the matrix, these fossils are at first sight amongst the most unlikely to be of service to the stratigrapher. White (1956), however, has found the pteraspids of importance in Lower Devonian correlations where marine invertebrates are rare or wanting.

III. THE DEVONIAN SUCCESSION IN SOUTH DEVONSHIRE

Although one can probably nowhere examine a structurally unbroken sequence through the complete Devonian system in South Devon, a stratigraphical order or list of formations (albeit not very strictly defined ones) is possible. These rock units yield fossils providing correlation between Devonshire and the continent and, although their palaeontology is still far from completely explored,

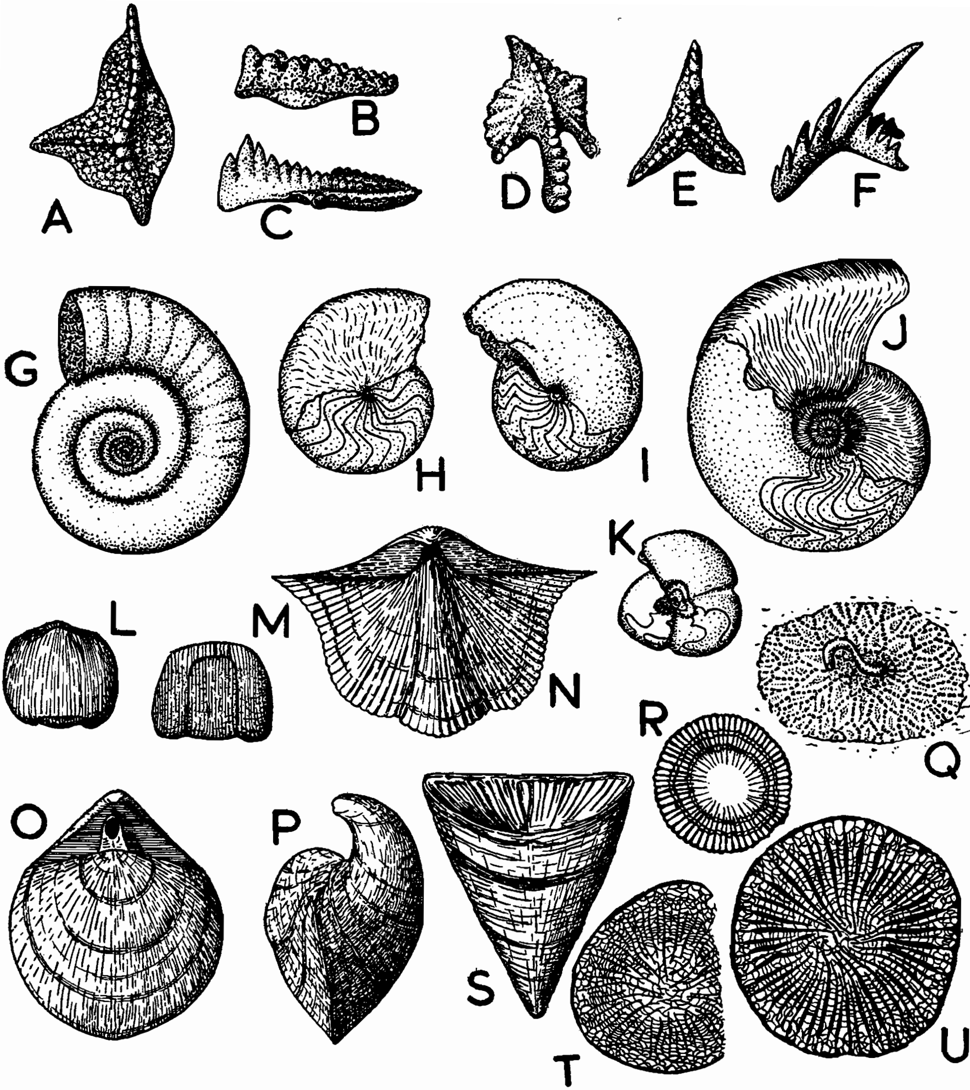

FIG. 2.

Some Devonian index fossils. A–F, Conodonts, all x 20 : A, *Palmatolepis*, Upper Devonian; B, *Icriodus*, Middle and Upper Devonian; C, *Polygnathus*, Lower Devonian to Lower Carboniferous; D, *Ancyropenta*, Upper Devonian (Frasnian); E, *Ancyroides*, Upper Devonian (Frasnian); F, *Tripodellus*, Upper Devonian.

