THE UPPER DEVONIAN SALTERN COVE GONIATITE BED IS AN INTRAFORMATIONAL SLUMP

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ABSTRACT. The Saltern Cove Goniatite Bed, which contains upper Frasnian conodonts, ostracods, and goniatites, is shown also to contain blocks of Famennian limestone and to lie within a sequence of Famennian sediments. From the sedimentology, it is considered that Famennian limestone clasts were reworked into Frasnian muds which were then transported *en bloc* into Famennian sediments. A Schwellen area (rise) nearby is suggested by the nature of the derived limestone blocks.

SALTERN COVE (Grid Ref. SX 895585) 5 km south of Torquay, south Devon (text-fig. 1) is a classic locality for Upper Devonian goniatites. It was first described by Lee (1877) and subsequently by Ussher (1903), Anniss (1927), Lloyd (1933), Donovan (1942), and House (1963). The goniatites are now ascribed to the *holzapfeli* Zone of the Frasnian (Iδ), Upper Devonian. Recent work by the authors (briefly reported in Tucker and van Straaten 1970*a*) has shown that the stratigraphical context of the goniatites is not quite so simple as would first appear. Previously, all the Upper Devonian in Saltern Cove and Waterside Cove has been considered to be of Frasnian age (apart from the last 20 to 30 m at the north end of Waterside Cove, which were attributed to the lower Famennian). Results presented here show that all the succession from the north end of Saltern Cove is Famennian in age, though with several beds of older intraformational derived sediment. These include the Goniatite Bed.

STRATIGRAPHY AND STRUCTURE

The Devonian in South Devon is tectonically complicated and in the Torquay area Richter (1969) has recognized four phases of structural deformation. In the Saltern Cove area the bedding is near vertical and youngs northwards. There are several small faults and a strong cleavage is present, which is almost horizontal or dips south-east at a few degrees.

In the central part of Saltern Cove a 3 m thick bed of massive limestone (dated on coral evidence as middle Frasnian by Scrutton 1965) is succeeded by about 20 m of alternating limestone and red shale bands. The limestones are composed of corals, crinoids, and other carbonate debris, and represent the talus from a carbonate-producing area nearby. The northern part of the bay is occupied by some 25 m of purple and red mudstones, with rare crinoidal limestones, which are of lower Famennian age (*Cheiloceras* Stufe) at the top. These are terminated by a fault running ESE.–WNW. which forms the northern side of the cove (text-fig. 1). The succession (with dated ranges) from this fault to the north end of Waterside Cove is (youngest beds, most northern, at the top):

