8. *On the CHEMICAL and MINERALOGICAL EVIDENCE as to the ORIGIN of the DOLOMITES of SOUTHERN TYROL.* By Prof. ERNEST WILLINGTON SKEATS, D.Sc., F.G.S. (Read December 7th, 1904.)

[PLATES X-XIV—MICROSCOPE-SECTIONS.]

I. INTRODUCTION.

THE country of the 'Dolomites' has long been classic ground to geologists. The researches of Dolomieu¹ at the end of the eighteenth century, and of L. von Buch² early in the nineteenth, first aroused the interest of geologists in the district. Their attention at first was mainly directed to speculations concerning the mode of origin of the mineral, named after the French geologist, of which the mountains are so largely composed; this question, even at the present day, is far from settled. The stratigraphy of the district has always presented many points of difficulty. The earlier observers, struck by the contrast in scenery and composition between the bold, precipitous, dolomite-masses and the marls and stratified tuffs of the green pasture-lands or 'Alpen,' were at a loss to explain their mutual relations, especially as very few fossils were at first discovered in any of the deposits. In 1834, however, Graf Münster,³ who had examined the strata near St. Cassian, enumerated, and (in part) described and figured 400 species of fossils from them, and subsequent observers have added largely to the number. The precise age of these deposits, which had till then been a matter of discussion, was settled by the examination of their fossil contents. It was shown not only that the beds were of Triassic age, but that, unlike the Trias of most of the European areas, they had been deposited under marine conditions. In 1845 Bronn⁴ suggested that the St. Cassian fauna had inhabited a shallow sea where coral-banks were numerous.

The stratigraphy of the district was first systematically described by Baron Ferdinand von Richthofen,⁵ in a brilliant paper, in which he claimed that the curious relations of the dolomitic and non-dolomitic strata could be explained if it were assumed that the masses of dolomite represented altered coral-reefs formed during a period of subsidence, while the St. Cassian marly and tufaceous deposits were laid down in the lagoons, bays, and channels of a coral-sea,

¹ 'Observations sur la Physique, &c.' vol. xxxix (1791) p. 3.

² 'Ueber Dolomit als Gebirgsart' Abhandl. d. k. Akad. Wissensch. Berlin, 1822-23 & 'Einige Bemerkungen über die Alpen in Baiern' *ibid.* 1828, p. 84.

³ Neues Jahrb. 1834, pp. 1-15 & pls. i-ii; see also *ibid.* 1842, p. 119.

⁴ *Ibid.* 1845, pp. 504-508.

⁵ 'Geognostische Beschreibung der Umgegend von Predazzo, St. Cassian & der Seisser Alpe in Süd-Tyrol' Gotha, 1860, 4to.

Richthofen gave a complete account of the literature on the subject which had appeared up to 1860. His views were amplified by the work of Dr. E. von Mojsisovics and the officers of the Austrian Geological Survey, and their results were published in 1879 in the former's book.¹ C. W. von Gümbel,² Dr. R. Lepsius,³ and others opposed the coral-reef theory of the origin of the Dolomites. In more recent years, Mrs. Ogilvie Gordon has paid much attention to the stratigraphy and the tectonics of this area, and in a series of papers⁴ has considerably extended our knowledge of the geology of the district. She has emphasized the objections to the coral-reef hypothesis; she regards the Schlern Dolomite as a deep-water marine deposit, and seeks to explain the reef-like character of the dolomite-mountains as a result of complicated earth-movements in Tertiary times. Among the latest publications on this district is a handbook of the International Geological Congress, published in 1903, by Prof. C. Diener and Dr. G. von Arthaber, which embodies the results of the most recent work in the area of which it treats, and includes a list of the most recent papers on the subject. In May 1904, the important work 'Bau & Bild von Oesterreich' was published, and Prof. Diener was responsible for that part of it which deals with the Dolomites of Southern Tyrol.

While most geologists are now in agreement upon the general stratigraphical succession of the deposits in the Dolomites, it will be seen that antagonistic views are held as to the mode of formation of the rock-masses which now constitute the dolomite-mountains. Those who uphold the coral-reef theory point to:—

- (1) The great resemblance of the isolated dolomite-masses to upraised reefs, and the fact that corals are occasionally found preserved in them.
- (2) Their 'heteropic' character, masses of dolomite thousands of feet thick representing in age, and tailing off laterally into, marly deposits of much less thickness.
- (3) 'Reef-blocks' found on the slopes of the Dolomites, and apparently intercalated among the sedimentary deposits outside them.
- (4) The unbedded character of the rocks and their great thickness.
- (5) The fact that the rocks, like recent reefs, are often dolomitized.

¹ 'Die Dolomit-Riffe von Süd-Tirol & Venetien' Vienna, 1879.

² 'Das Mendel- u. Schlern-Gebirge' Sitzungsber. d. math.-phys. Classe d. k. bayerisch. Akad. d. Wissensch. vol. iii (1873) p. 14.

³ 'Das Westliche Süd-Tirol' Berlin, 1878, 4to.

⁴ 'Contributions to the Geology of the Wengen & St. Cassian Strata in Southern Tyrol' Quart. Journ. Geol. Soc. vol. xlix (1893) p. 1; 'Coral in the Dolomites of South Tyrol' Geol. Mag. 1894, pp. 1 & 49; 'The Torsion-Structure of the Dolomites' Quart. Journ. Geol. Soc. vol. lv (1899) p. 560; 'Monzoni & Upper Fassa' Geol. Mag. 1902, pp. 309 & 384; and 'The Geological Structure of Monzoni & Fassa' Trans. Edin. Geol. Soc. vol. viii (1902-1903) special part.

The opponents of the coral-reef theory state that :—

- (1) The general absence of corals in the dolomite militates against the coral-reef hypothesis. Calcareous algæ and echinoderms, but not corals, are the most common fossils.
- (2) The apparent thinning-out of the dolomite into marls and ashes is due to faulting, while the Schlern Dolomite really succeeds the St. Cassian Marls, and does not pass laterally into them.
- (3) The reef-like shape of the masses is a structural feature due also to faulting.

In view of the large amount of work done within the last 10 years in the exploration of recent coral-reefs, and the examination of the materials of which they are composed, it may serve a useful purpose to enquire if the results obtained are of such a character as may prove helpful in determining the question whether the dolomite-mountains do or do not represent old coral-reefs.

The researches of Prof. Alexander Agassiz in many parts of the Atlantic, Indian, and Pacific Oceans, the expedition to Christmas Island under Dr. C. W. Andrews,¹ and to the eastern group of the Fiji Islands under Mr. E. C. Andrews of Sydney University,² have added largely to our knowledge of the structure and origin of upraised coral-islands. Mr. J. Stanley Gardiner has put on record his observations at Funafuti and in the Maldives³; while the borings at Funafuti in 1896 and 1897 (under the leadership of Prof. Sollas, and afterwards of Prof. David) provided the means for the systematic examination of the materials composing a typical atoll down to a depth of 1114 feet. The Funafuti Report has recently (1904) been published by the Royal Society. The chemical examination of the cores was commenced by Dr. C. G. Cullis, and continued by Mr. J. Hart-Smith and myself, under Prof. Judd; and one of the most interesting results obtained, apart from the highly-dolomitie character of parts of the material, consisted in the discovery that the rocks forming the cores were of extraordinary purity, being practically free from insoluble residue.

During the progress of the examination of the Funafuti materials, I had an opportunity of making a chemical and microscopical examination of the collection from the upraised mass of Christmas Island, and of a selection from the collections of Prof. Agassiz, Prof. David, and Mr. E. C. Andrews from the Fiji Islands and other parts of the Pacific Ocean. The results obtained were published in June 1903, in vol. xlii of the 'Bulletin' of the Museum of Comparative Zoology at Harvard College. There I drew attention to the fact that :—

¹ Geogr. Journ. vol. xiii (1899) pp. 17-35 (with map) & 'Monograph of Christmas Island' Brit. Mus. (Nat. Hist.) 1900.

² Bull. Mus. Comp. Zool. vol. xxxviii (1900) pp. 1-50 & pls. i-xxxix.

³ Proc. Camb. Phil. Soc. vol. ix (1898) pp. 417-503.

- (1) In those coral-islands which are remote from land-areas and volcanic rocks, the amount of insoluble residue in the limestones was negligible.
- (2) In coral-islands associated with volcanic rocks many of the limestones were found to be practically devoid of residue, but those in the proximity of the volcanic masses contained a larger quantity, amounting in some cases to over 4 per cent.