G–K, Ammonoids, all x 2/3 : G, *Clymenia laevigata*, Upper Devonian (Famennian); H, *Tornoceras* sp., Upper Devonian; I, *Maenioceras terebratum*, Middle Devonian (Givetian); J, *Manticoceras intumescens*, Upper Devonian (Frasnian); K, *Wocklumeria sphaeroides*, Upper Devonian (Famennian); L–P, Brachiopods, all x 2/3 : L, M, dorsal and lateral views of *Hypothyridina cuboides*, Upper Devonian (Frasnian) and also found in topmost beds previously thought to be Givetian; N, *Cyrtospirifer verneuili*, dorsal view, Upper Devonian; O, P, *Stringocephalus burtini*, dorsal and lateral views, Middle Devonian (Couvinian); Q–U, Corals, all x 2/3 : Q, *Pleurodictyum problematicum* (Siegenian) Lower Devonian; R, *Phacellophyllum caespitosum*, transverse section, Middle Devonian; S, *Calceola sandalina*, Middle Devonian (Couvinian); T, *Acanthophyllum fibratum* (? = *Hooeiphyllum* Taylor), transverse section, Middle Devonian (Couvinian); U, *Digonophyllum* (*Enteleiophyllum*) *sundwigense*, transverse section, Middle Devonian (Givetian).

Table 3. *Range of Pteraspids in Western Europe* (*White* 1956)

O. R. S.	Britain	N. France & Belgium	S.W. Germany	Stage
Breconian	*dunensis*	*dunensis* *dunensis*	*dunensis* *dunensis*	M. Emsian L. Emsian U. Siegenian M. Siegenian
	leachi	*leachi*		L. Siegenian
	rostrata & var. *monmouth-ensis*	*dewalquei* *rostrata* & sp. nov.		U. Gedinnian
Dittonian	*crouchi* & *rostrata*	*crouchi* & or *rostrata*	*crouchi* & *rostrata*	
Downtownian	*leathensis* *gosseleti*	*gosseleti*		L. Gedinnian

their relative positions in the sequence have remained virtually unaltered since W. A. E. Ussher first put the following table forward in 1890. Scarcely 30 miles away, the rocks of North Cornwall show a remarkably different development with far fewer calcareous strata and more volcanic material. South Devon approaches more closely the Belgian sequence with its massive reef limestones in the Middle Devonian.

While it has long been recognized that the Devonian rocks were deposited in a subsiding geosynclinal trough which continued southwards to Brittany, and eastwards into Belgium and the Rhineland, Hendriks (1959) has stressed that it was divided into secondary longitudinal basins by intervening ridges or axes. Monotonous grey muds were deposited in the basins; the ridges were the site of varied, often rapid sedimentation with the deposition of sandy beds and limestones. Volcanic rocks appear to be associated with the flanks of these ridges and may have been contemporaneous with periods of movement of the corrugated floor of the geosyncline. The presence of such ridges in other parts of the geosyncline is well established and the suggestion that mobile belts or ridges affected the pattern of sedimentation in S.W. England is attractive. Details of these formations and bibliographies are to be found in the various sheet memoirs of the Geological Survey. Several of the outstanding problems in the stratigraphy of these rocks have been discussed by Simpson (1951) and a general guide to the geology of the area with suggested geological traverses has been drawn up by Stuart and Dineley (in press).

Table 4. *Succession of major formations in South Devon*

Unit	Reference	Stage
11. Stourscombe Beds (E. Cornwall)	Selwood 1959, 1960	Famennian
10. Petherwin Beds	Reid *et al.* 1911, Selwood 1960	Famennian
9. Ashes and slates of Saltern Cove	Anniss 1927, Lloyd 1933	Famennian
8. Shaly limestones of Petit Tor and Lower Dunscombe	Annis 1933	Frasnian
7. Shales, ashes and limestone of Saltern Cove	Anniss 1927 Donovan 1943	Frasnian
6. Massive limestone of Torquay, etc., ashes, lavas	Lloyd 1933	Frasnian
	Taylor 1951, Middleton 1959, 1960	Givetian
5. Hope's Nose Limestone of Torquay	Lloyd 1933	Givetian
4. Daddy Hole limestones and shales	Lloyd 1933	Couvinian
3. Staddon Grits	Ussher 1912	Couvinian
	Hendriks 1951	Emsian
2. Meadfoot Beds	Lloyd 1933	Emsian
	Asselberghs 1921	Siegenian
1. Dartmouth Slate	Ussher 1904, 1907, 1912	Siegenian-?Gedinnian