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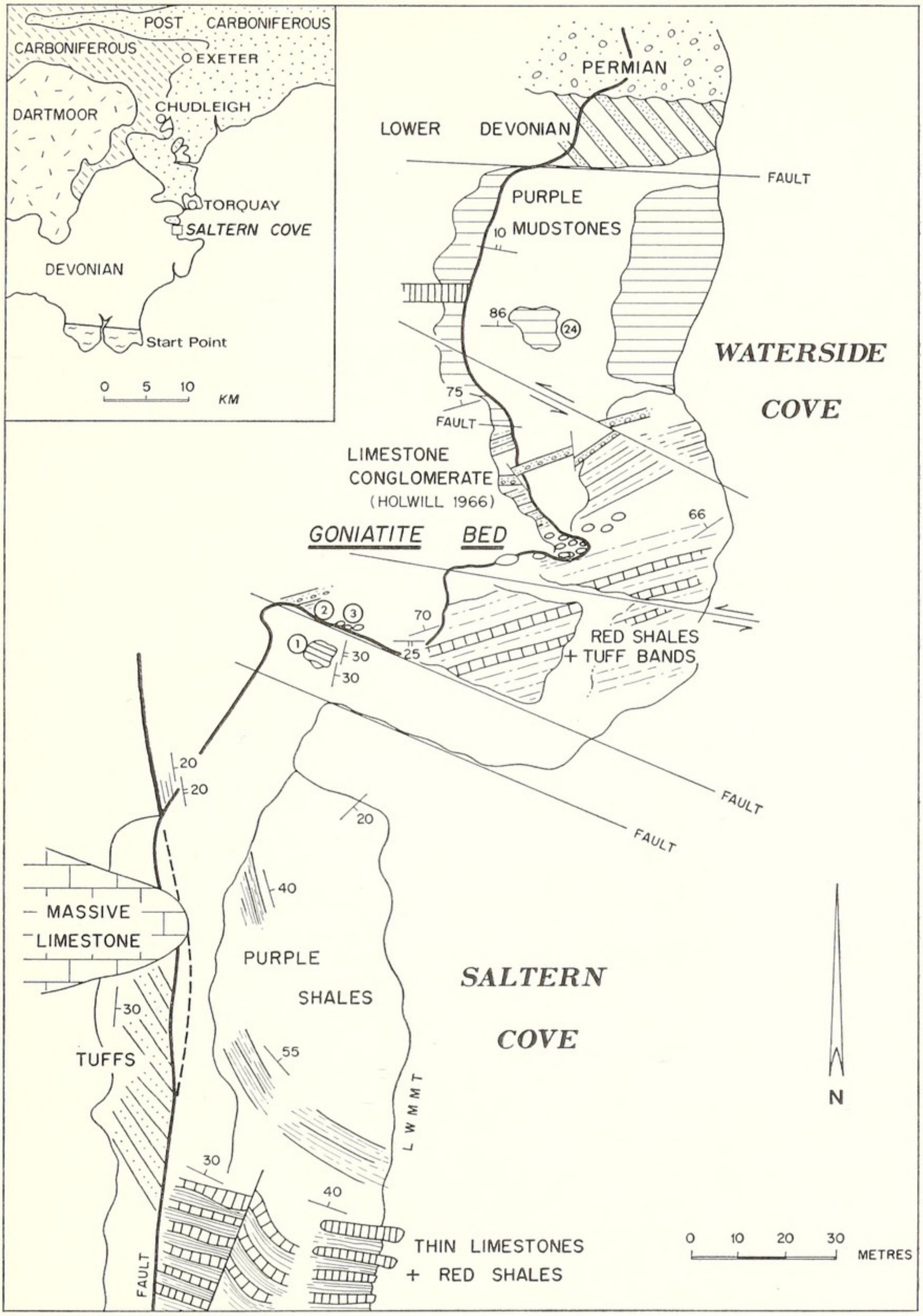


TEXT-FIG. 1. Geological sketch-map of Saltern Cove and Waterside Cove, South Devon (after mapping by the authors), showing location of conodont samples, 1, 2, 3, and 24.

Lower Devonian

— — — — Fault — — — —

40 m	Purple mudstones with tuff and shell bands (central part of Waterside Cove).	IIβ–IIIα
1 m	Limestone conglomerate (described by Holwill 1966).	clasts: IIβ–IIIα, I, Givetian
7 m	Red shales with nodules and tuff bands (southern part of Waterside Cove).	IIβ–IIIα
1 m	Red shale with numerous derived limestone and tuff fragments.	IIβ–IIIα
5 m	The Saltern Cove Goniatite Bed. Red silty shales with many limestone clasts (most southern part of Waterside Cove and promontory between Waterside and Saltern Cove).	shales: Iδ clasts: IIβ–IIIα
20 m	Red and purple shales with many tuff bands (coastal platform between Waterside and Saltern Cove).	IIβ–IIIα