It will be noticed that in a recent coral-reef, either the whole or some part of the materials of which it is composed is devoid of insoluble residue. It is obvious that this total or partial absence of insoluble residue ought to hold good as well for a fossil coral-reef as for a recent one. I determined, therefore, to visit the Dolomites of the Tyrol, to make representative collections in this much-debated region, and to see whether a chemical and microscopical examination of the specimens would afford any evidence as to the mode of origin of the deposits. By the favour of the Council of this Society in making me the first recipient of the proceeds of the Daniel-Pidgeon Fund, I was enabled to spend a considerable part of the summer-vacation of 1903 in making typical collections of the Triassic rocks in the district. I am indebted to Prof. Judd for giving me the opportunity of analysing the material collected, and I am glad to be able to lay before the Society the results of the investigation.

The area visited is all included within the roughly-circular basin in which the typical dolomites of Southern Tyrol are best seen. The fundamental rocks, exposed only at the border of the area, consist of quartz-phyllites and schists of great antiquity, possibly of Archæan age. The earliest sediments are Permian, and succeeding these are the Triassic deposits, which cover the greater part of the basin. The Alpine movements of the mid-Tertiary age originated a series of flexures and faults, of which the majority trend roughly north-and-south and east-and-west. The shallow anticlines formed as a result of these movements have, to some extent, determined the directions of the valleys. The northern and southern valleys include those of the Eisack, Fassa, Agordo, and Ampezzo. The eastern and western valleys are not so well defined (with the exception of the Pusterthal in the north of the area), and for the most part form subsidiary depressions joining the more prominent northern and southern valleys. Over the greater part of the area, the dolomite-rocks of the Upper Trias are exposed at the surface, while the Middle and Lower Triassic deposits are only seen on the flanks of the valleys. The Permian rocks are occasionally exposed in the deepest parts of these valleys. The stratigraphical succession varies somewhat in different areas, owing to the heteropic character of the deposits. In three typical localities it is as follows:—

<i>Schlern Area, North Side.</i>	<i>Seiser Alp.</i>	<i>Tre Croci and Cortina.</i>
Dachstein Dolomite. Raibl Beds.	 <i>Pachycardium</i> -Tuffs.	Dachstein Dolomite. Raibl Beds. Schlern or St. Cassian Dolomite.
Schlern Dolomite.	St. Cassian Marls.	St. Cassian Marls and Limestones.
Augite-Porphyrity (Lower Wengen).	Upper Wengen Beds. Augite-Porphyrity (Lower Wengen).	Wengen Sandstones. Wengen volcanic rocks.
Buchenstein Limestone.	Buchenstein Limestone.	
Mendola Dolomite.	Mendola Dolomite.	
Dont Schiefer (Lower Muschelkalk).	Dont Schiefer.	
Campiler Schiefer. Seiser Schiefer. } Permian.	Werfen Beds.	

The dolomite seen on the north-eastern flank of the Schlern Mountain, and in the Marmolata, Langkofl,¹ and Plattkofl massifs corresponds in age both to the Wengen and to the St. Cassian Beds. When followed eastward and northward, the dolomite is seen to rest upon St. Cassian deposits, and represents only the upper part of the dolomite from the areas just mentioned.

The Schlern Dolomite is the massive deposit that gives the characteristic appearance to many of the isolated massifs. It is this deposit which is generally claimed as being of coral-reef origin, and it is this horizon which I have particularly examined. The Mendola Dolomite has also been supposed to owe its origin to coral-reef conditions in mid-Triassic times.

II. THE CHEMICAL EVIDENCE.

The results of the chemical analyses of the specimens obtained from the localities visited will now be given. A few complete gravimetric analyses were made, and the results of these are recorded to two places of decimals. In the case of the majority of the specimens, only the insoluble residue and the iron and alumina, when present, were gravimetrically determined; the calcium was estimated volumetrically by a method described fully in a previous paper,² and the amount of magnesium was obtained by difference. The results of the volumetric analyses are recorded only to one

¹ The section of the rocks on the north-western flank of the mountain shows that the massive dolomite is underlain by bedded dolomitic limestones closely resembling the Buchenstein Limestone. Mrs. Ogilvie Gordon, however, has proved St. Cassian Beds on the eastern flanks of the mountain, and believes that the dolomite-masses overlie the St. Cassian Beds.

² Bull. Mus. Comp. Zool. vol. xlii (1903) p. 53.

DIAGRAMMATIC SKETCH-MAP OF PART OF SOUTHERN TYROL.

decimal place. For purposes of comparison, it will be most convenient to bring together the results of analyses of rocks from the same horizon, and see how the results vary when the deposit is followed from one area to another. Since the Schlern Dolomite is the principal deposit the formation of which has been attributed to coral-reefs, it is perhaps best to consider the results of analyses from that horizon first, and subsequently to compare with them analyses of the rocks, both higher and lower, in the stratigraphical succession.

The Schlern Dolomite.

Area of the Schlern.

A good section of the whole of the Triassic deposits is exposed from the summit of the mountain (8400 feet) along the marked path which is traversed during the descent to Bad Ratzes, and nearly 3000 feet of this consists of massive unbedded Schlern Dolomite. The rock, however, immediately below the plateau near the summit consists of bedded dolomite, and the first specimen analysed (No. 7) came from this upper bedded part. The succeeding specimens were taken at intervals of approximately 300 to 400 feet during the descent towards Bad Ratzes. The last specimen (No. 13) was from just above the junction of the dolomite with the augite-porphyrite:—

No.	CaCO ₃ . <i>Per cent.</i>	MgCO ₃ . <i>Per cent.</i>	Fe ₂ O ₃ & Al ₂ O ₃ . <i>Per cent.</i>	Insoluble residue. <i>Per cent.</i>
7	51·50	43·45	0·60	4·40
8	52·70	44·80	...	2·47
9	55·30	40·80	...	3·93
10	54·61	43·75	1·02	0·55
11	52·80	43·40	trace	3·73
13	67·00	32·80	...	0·20

Three other specimens may be considered here. No. 31 was collected near the summit of the Rossezähne, the eastern prolongation of the Schlern massif, near the point where it meets the fragmental volcanic deposits of the Seiser Alp:—

No.	CaCO ₃ . <i>Per cent.</i>	MgCO ₃ . <i>Per cent.</i>	Fe ₂ O ₃ & Al ₂ O ₃ . <i>Per cent.</i>	Insoluble residue. <i>Per cent.</i>
31	55·3	43·8	...	0·86
β	56·9	41·6	trace	1·53
27	60·1	39·1	...	0·73

Specimen β was from a rolled fragment, probably Schlern Dolomite, taken from the bed of the stream at Bad Ratzes. No. 27 was from a block of 'Cipit'-dolomite from the Seiser Alp.

In 1875 Prof. C. Døelter & Prof. R. Høernes wrote a paper on the composition of the Dolomites of the Tyrol, and published the results of a number of analyses.¹ They recorded two analyses from the dolomite of the Schlern Mountain: the first one from a

¹ Jahrb. d. k.-k. geol. Reichsanst. vol. xxv (1875) pp. 293-332.

specimen 80 feet below the summit, the second from a specimen 1000 feet above Schlernbach. The first specimen contained 1·33 per cent. of iron-oxide and residue, while ·71 of insoluble residue was obtained from the second.

The Langkofl.

In this area also the dolomite probably corresponds in age both to the Wengen and to the St. Cassian deposits, since on the north-eastern side of the mountain it is seen to follow conformably the representative of the Buchenstein Beds.

The first two specimens (Nos. 96 & 95) were blocks fallen from the upper part of the mountain. Nos. 94, 93, & 92 were taken in descending order, *in situ* from the eastern side of the mountain facing the Sella massif. No. 92 was taken only a foot or so above the junction with the bedded Buchenstein Limestone.

No.	CaCO ₃ . <i>Per cent.</i>	MgCO ₃ . <i>Per cent.</i>	Insoluble residue. <i>Per cent.</i>	
* 96	54·7	45·3	0·02	* Not in place.
* 95	54·7	45·3	0·013	
94	54·7	41·3	4·00	
93	68·9	29·0	2·13	
92	56·1	43·9	trace	

It will be noticed that three of the specimens are practically devoid of insoluble residue. Nos. 94 & 93, containing residue in considerable quantity, are specimens of a reddish dolomite-conglomerate, which lines the almost-vertical eastern face of the mountain. This material, both in its appearance and in its mode of occurrence, closely resembles a reef-talus. It will be seen that two of the specimens have the composition of a true dolomite.

The Marmolata.

The four specimens collected were obtained from the northern flank of the mountain, near its base, and during the ascent to the Fedaja Pass. No. 32 was from an immense fallen block, at the lower end of the Fedaja Valley. Nos. 33, 34, & 35 were from rocks higher up the valley, the two last-mentioned specimens being taken from the southern shores of the Fedaja See. The dolomite exhibits a fairly-steep northerly dip, and has at its base Buchenstein Beds. Hence, the lower parts of the mass from which the specimens were collected are probably of Wengen age. Augite-porphry lava of that age abuts against the northern slopes of the massif, and No. 35, containing 0·6 per cent. of insoluble residue, was taken from near the junction with the volcanic rock.