(1) *Lower Devonian*

The Lower Devonian rocks are generally held to lie about the axis of the so-called Dartmouth-Watergate Bay anticline. All suffered metamorphism sufficient to turn the argillaceous beds to slates and phyllites. Strongly developed slaty cleavage is the dominant line of parting within most of the rocks. Locally the strata are fossiliferous and the sequence has been interpreted as a series of dominantly muddy marine beds accumulating at moderate speed in shallow water, conditions deepening as the Middle Devonian epoch approached. Attempts to distinguish three separate Lower Devonian divisions by lithological characters in the field have so far been somewhat unsatisfactory though the Dartmouth Slates is perhaps the most readily recognizable of them. From one unit to another there is an unbroken gradation—vertically and probably also laterally, from the Dartmouth Slates to the Meadfoot Beds and similarly from Meadfoot Beds to Staddon Grits. Fossils found in the two later formations suggest that the Staddon Grits are in part at least equivalent to the Meadfoot Beds. Hendriks (1951) gives details and several other workers have since confirmed that the structural and stratigraphical account given by Ussher needs considerable revision.

The Dartmouth Slates. This group is lithologically fairly distinct, consisting largely of argillaceous beds which must on deposition have been a thick sequence of red, purple, green and even black clays, shales and marl. Ussher (1890) first coined the term Dartmouth Slates for the rocks between Scabbacombe Head and Slapton Sands where they are very dark, intensely cleaved and almost unfossiliferous. The base of the slates has not been found, while the top was

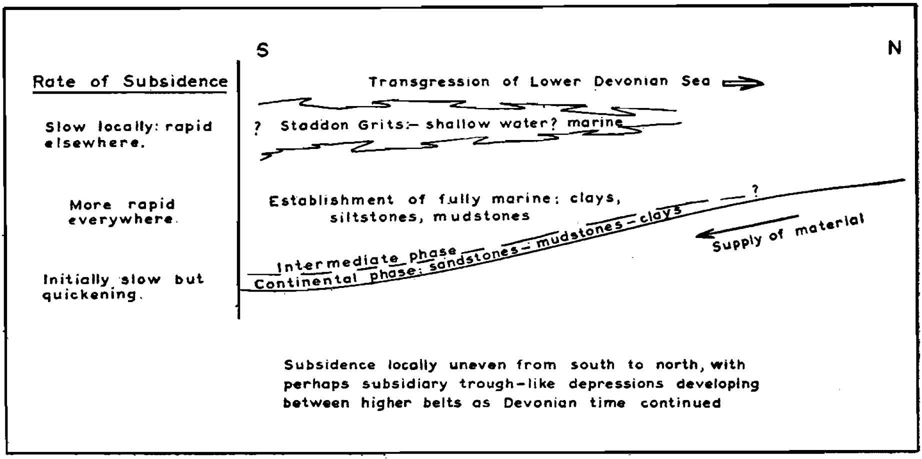

FIG. 3.
Possible arrangement of depositional belts in Lower Devonian (Dartmouth Slates) times.

drawn immediately below the bright red of the Meadfoot Beds—a line which is difficult to determine in the field, does not seem to correspond with any palaeontological boundary and may not even be of more than local occurrence. No estimate of the thickness of these beds can be very reliable; although repetition of strata by faulting and folding occurs, several hundred feet must exist. Not all the beds are slate; sandstones are also present, as can be seen between Erme Mouth and Plymouth Sound, and volcanic beds have been mapped by the Geological Survey near Dartmouth.

In what is probably the lower part of the exposed Dartmouth Slates the sandstone beds form as much as a third of the sequence and many remarkable sedimentary structures survive the metamorphism. Cross-bedding, ripple marks, sandstone "pipes" and erosion surfaces lined with intraclast conglomerates have been found and, together with other features, are very similar to those seen in the Dittonian rocks of Wales and the Borderland. The faunas of the Dartmouth Slates have until recently been most unsatisfactorily known. King (1934) gave some attention to them, and White (1956) made an important contribution in determining that the invariably squashed, fragmentary and distorted ostracoderm fish, "*Pteraspis cornibicus*", from the slates of Watergate Bay and Looe Bay is really in part *Protaspis*, in part *Rhinopteraspis leachi* and in part *Rhinopteraspis dunensis*, which establishes the beds as equivalent to the greater part of the Siegenian stage. The vertebrate fauna appears to be a large one with several forms yet undescribed occurring in both the slate and the pellet or intraclast conglomerate beds. In these respects this part of the Dartmouth Slates strongly suggests comparison with the non-marine Old Red Sandstone rocks, and a continental phase of deposition preceding the marine sedimentation of later stages here, as is also well-established in Europe, may be indicated. Hendriks' (1951) view is that the conglomerate beds are essentially of "flysch" type, apparently implying deposition in deeper waters than is suggested here. Despite the assertion that has been made to the contrary, the ostracoderm fauna is not proved to be of marine origin. The presence of *R. dunensis* suggests that the Dartmouth Slates range in age up to at least the Middle Siegenian (see Table 3).