— — — — Fault forming northern side of Saltern Cove — — — —

AGE DETERMINATIONS IN THE VICINITY OF THE GONIATITE BED

Beds above and below the Goniatite Bed

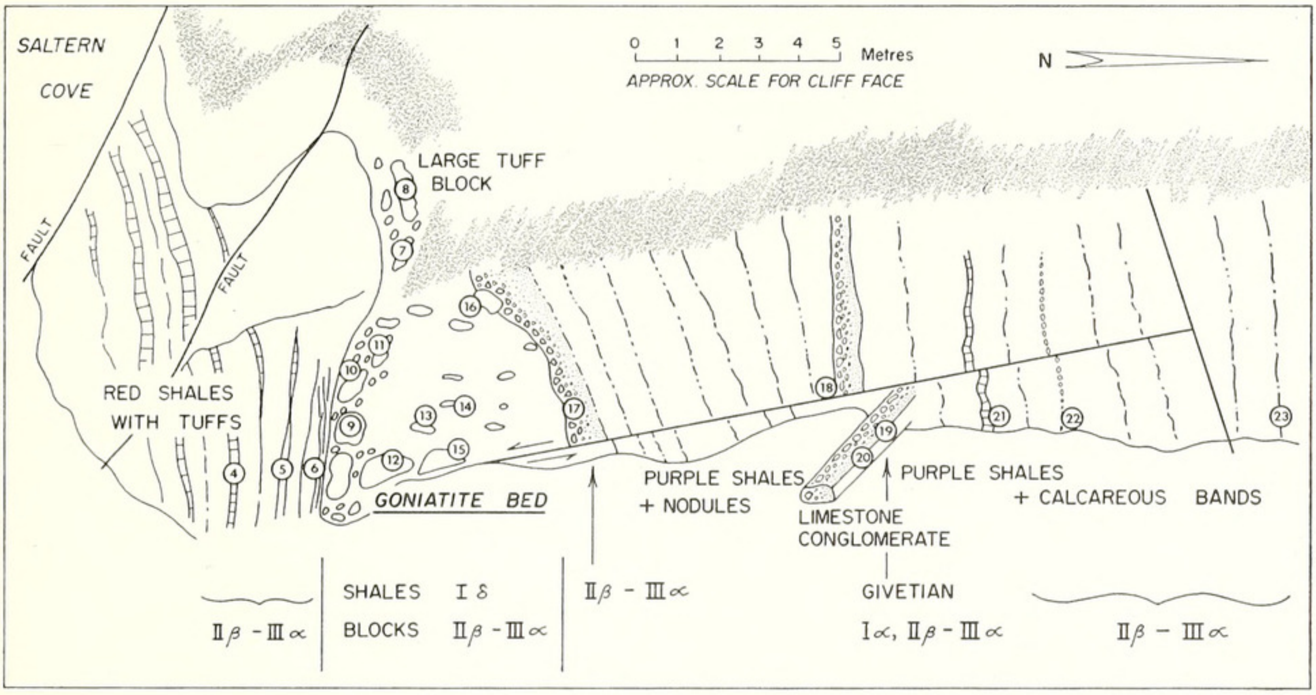
Samples from tuffs and calcareous nodules collected above and below the Goniatite Bed all yield conodonts of the *quadrantinodosa* Zone (IIβ–IIIα, upper *Cheiloceras*–lower *Platyclymenia*, Famennian). Location of the samples is shown in text-figs. 1 and 2, and conodont determinations in text-fig. 3. Limestone clasts from the conglomerate (Holwill 1966) give a range of ages; blocks with corals are Givetian–lower Frasnian (Holwill 1966), whilst fine-grained clasts give Frasnian and lower Famennian ages on conodonts (samples 18, 19, and 20).

Immediately below the Goniatite Bed, and cropping out on the south face of the promontory, is a thin but continuous calcareous band (sample 6) which is particularly rich in conodonts (often broken), thin-shelled bivalves, crinoid fragments, and ostracods. The ostracods, with their stratigraphic range after Blumenstengel (1965) are *Acratia* spp., *Amphissites bispinosus* (upper *Cheiloceras–Platyclymenia*, IIβ–III), and *Ceratacratia cerata* (Famennian, IIα–VI). Purple mudstones at the north end of Saltern Cove (sample 1, text-fig. 1) yielded *Entomozoe* (*Nehdentomis*) *nehdensis* Matern 1929 indicative of the lower Famennian (*Cheiloceras* Stufe).

The Goniatite Bed

(*a*) *Shales*. The goniatite fauna, recently revised by House (1963), belongs to the *holzapfeli* Zone (Iδ) of the upper Frasnian. The fauna is dominated by the genus *Archoceras*. The goniatites are usually a centimetre or less in diameter and are haematized. Most have been obtained from the shales in the cliff section just north of the promontory (text-fig. 2). Goniatites also occur on the south face of the promontory

(M. R. House, pers. comm., 1969). In addition, the authors have found goniatites at the same horizon in the vicinity of the large tuff block figured by Holwill (1966), 10 m west of the promontory. Other fossils present in the shales include *Buchiola* spp., orthocones, trilobites, brachiopods, crinoids (Anniss 1927), and haematized ostracods identified as *Entomoprimitia* spp. (upper Frasnian) and *Entomozoe* (*Nehdentomis*) *tenera* Rabien 1954 (Frasnian–lower Famennian, I–II). Conodonts, occurring in small 'reduction' centres, were obtained by breaking open shales. Generally the conodonts are rather