No.	CaCO ₃ . <i>Per cent.</i>	MgCO ₃ . <i>Per cent.</i>	Insoluble residue. <i>Per cent.</i>	
35	97·3	2·1	·6	* Not in place.
34	97·0	3·0	...	
33	95·8	4·2	...	
* 32	86·7	13·0	·26	

Sett Sass.

No.	CaCO ₃ <i>Per cent.</i>	MgCO ₃ <i>Per cent.</i>	Insoluble residue. <i>Per cent.</i>	* Not in place.
* 112	54.8	45.2	...	
107	54.6	44.2	1.20	
108	54.6	44.1	1.26	

Three specimens were collected from the northern end of Sett Sass. No. 112 was taken from a block fallen from the upper part of the mass; No. 107 from the upper, and No. 108 from the lower part of the mass at the junction with the St. Cassian Limestone below.

The Richthofen Reef.

Residue is absent from Nos. 112 & 110, but present in fair quantity in Nos. 107 & 108.

No.	CaCO ₃ <i>Per cent.</i>	MgCO ₃ <i>Per cent.</i>	Insol. res. <i>Per cent.</i>	The rocks are all dolomites of theoretical composition. The Richthofen Reef is a wedge-shaped mass, apparently interbedded with the St. Cassian Limestone which occurs below Sett Sass.
110 ...	54.7	45.3	...	

St. Cassian Limestones from Sett Sass.

Two analyses of St. Cassian Limestones from this district are included for comparison

No.	CaCO ₃ <i>Per cent.</i>	MgCO ₃ <i>Per cent.</i>	Fe ₂ O ₃ <i>Per cent.</i>	Insol. res. <i>Per cent.</i>	with the dolomites. No. 109 was taken from the rock lying between the base of the dolomite of
109...	90.7	6.0	3.33	trace	
111...	78.1	11.8	3.73	6.40	

Sett Sass and the Richthofen Reef; No. 111 from just below the Richthofen Reef. It will be seen that the limestones are only slightly dolomitized, that they are distinctly ferruginous, and that, while No. 109 is free from insoluble residue, No. 111 contains over 6 per cent.

The Cortina District.

Col Crepa.

Specimens Nos. 49 to 51 were collected, in descending order, from

No.	CaCO ₃ <i>Per cent.</i>	MgCO ₃ <i>Per cent.</i>	Insol. res. <i>Per cent.</i>	the western side, and Nos. 62 & 64 from the northern side of Col Crepa near Cortina. This hill consists of Schlern Dolomite faulted on all sides against St. Cassian and Wengen Beds. It will be noticed that the rocks, while highly dolomitic, are not theoretical dolomites, and that (with the exception of No. 51) they are practically free from insoluble residue.
49 ...	60.1	39.9	...	
50 ...	60.0	40.0	...	
51 ...	56.7	42.8	.46	
62 ...	59.9	40.1	.013	
64 ...	62.0	38.0	.02	

The following seven analyses are from scattered localities within a few miles of Cortina :—

Giau Pass.

No.	CaCO ₃ . Per cent.	MgCO ₃ . Per cent.	Insol. res. Per cent.	No. 37 was from the Giau Pass, about 6 miles south-west of Cortina. The specimen was not in place, but the altitude of over 7000 feet at which it was found renders it probable that the rock belongs to the Schlern-Dolomite horizon.
37...	91·5	7·4	1·13	

Hexenfels.

No.	CaCO ₃ . Per cent.	MgCO ₃ . Per cent.	Insol. res. Per cent.	Nos. 56 & 59 were collected about 7 or 8 miles west of Cortina. No. 59 being from just below the junction with the Raibl Beds.
56 ...	54·33	45·36	0·05	
Travernanze Valley.				
59 ...	60·0	39·5	0·16	

Sorapis.

No.	CaCO ₃ . Per cent.	MgCO ₃ . Per cent.	Insol. res. Per cent.	No. 55 was collected from the western flanks of Mount Sorapis, about 4 miles south-east of Cortina.
55 ...	55·5	43·3	1·20	

Monte Cristallo.

No.	CaCO ₃ . Per cent.	MgCO ₃ . Per cent.	Insol. res. Per cent.	No. 46 was from the south side of Monte Cristallo, just below the junction with the Raibl Beds.
46 ...	58·5	38·3	3·20	

Tre Croci.

No.	CaCO ₃ . Per cent.	MgCO ₃ . Per cent.	Insol. res. Per cent.	Nos. 40 & 41 were taken from an exposure of St. Cassian Dolomite, east of Tre Croci.
40 ...	57·2	42·5	0·26	
41 ...	54·6	43·9	1·53	

It will be seen that Nos. 40, 56, & 59 contain only a small amount of residue, while the remaining specimens have over 1 per cent. With the exception of No. 37, the rocks are highly dolomitic.

The Dürrenstein Area.

No. 66 came from the summit of the Dürrenstein (9300 feet).				Nos. 67, 68, & 69 were taken during the descent to the Seeland Alp. No. 72 came from the eastern base of the Strudelkopf, the southern continuation of the Dürrenstein massif. Nos. 68 & 69 contain a relatively - high amount of residue, the remaining three specimens practically none, while all are dolomites of well nigh theoretical composition.
No.	CaCO ₃ . Per cent.	MgCO ₃ . Per cent.	Insol. res. Per cent.	
66 ...	55·2	44·8	...	
67 ...	54·5	45·5	0·026	
68 ...	55·2	43·9	1·93	
69 ...	54·4	44·3	1·26	
72 ...	54·2	45·7	...	

The Drei Zinnen Area.

No.	CaCO ₃ . Per cent.	MgCO ₃ . Per cent.	Insol. res.	The three specimens were collected during the descent of the upper part of the Rienz Thal, on the western flanks of the Drei Zinnen. No. 71 A was not in place. All three specimens represent dolomites devoid of insoluble residue.
71A...	54.7	45.3	...	
70 ...	54.3	45.7	...	
71 ...	55.0	45.0	...	

It now remains to record, for comparison with the Schlern Dolomite, analyses from rocks below and above it.

Analyses from Beds below the Schlern Dolomite.

Wengen Limestone.

No.	CaCO ₃ . Per cent.	MgCO ₃ . Per cent.	Fe ₂ O ₃ . Per cent.	Insol. res. Per cent.	The Wengen Beds of the Seiser Alp include some limestones, and an analysis of one of them (No. 22) shows that a very high percentage of insoluble residue and less than 5 per cent. of magnesium-carbonate are present.
22 ...	64.9	4.7	4.62	20.84	

Buchenstein Beds.

Immediately below the dolomite of the Schlern, Langkofl, and Marmolata comes a nodular siliceous limestone—the Buchenstein Limestone. Two analyses were made from this horizon. No. 18 is from the base of the Schlern, above Bad Ratzes; No. 88 from the Gader Gorge, in the Valley of Abtei, about 1 mile north of St. Leonhard. Both analyses show a high percentage of insoluble residue and a small amount of magnesium-carbonate.

Mendola Dolomite.

The Mendola Dolomite occurs only in certain districts, and represents a local modification of the Upper Muschelkalk. No. 19 is from the Schlern massif, below the Buchenstein Limestone and above Bad Ratzes. No. 26 is from the Pufels Schlucht, north of the Seiser Alp, and leading into the Gröden Valley. The insoluble residue in each case approaches 1 per cent., and the magnesium-carbonate falls short of that in a theoretical dolomite by 3 or 4 per cent.

No.	CaCO ₃ . Per cent.	MgCO ₃ . Per cent.	Residue. Per cent.
19 ...	58.2	40.9	.93
26 ...	57.4	41.9	.73

Lower Muschelkalk.

Only one analysis was made from this horizon, the specimen (No. 86) being taken from the Gader Gorge in the Valley of Abtei. It will be noticed that the rock contains comparatively-little magnesium-carbonate, but much insoluble residue.

No.	CaCO ₃ .	MgCO ₃ .	Residue.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
86	56·6	12·2	31·20

Analyses from Beds above the Schlern Dolomite.

Succeeding the Schlern Dolomite is a deposit of variable character, marls containing gypsum, coral-limestones, or dolomitic rocks. They are known as the Raibl Beds, are usually iron-stained, and are never of any great thickness. Following these comes a great thickness of limestones or dolomites, usually of a bedded character, known as the Dachstein Beds. These form the uppermost beds of the Trias, corresponding in age to the Rhætic deposits, and they are in some places more than 3000 feet thick.

Dachstein Dolomite.

No.	CaCO ₃ .	MgCO ₃ .	Insol. res.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
1 ...	56·5	43·4	·07
42 ...	60·4	39·6	trace.
61 ...	58·7	41·3	·013
104 ...	54·8	45·2	trace.

No. 1 is from the summit of the Schlern.
 No. 42 from the southern flanks of Monte Cristallo, below Tre Croci.
 No. 61 from the Val de Travernanzez, west of Monte Tofana.
 No. 104 from the western end of Sett Sass.