The Meadfoot Beds. Apparently following without break upon the Dartmouth Slates in the longer coast sections, the Meadfoot Beds in fact take their name from the locality in Torquay where their relationships to the earlier strata are not revealed. Ussher (1903, 1904) examined these rocks between Plymouth Sound and Start Bay, mapping two major outcrops separated by Dartmouth Slates, and a revision of the stratigraphy was proposed by Hendriks in 1951. The Meadfoot Beds comprise a very variable set of strata, frequently showing an alternation of fine laminae of slate and silty material or consisting of cleaved massive mudstones and siltstones. Colours are often bright with red, grey-green and even black beds present. Volcanic bands are sometimes encountered, and calcareous lenticles and seams occur from place to place. Ussher (1898) attempted to subdivide the group into a number of smaller units, but his lithological criteria are unconvincing in the field and the practice has not been followed. Fossils occur at many levels, sometimes in crowded bands, elsewhere as isolated specimens. Preservation is almost invariably poor, but a large faunal list has been compiled. The assemblages indicate marine conditions and are consistent with lithologies that suggest a fairly shallow muddy environment. The brachiopods *Acrospirifer pellico* (= *Spirifer hercyniae*), *A. paradoxus*, *Spinocyrtia subcuspidatus*, *Spirifer* (*Hysterolites*) *excavatus* and *Tropidoleptus rhenanus* and the trilobite *Homalonotus* (*Burmeisterella*) *armatus* point to a correlation with the Upper Siegenian and higher beds of the Ardenne (Asselberghs, 1921). *Rhinopteraspis dunensis* and species of "*Drepanaspis*" have also been tentatively identified from these strata. Other fossils include scattered crinoids, bryozoa and corals, including the (Emsian) *Pleurodictyum problematicum*. Locally the beds are threaded through with abundant *Chondrites*, a rather twig-like trace-fossil one or two inches long.

In the Slapton and Bigbury Bay areas the rocks clearly display the effects of severe compression and dislocation and their junction with the Dartmouth Slates is in the writer's opinion quite arbitrary. There are appreciable variations in the succession and rather vaguely defined broad lithological units can be made out in coastal sections. It has so far not been possible to correlate these units from one side of the South Hams promontory to the other.

Occasional bands of red or brown-weathering and badly decomposed rocks which appear to be concordant with the bedding have been interpreted as contemporaneous volcanic rocks, but they may be sills of pre-metamorphism date.

Once again the question of thickness cannot be answered satisfactorily. The top of the Meadfoot Beds is almost impossible to map over most of the area, but the appearance of rather massive pale red quartzose and quartzitic sandstones is usually taken as marking the base of the Staddon Grits. Between these beds and the Dartmouth Slates over a thousand feet of Meadfoot Beds may exist, locally repeated and "thickened" by plication.

The Staddon Grits. The type area of the Staddon Grits is at Staddon Heights on the eastern side of Plymouth Sound and here the cliff sections show a contorted but apparently more or less complete succession from the Meadfoots to the grey shales and calcareous beds of Middle Devonian age. Again it is difficult to fix an exact and convenient line at which to draw the division between adjacent rock groups. In the Staddon Heights area the beds generally referred to as Staddon Grits are thick-bedded to massive, pale and purplish quartzose and quartzitic sandstones, interbedded with thinner shales or slates. There are also conglomeratic bands, some of which are conspicuous and appear to lie upon erosion surfaces. The thickness of the Staddon Grits at Staddon is exaggerated by plication of the strata: it is probably not very large. While the Staddon Grits maintain a strong development westwards into Cornwall, they appear to diminish eastwards and attempts to map them towards Torbay have not been very convincing. This apparent decrease in thickness may, however, be due to tectonic causes, though there is no undeniable evidence for it. There is indeed