TEXT-FIG. 2. Sketch of the promontory between Saltern Cove and Waterside Cove, viewed obliquely, showing location of conodont samples 4 to 23.

more common than the ammonoids. Of some 50 collected, half were identifiable, and indicated an upper Frasnian age: *Palmatolepis gigas* Miller and Youngquist 1947, *Palmatolepis subrecta* Miller and Youngquist 1947, *Palmatolepis triangularis* Sannemann 1955, and *Polygnathus* spp. The goniatites, ostracods, and conodonts all indicate a similar age. No Famennian conodonts were found.

(*b*) *Calcareous clasts within the Goniatite Bed.* Within the Goniatite Bed are a number of angular and rounded limestone blocks (sample numbers 7 to 16, text-fig. 3). Most are about 20 cm × 10 cm × 10 cm, but some reach up to 2 m × 50 cm × 30 cm. The block of 'calcareous tuff' figured by Holwill (1966) measures 3 m × 1 m × 50 cm (sample 8). All yielded conodonts (by formic acid digestion) of the *quadrantinodosa* Zone (upper IIβ–lower IIIα) or *rhomboidea–quadrantinodosa* Zones (IIβ–lower IIIα). Other fossils found in the limestones were crinoid fragments, orthocones, ostracods, gastropods, and one goniatite (species indeterminate). The Goniatite Bed (red shales with limestone clasts) and the limestone conglomerate can also be found at the north-west corner of Saltern Cove. Conodonts from limestone blocks here (samples 2 and 3) again show the presence of the lower Famennian.

STRATIGRAPHICAL INTERPRETATION

The data presented above show the apparently anomalous situation in the Goniatite Bed where an argillaceous sediment older than the adjacent shales contains limestone blocks which are two whole goniatite zones younger than the enclosing sediment. There are three possible explanations:

1. *Mis-correlation of goniatites and conodonts.* The ostracods and conodonts in the shales are the same age as the goniatites. This shows that there is no local mis-correlation

	SALTERN COVE			BELOW GON. BED			LIMESTONE BLOCKS WITHIN GONIATITE BED										ABOVE GONIATITE BED							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Ancyrodella rotundiloba BRYANT 1921																				X				
Icriodus spp.										X												X		
Palmatolepis distorta BRANSON & MEHL 1934		X		X																				X
Pal. glabra lepta ZIEGLER & HUDDLE 1969								X								O		X			X	X		
Pal. glabra pectinata ZIEGLER 1960				X	X		X			X	X	X		X	X		O	O						X
Pal. glabra prima ZIEGLER & HUDDLE 1969	X		X		X						X													
Pal. gracilis gracilis BRANSON & MEHL 1934				X																				X
Pal. minuta minuta BRANSON & MEHL 1934					X	X	X		X	X	X	X	X	X		X		X						X
Pal. perlobata schindewolfi MÜLLER 1956				X	X								X						O					X
Pal. quadrantinodosa inflexa MÜLLER 1956														X								X		
Pal. quadrantinodosa inflexoidea ZIEGLER 1962			X										X											
Pal. quadrantinodosa marginifera ZIEGLER 1960			X	X	X	X		X		X			O				X	X	X		X	X		X
Pal. spp.		X				X			X											X	X			
Polygnathus diversa HELMS 1959																								X
Pol. glabra glabra ULRICH & BASSLER 1926										X									X					
Pol. nodocostata s.l. BRANSON & MEHL 1934				X		X			X	X		X	X		X	X	X	X				X		X
Pol. nodocostata cf. *pennatuloidea* HOLMES 1928					X																			
Pol. nodoundata HELMS 1961				X																	X			
Pol. triphyllata ZIEGLER 1960													X	X	X									
Pol. spp.				X		X	X	X	X	X		X	X	X	X				X			X		X
Polylophodonta confluens ULRICH & BASSLER 1926																			X					
Spathognathodus amplus BRANSON & MEHL 1934															O									
Spathognathodus spp.				X		X		X		X			X		X						X		X	