In each case the specimens were collected from the base of the deposit, immediately above the junction with the red Raibl Beds. It will be noticed that the base of the deposit is a dolomite of very great purity and approaching the theoretical composition.

The Dachstein Beds are not always so devoid of insoluble residue, for Profs. Døelter & Hørnes¹ record two analyses of dolomites containing respectively ·67 and ·98 per cent. of residue, the first from the summit of Perdoi (south of Monte Sella), the second from the Fanis Alp.

Raibl Beds.

No. 4 is from the Schlern plateau, just below Burgstall; while

No.	CaCO ₃ .	MgCO ₃ .	Insol. res.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
4 ...	52·8	43·6	3·53+Fe ₂ O ₃
73 ...	68·1	28·2	3·66

No. 73 is from below the military post on the western flanks of the Dürrenstein, above the Seeland Alp. In each case the amount of in-

soluble residue present is considerable.

¹ Jahrb. d. k.-k. geol. Reichsanst., vol. xxv (1875) pp. 322, 323.

III. DISCUSSION OF THE CHEMICAL RESULTS.

In considering the results of the foregoing analyses, two points of especial interest arise :—

- (1) The mode of formation of masses of dolomite.
- (2) The significance of the presence or absence of insoluble residue in a limestone.

The first point will be dealt with in considering the mineralogical evidence.

Sir John Murray's work in connection with the *Challenger* Expedition added largely to our knowledge of the nature, composition, and mode of formation of the deposits which are now being laid down on the sea-bottom. It was found that in all the deep-sea deposits insoluble residue was present in amounts which rarely, if ever, fell below 1 per cent., often reached 3 to 5 per cent., and occasionally rose to as much as 20 per cent. It is generally agreed that deep-sea deposits rarely attain any great thickness, since they accumulate with extreme slowness. The presence in deep waters of carbon-dioxide under pressure determines the solution of much of the calcareous parts of the tests of the minute organisms which form the deposit, and as solution proceeds the proportion of insoluble to calcareous material becomes greater. From external sources other products, such as finely-divided volcanic material and cosmic dust, also contribute to the amount of insoluble matter in deep-sea formations. When a deposit composed of the skeletons of calcareous organisms is being laid down near a coast formed of non-calcareous rocks, finely-divided detrital matter intermingles with the calcareous skeletons, so that the resulting limestone is rendered impure.

Some thin fringing coral-reefs may be of this character. I have recorded an analysis of such a reef-rock from Singatoka (Viti Levu).¹ Shallow-water impure limestones may also be formed by the intermingling, not of detrital matter, but of finely-divided volcanic debris with the purely-calcareous material. Recent coral-reefs growing in the vicinity of volcanoes ejecting ashes often have such insoluble matter included within them. Mango, an upraised coral-island in the Lau group of the Fijis, provides an example of an impure limestone of this character.²

A chemically-pure limestone must have been deposited under some such conditions as the following :—

1. The material must have accumulated rapidly. If it had been slowly deposited, solution of the calcareous parts of the organisms and the raining-down of volcanic material and cosmic dust would raise the percentage of insoluble residue.

2. The deposit must have been laid down in shallow water, since only under these conditions do calcareous organisms exist in sufficient abundance to give rise to thick and rapidly-formed deposits.

¹ Bull. Mus. Comp. Zool. vol. xlii (1903) p. 79.

² *Ibid.* pp. 71-73.

3. In general, such a limestone would not be deposited near a non-calcareous shore-line, nor in the vicinity of volcanoes ejecting ashes.

These conditions are fulfilled, so far as I am aware, by only one kind of deposit forming at the present day, namely in coral-reefs, especially in those remote from great land-masses. I have already drawn attention¹ to the high degree of purity of the limestones from many of the upraised coral-islands of the Indian and Pacific Oceans; while, in the Report on the Atoll of Funafuti,² the chemical results demonstrate that this typical atoll is composed entirely of limestone and dolomite almost wholly free from insoluble residue.

In considering the origins of limestones of geological antiquity, we may say in general that:—

1. A chemically-pure limestone has been formed under ‘coral-reef’ conditions.

2. A limestone which, throughout its bulk, does not contain less than 1 per cent. of insoluble residue, has been formed either in deep water or as a detrital deposit, or has been laid down within the range of the finer ejectamenta from a volcano.

3. A limestone which in parts is pure, and in parts contains residue, has probably been formed under ‘coral-reef’ conditions, but from time to time the area of deposition has been invaded either by detrital or by volcanic material.

We are now in a position to interpret the results of the analyses, so far as the amount of residue which they contain may throw light upon the mode of origin of the deposits.

Wengen and St. Cassian Dolomites.

Area of the Schlern.

From a consideration of the amount of residue alone, one might be led to conclude that the rocks in this area represent deep-sea deposits, since most of the analyses show well over 1 per cent. of residue. One specimen, however, contains only .2 per cent. If the deposit were of deep-water origin, we should expect it to be thin and well-bedded. We have to deal, however, with a mass of unbedded dolomite approaching 3000 feet in thickness, laid down contemporaneously with a much thinner series of shallow-water limestones, marls, and tuffs, formed over the area of what is now the Seiser Alp, to the north of the Schlern massif. The probability is, then, that this mass of dolomite represents a limestone rapidly formed in a subsiding area, and impregnated with very finely-divided volcanic material from submarine volcanoes lying to the north.

This view is supported by the fact that, interbedded with the Schlern Dolomite a few hundred feet above its base, there occurs a deposit, a few feet thick, in which the volcanic fragments are bigger

¹ Bull. Mus. Comp. Zool. vol. xlii (1903) pp. 103–104.

² Roy. Soc. 1904, pp. 368 *et seqq.*

and so numerous that the rock assumes the character of a submarine calcareous tuff. In this connection it may be mentioned that a partial analysis of the insoluble residue from specimen No. 7, near the Schlern plateau (p. 103), gave 64.26 per cent. of silica and 23.23 per cent. of ferric oxide and alumina. Slight reactions for calcium, magnesium, and sodium were obtained, and a stronger indication of the presence of potassium. A short distance below the summit of the Schlern, on the southern and western sides, a later outpouring of the augite-porphry lava is interbedded with the Schlern Dolomite.

Area of the Langkofl.

The two specimens which contain much residue come from material lining the steep eastern slope of the mountain, and possibly represent a reef-talus. Analyses from the solid mass of the mountain show only a trace of residue. This, in conjunction with the great thickness of the deposit, supports the view that it was a coral-limestone formed during subsidence.

Area of the Marmolata.

Of the specimens collected *in situ*, two contain no residue, and two analysed by Profs. Døelter & Hørnes¹ are similarly free from insoluble matter. The only specimen containing an appreciable quantity (.6 per cent.) was collected from near the junction of the dolomite with the contemporaneous lava poured out to the north of the area. The facts again favour the view of the formation of the deposit as a coral-limestone during a period of subsidence.

The three areas just considered were subjected to similar conditions of deposition, during a movement of subsidence commencing not later than the Wengen period (in the Schlern area it commenced in the Upper Muschelkalk period), and continued until a 'negative' movement which set in at the commencement of the Raibl period.

In the remaining areas to be considered, the formation of the deposit, which now consists mainly of dolomite, did not commence until after the deposition of the Lower St. Cassian Marls and Limestones. It is not surprising to find, therefore, that the dolomite is much thinner than in the areas already considered; at Tre Croci, near Cortina, for instance, the thickness is reduced to about 300 feet.

St. Cassian Dolomites.

Area of the Sella.

An examination of the results of analyses from the dolomite of the Sella shows a progressive decrease in the amount of residue present, from below upwards. It would seem that to the north and east of the Schlern, Langkofl, and Marmolata massifs we

¹ Jahrb. d. k.-k. geol. Reichsanst. vol. xxv (1875) p. 319.

have an area which, after the cessation of volcanic activity in St. Cassian times, consisted probably of shallow-water depressions and lagoons in which the subsequent deposit was laid down. At first, no doubt, the reefs were contaminated by detrital fragments from the volcanic deposits in the neighbourhood, and this is borne out by a chemical examination of the deposits. As subsidence and deposition continued, the volcanic detritus was gradually sealed up, and the subsequently-deposited material became freer from residue, as is seen from an inspection of the results of the analyses from higher horizons. It may or may not be significant that the later-formed limestones have been more completely dolomitized than the older deposits in this area.

The St. Cassian District.

The analyses would appear to indicate that the Lavarella mass is free from residue, and is probably of coral-origin. At Sett Sass, south of St. Cassian, the first-formed deposit, like that of the Sella, was mixed with insoluble material, and the origin of the two deposits appears to be the same. The Richthofen Reef, a lenticular mass in the earthy St. Cassian Limestone, below the dolomite of Sett Sass, appears to have been formed during a quiescent period, in clear water devoid of sediment.