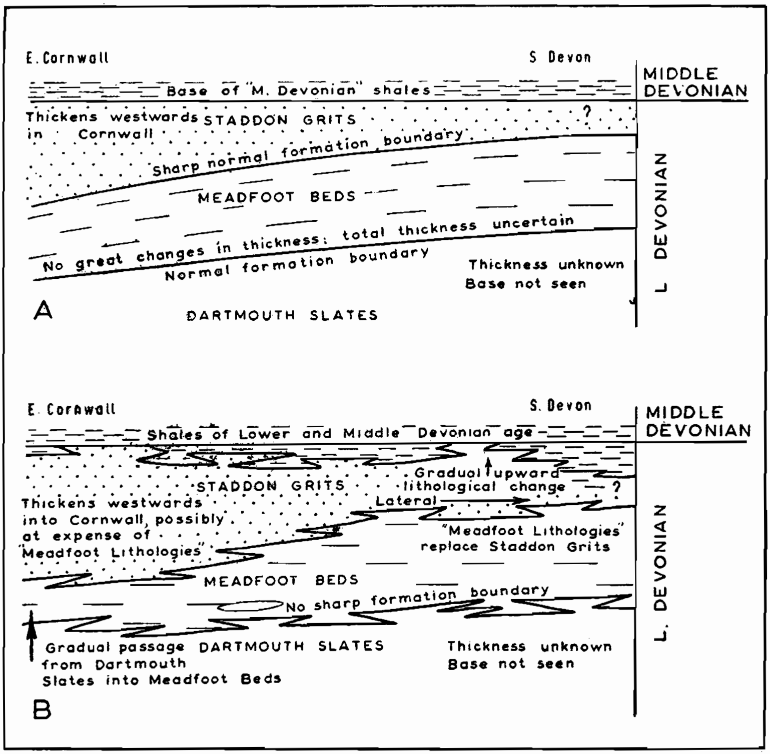

FIG. 4.

Alternative interpretations of Staddon Grits/Meadfoot Beds relationships.

a strong possibility that the Staddon Grits are not a separate formation overlying the Meadfoot Beds, but are a lateral development of them, thickening at the expense of the more argillaceous strata.

The relationship of the Staddon Grits to the grey shales of Jennycliff, north of the Heights, is still not entirely clear. Hendriks (1951) notes that fossils indicating a Siegenian or Emsian date occur within the shales, *i.e.*, the slates on both sides of the Heights are of the same age. The grits then would appear as a local development within the slates, and have been regarded by Hendriks (1958) as formed on a ridge or geanticlinal swell within the main Cornubian geosyncline. The fauna of the Staddon Grits is meagre, but consists of essentially similar fossils to those found in the Meadfoot Beds, often gathered onto locally densely packed lenticles. It has, however, been reported that *Spirifer cultrijugatus* occurs in the topmost Staddon Grits and this would seem to indicate a Couvinian age for the beds there. Thus, what seemed in Ussher's day to be a fairly straightforward vertical sequence of three distinct formations is now regarded as a group showing progressive lateral and vertical changes from one rock type to another in different places at different times. The all-important fossil evidence is still not as conclusive as might be wished and the structure is still not completely deciphered.

(2) *Middle Devonian*

The strata generally referred to the Middle Devonian are perhaps best regarded as a thick group of slates or shales in which are set lenticular sheets and masses of limestone and volcanic rocks. As mentioned above, these calcareous and volcanic members possibly originated on discontinuous ridges or shallows within the developing geosyncline. Coarse clastic sedimentation—sand, silt, etc.—did not occur to any appreciable extent though shallow-water conditions are abundantly indicated in the limestone areas around Torbay and Plymouth. The limestones are locally very fossiliferous and are well-known as building and ornamental stones. Dominantly grey in colour though sometimes stained pink, they are often largely recrystallized, shattered and recemented, and a bituminous smell is given off from freshly broken pieces of some of the beds.

The early investigators of the Middle Devonian rocks of South Devon realized to some extent that lateral change took place in the lithological characters of the beds. They lacked, however, the detailed palaeontological dating of the beds which is now possible. Many of the key fossils used to define series, stages and finer time-rock divisions in European Devonian formations are now recognized in Devon. What is still a difficulty is that the local formation boundaries in Devon and the time-rock lines of Europe do not always coincide.

Metamorphism has been less successful in destroying the fossils within the limestones than in the slates, but distortion is not uncommon. As work continues, the stratigraphical value of many of these fossils will be determined. Already Taylor (1951) and Middleton (1959) have been able to demonstrate that the corals are of use in establishing zonal schemes based on those erected in Europe by Wedekind. Some brachiopods are of stratigraphical value and, although rare, the ammonoids are becoming better known and appear to be stratigraphically sensitive here, as in Germany.

The limestones are of several different types, broadly grouped as (1) massive and (2) thin-bedded, and they occur at two main stratigraphical levels, the higher extending into the Upper Devonian. The lower limestones are generally very dark and of the thin-bedded variety, interleaved with grey or black shales, somewhat bituminous and often very fossiliferous as at Daddy Hole and Babbacombe. Here the tabulate coral and bryozoa fronds exposed in profusion on the bedding-planes appear to be sweepings from coral fields not far away. With them are small stromatoporoid colonies and numerous isolated rugose corals, also not far-travelled; brachiopods and other small benthos are gathered in pockets.