TEXT-FIG. 3. Conodont determinations from Saltern Cove and Waterside Cove, South Devon. 0 = cf. determination. The specimens are deposited in the archives of the Department of Geology, University of Reading, where they are numbered S22901–22924. The conodont zones represented by the samples (after Ziegler 1962, 1965, and Klapper 1966) are as follows:

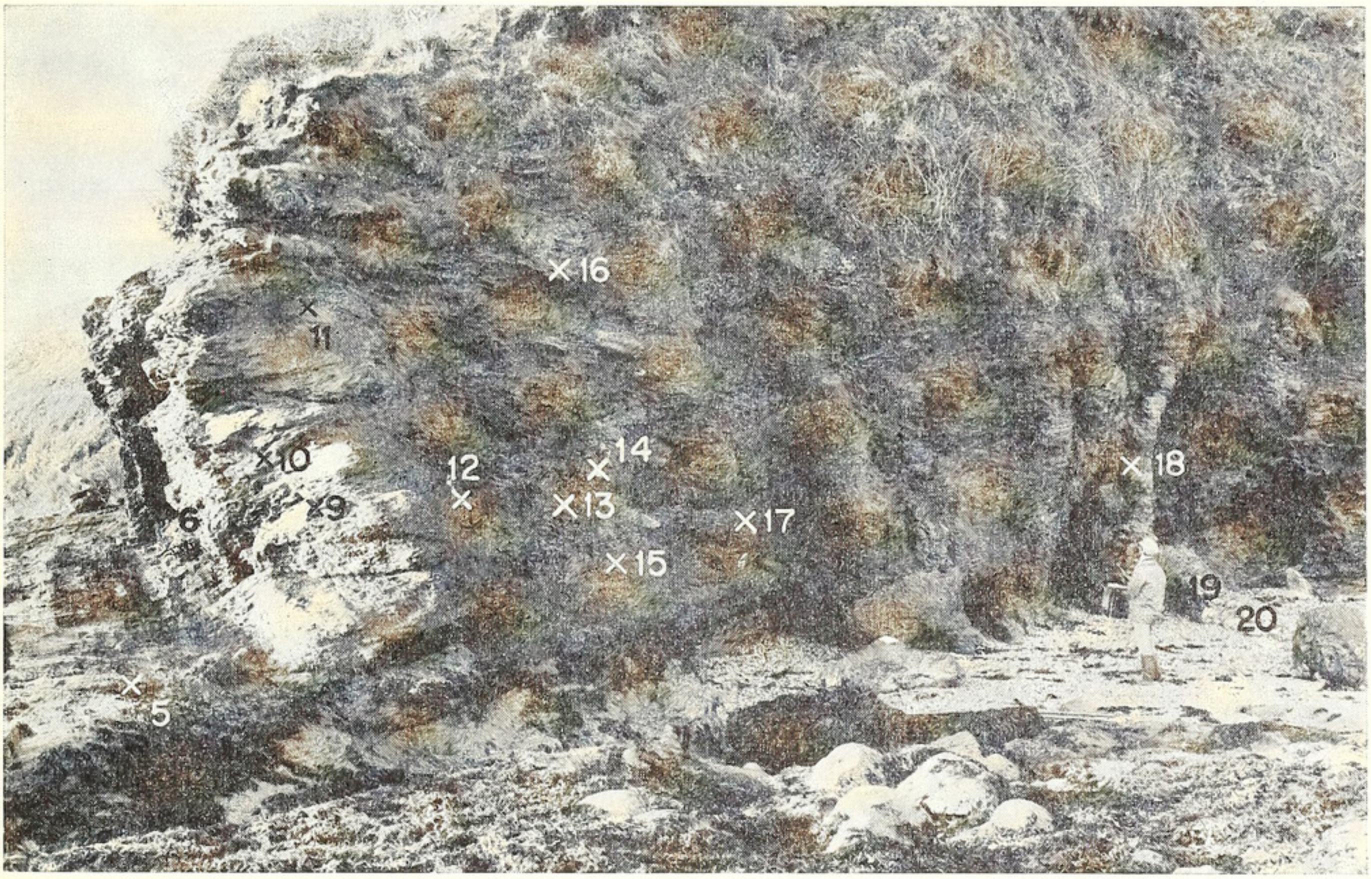
Sample 20 *asymmetrica* Zone (Iα).
Samples 1, 5, 7, 11, 12, 15, 16 *rhomboidea–quadrantinodosa* Zones (IIβ–lower IIIα).
Samples 3, 4, 6, 8, 10, 17, 18, 19, 21, 24 *quadrantinodosa* Zone (upper IIβ–lower IIIα).
Samples 13, 14, 22 lower *quadrantinodosa* Zone (upper IIβ).
Sample 2 *quadrantinodosa*–middle *velifera* Zones (upper IIβ–IIIβ).
Sample 9 upper *triangularis*–upper *velifera* Zones (Iδ–IIIβ).