The Cortina District.

The faulted dolomite-mass of Col Crepa and Belvedere contains little or no residue, and appears to have been a coral-limestone formed rapidly in clear water. The analysis from the Hexenfels rock near Cortina also indicates a dolomite of great purity. The remaining analyses, from scattered localities in the neighbourhood, show generally more residue, and the rocks were possibly deposited in a coastal area supplying detrital material to the deposits.

The Dürrenstein Area.

The dolomite in this northern part of the district is much thicker than near Cortina. Rapid deposition under reef-conditions in a subsiding area would appear to have set in at the commencement of the period (an analysis from the base of the Strudelkopf shows no residue), and to have continued until the close, with intermittent deposits into which detrital matter was introduced (Nos. 68 & 69).

The Drei Zinnen Area.

The specimens from the Rienz Valley at the base of the Drei Zinnen are dolomites of great purity, in all probability deposited under reef-conditions.

We have now to consider the composition of the beds below and above the Schlern and St. Cassian Dolomites.

In areas outside the Schlern, the Langkofl, and the Marmolata, Q. J. G. S. No. 241.

the dolomite rests upon limestones and marls, named after St. Cassian, where they are well seen. They are for the most part earthy limestones, oolitic in places, and probably of detrital origin, since for the most part they contain a rather large amount of residue. Locally, as at Sett Sass, they become very rich in beautifully-preserved branching corals, and an analysis of one of these shows that, while it is very ferruginous, it is almost devoid of insoluble residue. On the Seiser Alp, intercalated with the volcanic tuffs of St. Cassian age, lenticular masses and blocks of limestone or dolomite, which are known as 'Cipit'-limestone, occur. An analysis of a specimen taken from one of these blocks shows it to be highly dolomitic and to contain surprisingly little residue (73 per cent.), considering its intimate association with the St. Cassian tuffs. As these blocks not infrequently contain reef-forming corals, there seems little doubt that they represent scattered reef-like patches of corals, which established themselves during a temporary abatement of volcanic activity in the areas in which they are found.

An analysis of one of the earthy Wengen limestones found on the northern slopes of the Seiser Alp, shows a great admixture of insoluble matter, probably volcanic in origin. Proximity to land is indicated by the local occurrence (in the Gader Valley, for instance) of plant-remains in the Wengen deposits.

The Buchenstein Limestones, while not so earthy as those of Wengen age, are shown in two cases to contain between 7 and 9 per cent. of residue, and are probably of detrital origin, as contemporaneous volcanic rocks of Buchenstein age appear to be rare.

The Mendola Dolomite contains over 40 per cent. of magnesium-carbonate, and rather less than 1 per cent. of residue in the two examples analysed. It presents, therefore, a considerable resemblance to some of the Schlern Dolomites, and may have been formed as a reef to which some detrital material had access.

The only remaining limestones from the Older Triassic rocks are of Lower-Muschelkalk age. These are very impure, an analysis of one from the Gader Gorge showing over 30 per cent. of residue. They are, in all probability, of detrital origin. Possibly the older crystalline rocks of the neighbourhood were not entirely submerged, and these would serve to account for the presence of so much insoluble matter.

After the formation of the Schlern Dolomite the area of deposition was restricted, in consequence of 'negative movements': some of the area was raised above sea-level, and the succeeding Raibl Beds were laid down in lagoons, salt-water lakes, etc., for we find that in different places the Raibl deposits vary greatly in character. Reddish marls, sandstones, gypsum, dolomite, and patches of coral are all represented. Possibly some of the magnesium in these beds is to be attributed to direct deposition from concentrated salt-water, and the erosion and solution of some of the Schlern Dolomite, as well as the presence of minute volcanic fragments, would suffice to account for the 3 or 4 per cent. of insoluble residue found in

some of the dolomites of Raibl age. At the close of the Raibl period a further depression of the district became general, and thoroughly-marine conditions supervened. The first-formed Dachstein deposits were probably of the nature of coral-reefs, since the base of the dolomite is very free from residue. The bedded character of most of the deposit and its fossil contents make it probable that, for the greater part, it was of sedimentary origin, and Profs. Døelter & Hørnes record two analyses from the upper part of the mass in which the residue approaches 1 per cent.¹

IV. THE MINERALOGICAL EVIDENCE.

About eighty of the specimens collected were sliced, with a view to the examination of any organisms which might be recognizable, and for the study of the mineralogical characters exhibited by the various limestones and dolomites. The results of the examination of the sections of Schlern Dolomite will be considered first, and afterwards the results obtained with rock-sections from other horizons will be stated briefly.

The Schlern Dolomite.

Area of the Schlern.

No. 7. Bedded dolomite, from the edge of the Schlern plateau.

Transverse and longitudinal sections of echinoderm-spines occur, while similarly-orientated coral-sections are recognized somewhat doubtfully, owing to loss of structure during dolomitization. Both allotriomorphic and idiomorphic crystals of dolomite are present, the idiomorphic crystals having cloudy centres. Minute iron-stained patches scattered throughout the section may represent finely-divided volcanic matter.

No. 8. About 500 feet below the edge of the Schlern plateau.

No organisms can be identified. The former presence of corals may perhaps be inferred from the meandrine arrangement of those dolomite-crystals which have regularly-arranged dark centres. Minute brown inclusions present are almost isotropic, and may be volcanic.

No. 10. About 800 feet below No. 8. (See Pl. XI, fig. 1.)

The section consists largely of allotriomorphic, dark-centred dolomite-crystals exhibiting a meandrine arrangement. Some minute opaque iron-stained fragments are to be seen.

No. 11. About 300 feet below No. 10.

No organisms have escaped the loss of structure consequent upon dolomitization. The section consists of allotriomorphic cloudy crystals of dolomite, with scattered fragments of magnetite and green augite, the latter being similar in appearance to the pyroxenic constituent of the tuffs and lavas of the Seiser Alp.

¹ Jahrb. d. k.-k. geol. Reichsanst. vol. xxv (1875) pp. 322, 323.

No. 12. About 300 feet below No. 11.

This is a submarine calcareous tuff. Numerous fairly-large and rounded fragments of a fine-grained decomposed basalt or melaphyre occur. Lath-shaped crystals of plagioclase and irregular fragments of magnetite are set in a brown structureless matrix, while steam-cavities are lined or filled with low-polarizing chlorite. Two or three basic types of basalt are present, some so dark in colour as to be almost opaque; others are much more felspathic, while some brown and almost isotropic palagonite-fragments occur. These are enclosed in a matrix consisting partly of clear calcite, partly of dolomite with regularly-arranged brown inclusions. The volcanic fragments are in contact indifferently with dolomite and with calcite. This association lends no support to the view that the volcanic fragments constitute the source of the magnesium present in the rock.

No. 13. This specimen occurs below No. 12, at the foot of the vertical cliff, and at the top of the talus-slope passed on the descent of the mountain towards Bad Ratzes.

The rock consists of a very fine-grained allotriomorphic dolomite, and contains no recognizable organisms.

β. Rolled block from the stream, just above Bad Ratzes. (See Pl. XIII, fig. 2.)

Dark-centred dolomite forms the bulk of the rock, and is arranged in a meandrine way which suggests the former presence of corals. The rock is cavernous, and the cavities have been lined by a secondary deposit of clearer dolomite deposited from solution, and showing alternate layers of clearer and more cloudy dolomite.

No. 31. Summit of the Rosszähne.

Much meandrine dark-centred dolomite is present, together with later-formed, bigger and clearer dolomite-crystals. Some small reddish fragments, possibly volcanic, are seen in the section.

No. 27. 'Cipit-dolomite' from a block on the Seiser Alp.

A fine-grained rock, consisting mainly of idiomorphic crystals with cloudy centres. Some of the rhombohedral kernels of the crystals have been removed, either by solution or by grinding when making the slice. A few reddish fragments occur, and are probably of volcanic origin.

Area of the Langkofl.

No. 95. Fallen block from the eastern flank of the mountain.

A rock which shows both concentric and radial structures in the hand-specimen, but radiating crystals only in section. No idiomorphic crystals are present.

No. 94. Material lining the eastern flank of the mountain.

A fragmental rock which, from its appearance and mode of occurrence on the flank of the mountain, is suggestive of a reef-talus. A dark calcareous cement embeds broken, idiomorphic, dark-

centred dolomite-crystals. Some of the dark centres of the crystals are composed of calcite, as they are stained by Lemberg's solution. The majority of the crystals are cavernous on a microscopic scale, and this gives the appearance of cloudiness to these individuals. One clear crystal of orthoclase, showing both cleavages, is to be noted, and exceedingly-minute, dark-reddish to opaque particles are possibly of volcanic origin.

No. 92. Above the bedded dolomite, at the head of the valley above Wolkenstein.