Both thin-bedded and massive varieties of limestone are present at Hope's Nose, the latter being truncated by an erosion surface and overlain by the thin-bedded limestone. The Couvinian index coral *Calceola sandalina* occurs, together with the other common forms *Mesophyllum damnoniense*, *Cystiphyllum vesiculosum*, *Alveolites* sp., *Heliolites porosa* and *Thamnopora* sp. It seems very likely that the thin-bedded limestones here and higher in the succession were to a large degree produced from the destruction of contemporaneous limestone formed nearby in shallower waters. Many of their details correspond well with features seen in the Carboniferous reef and other limestone associations of north-

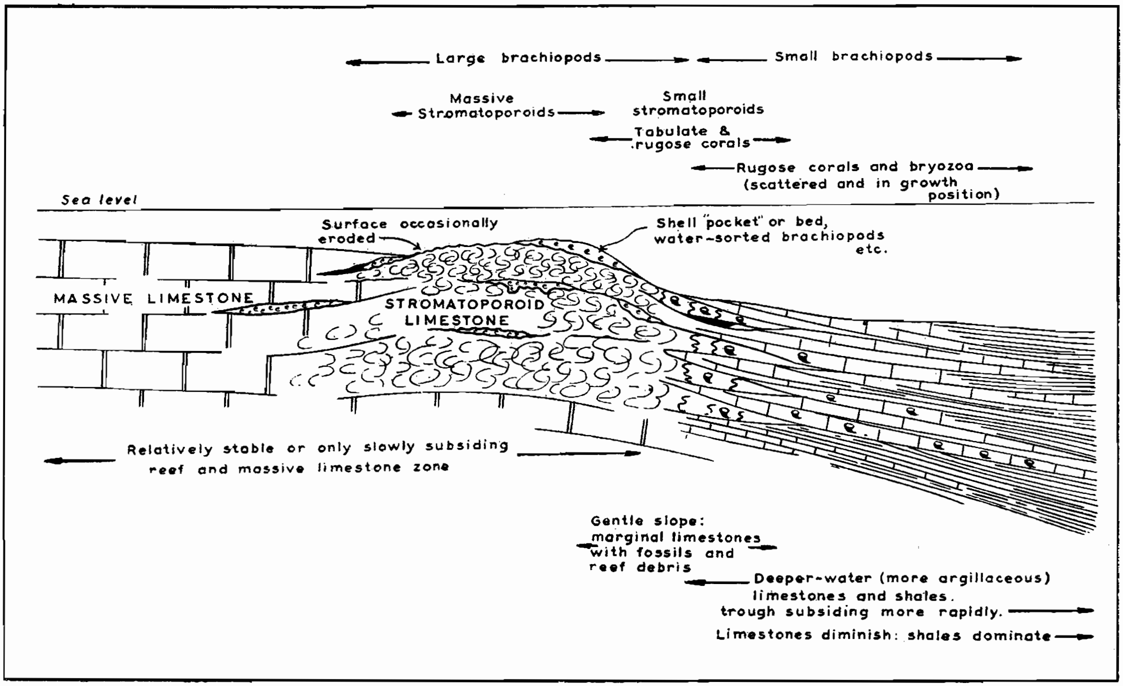

Fig. 5.

Suggested ecological and depositional zones around the Middle Devonian reefs of Torbay.

ern England. The major reef-forming organisms in the Torquay area were probably stromatoporoids and algae, tabulate corals and bryozoa occupying a secondary but not insignificant role. Delicate algal structures within the limestones probably hardly ever survive the metamorphism, but some have been identified. The masses of stromatoporoid colonies, growing one upon another, which built up these reef-like bodies on the shallow sea floor may be seen in many of the quarries in Torquay, and clearly accumulated to thicknesses of over 100 feet. Their growing (upper and outer) surfaces, probably very near sea level, may have been swept by currents and tides. Peripheral to and perhaps extending into slightly deeper water than the stromatoporoids were the coral fields and beyond them lay the muddier water receiving the detritus from the shallower areas and supporting a brachiopod fauna of its own.