of the goniatite and conodont chronologies and that the German system (Ziegler 1962) is applicable to the area. Indeed, at Chudleigh, 30 km NNW. of Saltern Cove, the conodont succession from the *Cheiloceras* Stufe is essentially in agreement with the German chronology and with the goniatite succession (Tucker and van Straaten 1970*b*).

2. *A complication of the tectonics.* From the bedding/cleavage relationship around the promontory (bedding vertical, cleavage horizontal) a fold cannot possibly be constructed so that the Goniatite Bed occurs in the centre of a tight anticline, unless such a fold was developed during an earlier deformational phase. However, the beds above and below the Goniatite Bed show normal grading (northwards), indicating that early folding did not take place. From text-fig. 4 it is clear that faulting and/or shearing has not occurred around the Goniatite Bed. The tectonic deformation is only such that the limestone

blocks have been rotated by the cleavage, and once continuous ash bands are sheared. A complication of the tectonics then is most unlikely to have caused these Frasnian shales to occur in a Famennian succession.

3. *Large-scale transportation of sediment.* A sedimentary explanation means that the youngest elements in the Goniatite Bed, the limestone clasts, were reworked into older argillaceous sediments and that the whole was then transported *en bloc* into a muddy



TEXT-FIG. 4. The Saltern Cove Goniatite Bed. Location of samples indicated.

succession indistinguishable in age from the clasts. The presence of goniatites, conodonts, and ostracods all of the upper Frasnian, and the absence of Famennian goniatites and conodonts within the shales of the Goniatite Bed, indicate transportation *en bloc* of the Frasnian muds (with their Famennian limestone clasts) rather than a simple reworking of the Frasnian fauna into Famennian muds. Evidence that this was the case can be seen from an examination of the sedimentology of the succession.

LAMINATION OF SEDIMENTS. A petrographic examination of the shales of the Goniatite Bed shows that they are quite distinct from the shales above and below in one important respect, that good lamination is absent. In spite of the strong cleavage, thin continuous laminae of medium to coarse silt, 0·5 mm thick, occur in the shales above and below. In the goniatite shales, however, the same amount of silt is present but is either irregularly distributed or present in discontinuous lenses. Numerous graded tuff bands, from a few millimetres to 40 cm thick, occur at intervals of 20–30 cm above and below the Goniatite

Bed, and can be traced for up to 70 m across the wave-cut platform. A small channel structure is also exposed here. However, in the shales of the Goniatite Bed macroscopic laminations of this type are completely absent. It is suggested that transportation of the sediment destroyed its primary lamination. There is no evidence of any erosional structure between the Goniatite Bed and the underlying laminated shales.

LIMESTONE CLASTS. The blocks of Famennian limestone and tuff are clearly derived. There is some concentration of clasts towards the base of the Goniatite Bed, but many occur randomly scattered throughout the shale. The limestones are micritic with an appreciable amount of silt. Some are almost completely dolomitized. Prominent pressure solution planes (stylolites) occur in some blocks and there are also cavity-fill structures. A few clasts contain a network of cavities filled first by fibrous calcite, and then silty shale material. Many of the limestone blocks are reminiscent of the condensed pelagic facies (Schwellen facies, Cephalopodenkalk) which at Chudleigh, and commonly in Germany, follows Givetian/lower Frasnian shallow-water massive limestones (Tucker unpub. thesis, Reading 1971).