An allotriomorphic, slightly-cavernous dolomite. The former presence of meandrine organisms is indicated by the arrangement of the dolomite-crystals with dark centres.

Area of the Marmolata.

No. 35. Southern shore of the Fedaja See; from a height of 6500 feet.

A limestone crowded with small branching structures, which under the quarter-inch objective appear to be chambered.

A few dolomite-crystals and fragments of crystals are present. Some of these have regularly-arranged dirt-inclusions, while others consist of alternate zones of dolomite, calcite, and again dolomite. Meandrine patches of cloudy material represent decomposed organisms. Much of the calcitic groundmass is cloudy, and polarizes not in distinct crystals, but as an aggregate. Planes of movement and recrystallization are noticed in places. Where recrystallization has resulted in the formation of large twinned and cleaved crystals, these are in places found to be crowded with minute acicular bodies. At first these seem to be opaque, but when closely examined they are seen to be translucent.

One fragment, possibly volcanic, is present.

No. 34. West of No. 35 and lower down the valley, northern part of the Marmolata.

Similar generally to No. 35. The branching chambered structure is common. The section has been stained with Lemberg's solution, and some of the branching structures appear to be cavities in the slice filled with the stain, since they do not affect polarized light. The great majority, however, show polarization-colours, and, as is usual with organisms, they are stained more deeply than the background. Most of the slice consists of calcite, twinned and cleaved, and showing planes of movement and small veins of secondary calcite. A few crystals and fragments of idiomorphic dolomite occur. Some of the fragments look clastic, and extinguish not uniformly but as an aggregate, which would suggest that a secondary change in the mineral had occurred.

No. 33. A few feet above No. 34.

No dolomite is present, and planes of movement are very conspicuous. In other respects it closely resembles Nos. 34 & 35, and the branching structure is again common.

No. 32. From an immense fallen block, lower down the valley than No. 33. (See Pl. X, fig. 2.)

A large part of the slide consists of idiomorphic rhombohedral dolomite-crystals. The crystals are cloudy, with inclusions arranged parallel to their boundaries, and some of these inclusions are calcite. The rhombohedra are porous on a minute scale, and show the characteristic cleavages. The dolomite-crystals are set in a background of large platy crystals of calcite, which show lamellar twinning as well as cleavage. Signs of movement in the rock are common, and no organisms remain.

Area of the Sella.

The following specimens were collected from the slopes of the mountain, near the head of the Gröden Pass.

No. 101. Block fallen from above.

The greater part of the section is composed of cloudy allotriomorphic dolomite-crystals, often arranged in a circular manner and suggesting sections of corals. Empty spaces in the rock are lined and nearly filled with clearer and more idiomorphic crystals of the same mineral.

No. 100. Near the summit of the Gröden Pass. (Pl. X, fig. 1.)

Large areas of calcite include partly-disintegrated organisms resembling calcareous algæ (*Sphærocodium*?) which are only recognized by a 'dirt-line' marking the external boundary of the organism. A few dolomite-crystals occur within the calcite-areas, and are idiomorphic. Considerable areas of dolomite consist, however, of allotriomorphic crystals.

No. 99. Fifty feet below No. 100.

Very similar to No. 100. Large areas of calcite include imperfectly-preserved organisms, as well as a few rhombohedra of dolomite. A fair quantity of allotriomorphic dolomite-crystals is present, and includes irregular smaller patches of calcite, while exceedingly-narrow strings and bands of calcite traverse the dolomite-areas of the slide.

No. 98. St. Cassian Limestone, immediately below No. 99.

The rock consists mainly of calcite. The dolomite-crystals are well seen only under the quarter-inch objective, and are for the most part restricted to the matrix of one portion of the section in which unaltered sections of calcite-shells occur. The majority of the dolomite-rhomboheda have outer zones of chalybite, while a few have a middle layer of chalybite, the inner and outer portions consisting of dolomite alone.

The St. Cassian District.

Lavarella.—Collected from the cliff-face, in descending order.

No. 82. A cloudy, cavernous, fine-grained dolomite. The cavities in the rock are partly or wholly filled with large idiomorphic

dolomite-crystals showing dirt-zones. The remaining spaces are sometimes filled with a finer-grained mixture of calcite and small dolomite-rhombohedra, some of which show external zones of calcite.

No. 81. A very similar rock to No. 82. Meandrine organisms are indicated by the arrangement of dark-centred dolomite-crystals. Cavities in the rock have been subsequently filled with clear, coarsely-crystalline dolomite.

St. Cassian Limestones from St. Cassian.

No. 77. Above St. Cassian and below Lavarella. (Pl. XI, fig. 2.)

A well-preserved oolitic limestone. The oolitic grains are well formed, they show both concentric and radiating structure, and their centres in some cases consist of shell-fragments. For the most part, they are not in contact one with the other, but are separated by a cement of calcite in which are embedded numerous very minute rhombohedra of dolomite and chalybite (about $\frac{1}{2500}$ inch in length). The dolomite and chalybite are practically restricted to the matrix of the rock, while later-formed cracks have been filled exclusively with calcite.

No. 76. A few feet below No. 77.

Irregular fragments of partly-disintegrated organisms¹ (including *Sphærocodium Bornemannii* and other calcareous algæ) and pieces of limestone are embedded in a matrix of crystalline calcite. Minute crystals of dolomite occur scattered through the matrix, and some of them have outer zones of calcite. Cubes of pyrite, marginally altered to limonite, are abundant, and cracks traversing the slide are filled exclusively with calcite.

Sett Sass. (Schlern Dolomite.)

No. 112. Block fallen from the summit. (See Pl. XIV, fig. 1.)

The section consists of rounded bodies united by a granular dolomitic cement. The rounded bodies are most probably sections of organisms, possibly calcareous algæ (*Gyroporella* ?), which have been completely dolomitized. Whereas the dolomite in the matrix is granular, that within the organisms consists of distinct rhombohedra with cloudy centres. It is noteworthy that dolomite formed by the alteration of a matrix of calcite-crystals is usually clear, while that formed by the alteration of organisms is almost invariably cloudy. The boundaries of the organisms are defined in this section by dolomite-crystals with very dark centres. Empty spaces occur within some of the organisms, and these cavities are lined with clearer secondary dolomite.

No. 107. Immediately below the junction with the Raibl Beds, northern end of Sett Sass.

The section consists mainly of cloudy dolomite, in which occur

¹ Kindly determined for me by Dr. G. J. Hinde, F.R.S.

irregular spaces and cracks filled with clearer secondary dolomite. Scattered through the rock are some crystals of pyrite, altered to oxide of iron.

No. 108. Base of Sett Sass, facing the Richthofen Reef.

Part of the slide consists of allotriomorphic, part of idiomorphic crystals of dolomite, with regularly-arranged dark centres, set in a matrix of a muddy-looking material. Cracks have been filled with clear allotriomorphic secondary crystals, while a little pyrite with an aureole of iron-oxide is also noticeable.

The Richthofen Reef.

No. 110. From the outer face of the Richthofen Reef.

The rock has a cloudy granular matrix, in which are seen large cloudy rhombohedra of dolomite with light borders. Irregular cavities are lined with large, clear, secondary dolomite-crystals.

St. Cassian Limestone from Sett Sass.

No. 109. St. Cassian Limestone with corals (?), between Sett Sass and the Richthofen Reef. (Sec Pl. XII, fig. 2 & Pl. XIII, fig. 1.)

The slide consists mainly of a transverse section of a coral; and a longitudinal section of one of the calcareous algæ, probably *Sphærocodium*, is also present. The coral is embedded in a matrix of calcareous mud, part of which still remains, but most of it has clarified by recrystallization as a clear mosaic of calcite. This muddy matrix has served to prevent the degradation of the coral, the structure of which, for the most part, is wonderfully preserved. The original aragonite-fibres of the stereoplasm, the brown colour of the septa, the centres of calcification, and even the secondary aragonite, subsequently deposited in optical continuity with the coral-fibres, remain unaltered. The appearance of the coral in section is such, that it is difficult to believe that one is dealing, not with a coral from an unaltered modern reef, but with one of Triassic age.

The Cortina District.

Col Crepa.

No. 49. Top of the western part of Col Crepa.

While the section shows a certain amount of a fine, granular, dark matrix, most of the slide is comprised of clear allotriomorphic dolomite-crystals, in which no organisms can be detected.

No. 51. Slickensided and brecciated rock from a fault-plane, few yards below No. 49.

Large and small, composite, angular fragments of clear dolomite are set in a fine dolomitic matrix. The larger fragments consist of several allotriomorphic crystals, and some of these show evidence of lamellar twinning in polarized light, a very unusual occurrence in dolomite.

No. 62. Top of the north side of Col Crepa.

A clear allotriomorphic dolomite, showing no signs of organic structure, except in some parts of the section where cloudy crystals are arranged in a meandrine fashion, suggesting the former presence of corals.