Periodic spasms of crustal unrest may locally have caused the destruction of newly grown organic deposits as the geanticlinal belts within the geosyncline rose. From these centres organic debris and lime-mud would be swept out into deeper waters to accumulate as thin-bedded argillaceous limestones. Occasional brachiopod beds as at Lummaton Hill indicate the type of fauna that colonized the surface of these stromatoporoid fields. (For detailed description and faunal list see Lloyd, 1933 and Whidbourne, 1889–95.) The highest limestones of the Torbay area are again thin-bedded and gradually pass vertically and laterally into shales or slates. Their faunas are large and have yielded stratigraphically important fossils. Index fossils such as *Maenioceras terebratum* (U. Givetian), *Hypothyridina* (*Rhynchonella*) *cuboides* (Frasnian), *Stringocephalus burtini* (Givetian) show that the junction between the Upper and Middle Devonian series occurs almost at the top of this limestone group, but it is not a junction amenable to being mapped in the field. Certainly the massive limestone and shell-beds at Lummaton appear to be uppermost Givetian on the basis of included ammonoids, and further results from the study of the local rugose coral faunas are awaited.

Middleton (1959) has suggested that the rugose corals of the Newton Abbot region can be incorporated in a scheme of eight zones closely comparable with that established in the German Middle Devonian by Wedekind. His table of Middle and Upper Devonian formations found in parts of South-East Devon (1960) is shown below. In the three closely situated areas distinguished by Middleton differing successions reflect the varying local conditions of deposition.

The Plymouth Limestone includes both massive and thin-bedded varieties, in part dolomitic, and ranges in age from Couvinian to Frasnian. Taylor (1951) has described the several distinct sub-divisions involved in a large isoclinal fold (Fig. 6) and lists a large rugose coral fauna. Amongst the 32 species reported, the most numerous are *Acanthophyllum* cf. *fimbratum*, *Gyrophyllum regressum*, *Phacellophyllum caespitosum* and *Enteliophyllum sundwigense*. This fauna is very similar to that of the Middle Devonian of Eifel and, as at Newton Abbot, representatives of the German zones seem to be established.

Volcanic rocks. Volcanic outcrops are scattered principally across the Middle and Upper Devonian areas of the map. In the Totnes-Dartmouth area Champer-

Table 5. *Middle and Upper Devonian formations in parts of South-East Devon* (*Middleton*, 1960)

			Zone	Ashburton Area	S. of Newton Abbot	Dartington Area
UPPER DEVONIAN	Upper (Famennian)		VI	Purple and green slates	Grey or buff slates	
			V IV	with ostracods	Thin limestone	
			III			
			II	Chipley Lavas	Grey or buff slate with ostracods	Top not seen
	Lower (Frasnian)		I δ	Spilite and keratophyre	Biohermal limestone	Limestone / Dark grey Slates
			γ			
			β			
			α	Ashburton Limestone		
MIDDLE DEVONIAN	U.	GIVETIAN	Dy	base not seen	Keratophyre tuffs	Dartington tuffs
					Biostromal and clastic limestones	Biostromal and clastic limestones
	M.		Sp			
			St		Limestone and fossiliferous slate	
	L.	COUVINIAN	L		Spilitic andesite	Fossiliferous slate

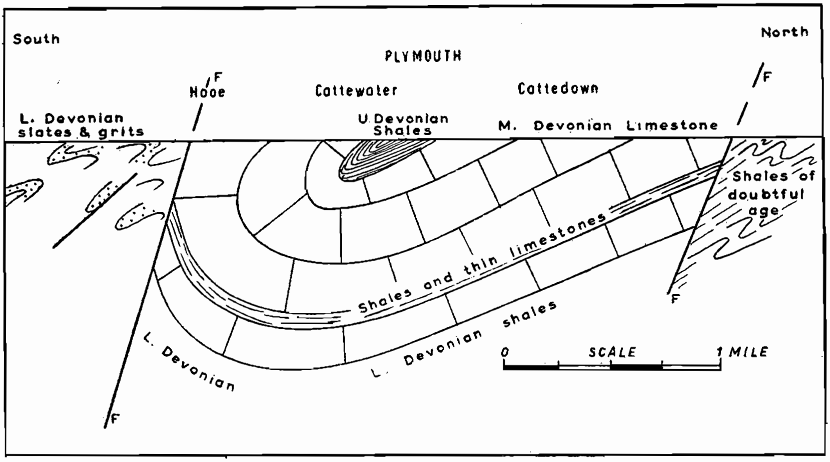

FIG. 6.