The events which led to the formation of the Goniatite Bed are as follows:

1. Deposition of Frasnian muds (containing goniatites, conodonts, and ostracods) perhaps on the slopes of a Schwelle (submarine rise).
2. Deposition of Famennian limestones on a Schwelle.
3. Reworking of clasts of the Famennian limestone into the Frasnian muds.
4. *En bloc* transportation of the Frasnian sediments with clasts of Famennian limestone into Famennian muds.

Another band with many tuff and limestone fragments occurs immediately above the Goniatite Bed, and conodonts (sample 17) suggest that the clasts are of the same zonal age as the shales. The limestone conglomerate (7 m above the Goniatite Bed) described by Holwill (1966) contains limestone fragments of various types and ages. The bed is graded and Holwill suggested a proximal turbidity current origin.

COMPARISONS

Three types of sediment transportation have occurred at Saltern Cove. (A) Of more frequent occurrence, movement of lithified shallow-water sediments (limestones) downslope into a deeper water environment, where the transported material is generally older than the host sediments. An example of this is the limestone conglomerate of Holwill (1966), mainly composed of Givetian and Frasnian clasts, but with some micritic limestones of Famennian age (samples 18 and 19). (B) Transportation of lithified shallow-water sediments downslope where the reworked clasts are of the same zonal age as the deeper water sediments. An example of this is the bed of reworked tuff and limestone fragments occurring immediately above the Goniatite Bed (sample 17). Other bands containing calcareous clasts occur higher up the succession in Waterside Cove and are probably also of this type. Slumping of this second type, with no stratigraphical break, is typical of most intraformational conglomerates and is known in a similar situation in the Upper Devonian of the Harz Mountains, Germany (Stoppel and Zscheked 1963). (C) *En bloc* transportation of argillaceous sediments which are older than the host sediments, e.g. shales of the Goniatite Bed. Slumping of the third type involving transportation of muds is less common and may be difficult to prove: it is detectable only where either the stratigraphical break is large enough, or sufficiently fine dating is possible. In the absence of the latter, only the lack of lamination might give a clue to the detailed history.

SIGNIFICANCE OF SLUMPING AT SALTERN COVE

The two pelagic facies of the Upper Devonian, the condensed limestones (Schwellen or rise facies) and ostracod shales (Becken or basinal facies) are developed in south-west England, though the rise facies is only well known at Chudleigh (House 1963, Tucker and Straaten 1970*b*). However, it may be present at Petit Tor Combe (Grid Ref. SX 926665, 4 km north-east of Torquay) where patches of nodular limestone containing middle Frasnian goniatites occur (Ussher 1890; Lloyd 1933; and House 1963). The basinal facies is well developed in the Torquay district. The blocks of Famennian limestone at Saltern Cove indicate that pelagic carbonate was deposited in the vicinity on a topographic high. In the Upper Devonian of Germany condensed pelagic limestones occur above submerged 'reefs', on volcanic ridges and basement rises (geanticlines) within the Rhenish Geosyncline. The Torquay and Brixham shallow-water limestones, or the massive limestone immediately to the west at Goodrington may have been positive areas during the Famennian where pelagic carbonate accumulated. A slope facies can be recognized in the German Devonian in the transitional sediments between Schwellen and Becken. The slope facies consists mostly of shales with bands of calcareous nodules, but is characterized by the presence of slumped or reworked horizons. The Saltern Cove Goniatite Bed shows that a similar situation of submarine rise and slope existed during the Upper Devonian of this area.

Holwill (1966) considered volcanism as the immediate cause for the limestone conglomerate. However, for the Goniatite Bed, instability on a slope and movement of the underlying sediment is as likely an explanation, although the movement may have been initiated by volcanic activity.

CONCLUSIONS

1. The Saltern Cove Goniatite Bed is a transported deposit of Frasnian shales containing Famennian limestone blocks, developed within a sequence of early Famennian sediments. The sedimentology of the finer-grained sediments provides a clue to the stratigraphical interpretation. The type of slumping is unusual since *en bloc* movement of shales has occurred, which are older than the contained limestone clasts and adjacent sediments.
2. The derived Famennian pelagic limestones indicate the former existence of a Schwellen area.
3. Where tested, the German goniatite, conodont, and ostracod zonation is applicable, and confirmed in South Devon.

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