No. 64. A rock very similar to No. 62, a few feet below it.

Giau Pass.

No. 37. From the Giau Pass, about 6 miles south-west of Cortina. Not in place.

The slide shows a section of a coral preserved mainly in calcite. The structure of the coral is nearly obliterated; the external wall can, however, be traced, and the septa are defined by linear bands of dolomite- and calcite-crystals. Scattered through the coral occur a large number of minute, perfectly-idiomorphic crystals of quartz (see Pl. XIV, fig. 2). They are doubly terminated, and can be recognized by their shape, their grey polarization-colours, and their positive sign, when examined with a quartz-wedge. Unlike the quartz-crystals found in the Carboniferous Limestone of Derbyshire and other areas, they are not cloudy with inclusions, but perfectly clear and translucent. The longer diameters measure from $\frac{1}{300}$ to $\frac{1}{1500}$ inch. These crystals probably represent the colloid silica of the skeletons of the siliceous organisms originally present in the rock, which has been recrystallized.

Many of the dolomite-rhomboheda show minute bands of calcite extending through them, and coinciding in general with the directions of the cleavage-lines but extending slightly on either side. They possibly represent spaces formed by solution along cleavages, and subsequently filled with calcite. Staining with Lemberg's solution, and examination with the quarter-inch objective, causes these calcite-bands to be visible as fine pink lines.

The Hexenfels.

No. 56. From the base of the Hexenfels, near Falzarego Pass.

A clear dolomite, partly granular but mainly allotriomorphic. No organisms are visible, and specks of oxide of iron occur sparingly.

Travernanzez Valley.

No. 59. Near the junction with the Raibl Beds, just below the Col da Bec.

A clear coarse-grained dolomite, devoid of organisms.

Sorapis.

No. 55. Schlern Dolomite from the flanks of Sorapis, 1 mile north of San Vito del Cadore.

A fairly coarse-grained dolomite, devoid of organisms. Specks of a compound of iron are scattered through the section.

Monte Cristallo.

No. 46. South side of Monte Cristallo, immediately below the Raibl Beds.

The crystals of dolomite have dark centres. No organisms are recognizable; but darker areas possibly represent shell-sections.

Tre Croci.

No. 40. From an exposure of dolomite, east of Tre Croci.

Sections of ill-preserved organisms may represent calcareous algæ. The matrix of the rock is cloudy and granular.

No. 41. From 50 feet below No. 40.

A coarsely-crystalline, rather cloudy dolomite, containing no traces of organisms.

The Dürrenstein Area.

No. 66. From the summit of the Dürrenstein (9300 feet).

An almost clear, cavernous, coarsely-crystalline dolomite, devoid of organisms.

No. 68. About 500 feet above the Dürrenstein Hotel.

A fine-grained, rather cloudy dolomite, in which darker, more or less circular areas may represent the remains of calcareous algæ.

The Drei Zinnen Area.

No. 71 A. Block in a stream at the head of the Rienz Valley.

Broad areas of clear, coarsely-crystalline dolomite occur, with dark areas of smaller cloudy crystals arranged in a more or less meandrine way, and suggesting the former presence of corals.

No. 70. From the head of the Rienz Valley, the northern base of the Drei Zinnen.

Much of the section consists of cloudy dolomite. Cavities are lined or filled with more coarsely-crystalline, clearer dolomite.

Sections from calcareous rocks both above and below the horizon of the Schlern Dolomite were made, and descriptions of some of the more important rocks are here appended.

Below the Schlern Dolomite.

Wengen Limestone.

Seiser Alp.

No. 22. From the ravine just below the Selaus Alp Hut, Frombach.

A rock consisting mainly of small patches of granular calcite, fragments of shells, and of very-finely divided volcanic fragments, grey-brown in colour, and polarizing as an aggregate. Some elongated opaque particles scattered through the section are seen, on examination by reflected light, to consist of pyrite.

Buchenstein Limestone.

No. 18. A hard compact rock, interbedded with a siliceous nodular limestone, above Bad Ratzes.

The groundmass of the rock-section consists of structureless calcite, in which various organisms occur. These appear to be dolomitized, since they are not stained with Lemberg's solution. The most abundant form is long and curved, and probably represents cross-sections of thin-walled shells. Some of the bodies are somewhat oval, and may represent tangential sections of shells. Cross-sections of minute tubules are also present, and a section of a foraminifer is to be seen as well. One crystal of biotite was recognized in the slide.

Analysis shows that only 3·4 per cent. of magnesium-carbonate is present in the portion analysed; but examination of the rock-section shows that the amount present in places must be considerably in excess of the figure obtained by analysis.

No. 88. Nodular limestone from the Gader Gorge, north of St. Leonhard. (See Pl. XII, fig. 1.)

The rock has a granular matrix of calcite, in which various organisms preserved in calcite are embedded. These include a rotaline foraminifer, shell-sections, calcareous algæ, and other meandrine bodies, the precise nature of which cannot be determined. Along cracks the limestone has been altered by infiltrated water bearing salts of iron and magnesium; and as a consequence, pyrite, chalybite, and dolomite have been deposited in the immediate neighbourhood of the fractures.

The dolomite-crystals are all zoned, and most of them consist of alternate layers of dolomite and chalybite, although staining shows that some of the crystals consist of alternate zones of dolomite and calcite.

Mendola Dolomite.

No. 19. Above Bad Ratzes, and below No. 18.

A compact dolomite, consisting entirely of allotriomorphic crystals, showing no trace of organic structure.

Lower Muschelkalk.

No. 86. Gader Gorge, north of St. Leonhard.

The groundmass consists of calcite-crystals, some of which are twinned. Sections of shells are numerous; many angular quartz-grains occur; while some flakes of muscovite and one or two crystals of decomposed pyrite are also to be seen.

Above the Schlern Dolomite.

Dachstein Dolomite.

No. 1. From the summit of the Schlern (8400 feet).

A dolomite composed of allotriomorphic crystals. The only

traces of organisms are dark meandrine areas scattered through the section.

No. 42. From the fault-valley of Monte Cristallo, just below Tre Croci.

A compact, rather fine-grained dolomite, formerly crowded with organisms, of which only the 'ghosts' or dark outer borders can now be traced. Shells and meandrine forms constitute the most abundant organisms.

Raibl Deposits.

No. 4. Red dolomite from the Schlern plateau, below Burgstall.

A somewhat ferruginous, coarse-grained dolomite. Most of the crystals have dark reddish centres, and some of the iron is concentrated along definite lines or cracks. No organisms are recognizable.

No. 73. Below the military post, on the Dürrenstein massif.

The section consists of a transverse section of a coral, preserved in calcite and embedded in a fine-grained homogeneous matrix of dolomite.

No. 58. Near the summit of the Col du Bec, between Monte Tofana and Lagazuoi; near the base of the Raibl Beds.

A fragmental rock, made up of rounded pieces of somewhat iron-stained dolomite, together with some rounded basalt-fragments, all set in a matrix of dolomite. Some crystals of clear felspar are scattered through the rock. They show extinction-angles up to 20° from prism-edges, and sometimes include cubes of rock-salt.

Irregular, clear, secondary quartz fills cavities in the rock. The quartz is traversed generally by almost rectangular cracks, and has inclusions of gas-bubbles, and also of clear idiomorphic rhombohedra of dolomite(?).

No. 106. Just above the Schlern Dolomite, northern end of Sett Sass.

A fragmental rock, composed mainly of small pieces of a spherulitic rhyolite showing an irregular radial structure. Secondary quartz is present, and contains inclusions of rock-salt, gas-bubbles, and dolomite(?) -rhombohedra. Felspars are also present, one of which shows simple twinning, and many contain included rhombohedra of dolomite(?). A fragment of chlorite, too, is present, and the rock has a small quantity of a calcareous or dolomitic cement.

V. ORGANISMS RECOGNIZED IN THE LIMESTONES AND DOLOMITES.

Many observers have studied the organic remains from the various deposits of the Alpine Trias. Naturally, the richly-fossiliferous St. Cassian Limestone has been most narrowly examined, and the varying lithological and palæontological characters of the Raibl deposits have also been closely studied. The Dachstein, Schlern, and Mendola Dolomites have received less attention from palæontologists, because fossils are far less commonly found, except in those

areas where the rocks have not been dolomitized. My collection was made, primarily to illustrate the chemical and mineralogical characters of the rocks from various horizons; so that most of the fossils recognized were those met with in the examination of thin sections from the limestones and dolomites.

The Schlern Dolomite.

Very few of the hand-specimens of Schlern Dolomite contain recognizable organisms. Corals are occasionally found in the mass of the rock from various horizons. They are almost always found as casts in dolomite, and only in a few places occur in abundance. In thin sections the calcareous algæ are the commonest fossils, especially various species of *Gyroporella* (*Diplopora*). Echinoderm-spines and lamellibranch-shells are not uncommon here and there; while foraminifera are occasionally found.