Diagrammatic section through the overfolded Plymouth Limestone (after Taylor, 1951).

nowne (1889) described the Ashprington Volcanic Series within the Middle Devonian, but scattered volcanic beds are to be found at many different horizons in other parts of the region. Despite their local abundance, the rocks have not proved easy to investigate for they have suffered decomposition as a result of the Armorican orogeny. Nevertheless, they can be interpreted as a group of generally basic lavas and ashes, deposited under water and locally including bands with marine fossils. At one or two localities they have been seen resting on, or grading into, hardened limestone. Volcanic effusion, seemingly connected with crustal movements taking place throughout the geosyncline, must have caused widespread destruction of life. Middleton's examination of the extrusive rocks south and west of Newton Abbot shows the pattern of volcanic activity to be comparable with events elsewhere—even as far off as Germany. It began with spilitic and intermediate ashes and lavas erupting in Lower Devonian times. Middle Devonian vulcanicity in the Ashprington area seems to have been almost continuous and in Upper Devonian times keratophyric crystal and vitric (glassy) tuffs accumulated in the Dartington area. Finally pillow lavas were erupted over a very wide area.

(3) *Upper Devonian*

The greater part of the Upper Devonian Series is argillaceous—grey-green, red and purple colours being usual. At the base of the series there is in the vicinity of Torbay and Plymouth a passage sequence of limestones and shales, often with thin volcanic beds. Occasional thin sandy beds are found at several places, while at higher horizons the limestones and ashes diminish and disappear. Almost the only fossils encountered are the ostracod *Richterina* (*Entomis*), the brachiopod *Spirifer* (*Cyrtospirifer*) *verneuli*, and the pelagic pelecypod *Posidonia venusta*. During later Upper Devonian times the ridges or shallows of the

Torbay and Plymouth limestone areas faded away and more uniform sedimentation seems to have spread. Near the Launceston area, however, black shales with deeper-water limestones and siliceous bands were deposited, and fine-grained sandstones were formed.

Anniss (1927) in his work on the limestone-shale and ash sequence at Saltern Cove was able to distinguish representatives of both the Frasnian and the Famennian stages. He investigated the occurrence of many small goniatites, discovered many years before, and confirmed a remarkable correlation with the Büdesheim Schiefer (Frasnian) of Germany, not only in the numbers and species of fossils but also their mode of occurrence. (See also Donovan 1942.)

At Torquay the shaly limestone on Petit Tor presents part of the sequence which has so far not been identified at Saltern Cove (probably because of faulting), and its large fauna suggests correlation with the Frasnian limestones of Belgium. At Lower Dunscombe, near Chudleigh, a small isolated outcrop of thin-bedded limestones surmounting the massive limestone has yielded a very distinctive fauna with trilobites, goniatites and conodonts establishing the upper part of the Frasnian stage (Anniss 1933, Dineley and Rhodes 1956).

The upper limit of the series has always been difficult to establish in the field and until recently no sequence was known to show a natural contact between the Devonian and the Carboniferous. The Petherwin Beds in the extreme west of the county have long been regarded as the youngest Devonian, and Selwood (1958, 1960) recently showed that they include two distinct types of deposit. The lower, of thin limestones and slates, includes a typically Famennian lamellibranch-brachiopod fauna, while the higher group of slates, sandstones and thin limestones yields cephalopods which correlate exactly with the *Platyclymenia* and *Clymenia* zones of Europe. Higher still in the sequence are dark slates with chert nodules and seams containing a *Wocklumeria* zone fauna and these are succeeded by further beds with the basal Carboniferous goniatite *Gattendorfia*. Selwood's work seems to show that here at least there is no stratigraphical break—no tectonic disturbance—occurring between the latest Devonian and the earliest Carboniferous times, and this is supported by Dearman and Butcher's (1959) discoveries north-east of Tavistock. They find the topmost Devonian rocks ("Transition Series") are grey-green slates and phyllites followed by calcareous bands with fossils indicating the Famennian *Platyclymenia*, *Clymenia* and *Wocklumeria* zones. Upon these come the black siltstones and slates of the basal (Carboniferous) Culm Measures.

SUMMARY

The Devonian rocks of south Devonshire present a varied suite of sediments, deposited in part of a complex geosyncline. The metamorphism and tectonic upheaval that they have suffered has made interpretation of the sequence very difficult and reference has to be made to the Devonian sections in Belgium and Germany.

In the Lower Devonian there is a strong possibility that the Dartmouth Slates, Meadfoot Beds and Staddon Grits do not form a simple succession, but are local lithological developments which to some extent may be coeval. The known Middle Devonian stratigraphy is virtually confined to the limestone areas around Torbay and Plymouth and various groups of fossils there are

proving useful in correlation with Devonian classic sections of Europe. The Upper Devonian "Series" also is recognized where the limestones are present and the unbroken passage of the Devonian into the Carboniferous is established on good faunal evidence at some points. It is clear that the lithological units do not usually correspond to the palaeontological divisions—the time-rock units established in Europe. Almost certainly some of the lateral changes in lithology are to be accounted for by local belts or regions of movement or uplift within the general trough of the geosyncline.

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