Sections of 38 specimens of Schlern Dolomite were examined under the microscope, and only one coral was recognized with certainty; while eleven other sections showed meandrine areas of cloudy dolomite, which might represent corals, but the loss of structure during dolomitization had been so great that not much confidence could be placed in their identification. Calcareous algæ were recognized in three sections, and organisms doubtfully referable to them occurred in five other slides. Sections of shells (probably lamellibranchs) and echinoderm-spines were each recognized in single slides. No less than seventeen sections of the dolomites, representing about 45 per cent. of the sections examined, failed to yield any traces of organic structure.

Deposits below the Schlern Dolomite.

St. Cassian Limestone.

Four sections were examined, and fossils were found to be more abundant and better preserved than in the dolomitized strata. In one section, a coral was seen, the structure of which was perfectly preserved in its original aragonite. Two sections contained numerous examples of more than one genus of calcareous algæ. Three of the sections showed fragments of shells, probably lamellibranchs; while one section contained the chambers of one of the foraminifera and also a tubular organism, probably a polyzoon.

Wengen Beds.

But one section was examined, and the only recognizable organisms were lamellibranchs.

Buchenstein Limestone.

Two sections were cut: algæ occurred in one, lamellibranchs in the other, and foraminifera in both.

Mendola Dolomite.

Examination of a single specimen failed to show any trace of organisms.

Lower Muschelkalk.

Lamellibranchs were noticed in the only section examined.

Deposits above the Schlern Dolomite.

Dachstein Dolomite.

Two sections were examined, and it was found that one slide contained remains of what were probably lamellibranch-shells, while both sections showed meandrine structures which were possibly the remains of corals.

Raibl Beds.

Four sections were cut; of these, one showed the transverse section of a compound coral, while the other three were apparently devoid of organisms.

VI. RELATIONS BETWEEN THE FOSSILS AND THE ORIGIN
OF THE ROCKS CONTAINING THEM.

Before attempting to interpret the results arising from the examination of the fossil contents of these rocks, especially of the Schlern Dolomite, it will be convenient to consider briefly our present knowledge as to the organisms composing coral-limestones, and the changes that they undergo.

In the first place, it has been shown that corals play a much less important part in building up coral-reefs than was formerly supposed.¹ Calcareous algæ are often more abundant than the corals; foraminifera and echinodermata often bulk largely; and polyzoa, lamellibranchiata, and other organisms are occasionally present in fair abundance.

The sequence of mineralogical and structural changes which coral-limestones undergo—a subject originally studied by Dr. Sorby—has in recent years been rather closely investigated. I have already dealt with some of the more striking changes occurring in upraised coral-islands²; while Dr. C. G. Cullis³ has examined in greater detail the mineralogical constitution and structural changes in thin sections of the rocks from the Funafuti boring.

It is found that organisms, the skeletons of which are composed of aragonite, are abundant in the most recent limestones, but gradually become recrystallized as calcite; and this change is accompanied by a loss of structure in the organism. For this reason, all the reef-forming corals, the gasteropoda, and some of the calcareous algæ,

¹ R. L. Sherlock, *Bull. Mus. Comp. Zool.* vol. xxxviii (1903) p. 349; E. W. Skeats, *ibid.* vol. xlii (1903) p. 53; & G. J. Hinde, 'Funafuti Report' *Roy. Soc.* (1904) p. 332.

² *Bull. Mus. Comp. Zool.* vol. xlii (1903) p. 53.

³ 'Funafuti Report' *Roy. Soc.* (1904) p. 392.

such as *Halimeda*, are much less readily recognized in thin sections of limestones in which this change has taken place. When, as not infrequently happens, dolomitization of the limestones occurs, not only are all traces of the organisms previously mentioned generally obliterated, but the more stable organisms with calcite-skeletons, like the echinodermata, the foraminifera, and most of the calcareous algæ, begin to lose structure, owing to the invasion of crystals of dolomite. In general, the more complete the dolomitization, the more complete is the destruction of the organisms composing the rock, until a perfectly-structureless, homogeneous dolomite may be formed. In recent coral-limestones these changes can be traced gradually in a succession of sections; but the early stages in the life-history of the Triassic dolomites of Southern Tyrol are closed. All the rocks are altered. Where they are not dolomitized, they have been recrystallized as the result of earth-movements; and where the rocks are undisturbed, dolomitization has been so complete that many of the rocks are dolomites of theoretical composition. In recent coral-limestones the rocks are often quite devoid of organisms; and it is therefore not surprising to find in rocks of Triassic age, which are often more completely dolomitized than any recent limestone, that organisms are always scarce, and in 45 per cent. of the sections are apparently unrepresented.

It will be seen that, with regard to the origin of the Schlern Dolomite, the evidence afforded by a consideration of its organic contents alone is inconclusive. The question is not whether the Schlern Dolomite was originally a coral-limestone entirely composed of corals, but whether or no it was a coral-limestone of a more common type (of which Funafuti and Christmas Island yield examples), wherein calcareous algæ and foraminifera bulk largely, while corals occupy an important but relatively-subordinate position. It is not possible to say definitely from this evidence that it was originally a coral-limestone; on the other hand, it seems to be equally unsafe to conclude with some geologists that the comparative absence of corals in the present condition of the rock proves that they were never present in the original limestone. The solution of the question as to the origin of the Schlern Dolomite should be sought on other than palæontological evidence, which, so far as it goes, does not preclude the possibility of the deposit having originated as a coral-limestone.

VII. MINERALOGICAL STRUCTURES AND CHEMICAL CHANGES IN THE LIMESTONES AND DOLOMITES.

Mineralogical Structures.

The examination of numerous thin sections from recent coral-limestones¹ has served to show that, in general, three types can

¹ E. W. Skeats, *Bull. Mus. Comp. Zool.* vol. xlii (1903) pp. 105 *et seqq.*; & C. G. Cullis, 'Funafuti Report' *Roy. Soc.* (1904) p. 404.

be recognized, each being characterized by some mineralogical peculiarity.

1. Many of the more recent limestones, while consisting largely of calcite, contain also organisms, the skeletons of which consist of aragonite; and not infrequently secondary aragonite has been deposited in crystallographic continuity with the aragonite of the organism.
2. Gradual alteration and recrystallization of the first type of limestone leads to the production of a rock in which organic remains and matrix alike consist entirely of calcite.
3. The replacement of calcium-carbonate by magnesium-carbonate in limestones either of Type 1 or Type 2 leads to the formation of a third type, characterized by the presence of crystals of dolomite; in some cases, the replacement proceeds so far that the limestone is entirely converted into dolomite.

(1) Examination of many sections of rocks belonging to the horizon of the Schlern Dolomite shows that the first type of limestone, characterized by the presence of aragonite, is now wanting. The St. Cassian Limestone of Sett Sass, however, provides a very interesting example of the aragonitic type of limestone. A section of a coral, when examined under a high power, shows a remarkable preservation of the original aragonite-fibres of the coral and of the secondary aragonite formed in crystallographic continuity with them. With this single exception, none of the rocks examined contained any crystals of aragonite.

(2) The Marmolata massif affords good examples of limestones consisting entirely of the mineral calcite. The rocks have been much recrystallized as a result of earth-movements, so that lamellar twinning is very common in the calcite-crystals, which are generally allotriomorphic. Many of the St. Cassian Limestones also consist entirely of calcite and calcite-organisms.

(3) Among the rocks in which the mineral dolomite occurs we have:—

(a) Dolomitic limestones, and (β) Dolomites proper.

In rocks belonging to the group *a* magnesium-carbonate generally forms from 10 to 30 per cent. of the mass, so that a larger or smaller amount of calcite is always present. In these limestones, the dolomite-crystals are generally markedly idiomorphic. One of the Marmolata rocks (No. 32) shows fine idiomorphic dolomite-crystals, surrounded by a matrix of calcite (Pl. X, fig. 2). The same feature is seen on a minute scale in No. 77, one of the St. Cassian oolitic limestones, in which tiny rhombohedra of dolomite occur, and are restricted to the matrix of the rock (Pl. XI, fig. 2). No. 34, one of the Marmolata rocks, is a limestone containing broken fragments of dolomite-crystals which have no definite extinction, and are possibly of detrital origin. No. 37, a dolomitic limestone from the Giau Pass, contains a longitudinal section of a coral with dolomite-crystals deposited in a

definite arrangement within the coral. What is still more interesting, is the occurrence within the mass of the coral of extremely minute, perfectly clear, doubly-terminated quartz-crystals, which constitute about 1 per cent. of the rock (Pl. XIV, fig. 2).

When the dolomitization of a limestone is nearly complete, it is noticed that the dolomite-crystals mutually interfere, so that the crystals are mainly allotriomorphic. Among the Schlern rocks, No. 7 affords a good example of a rock approximating to a dolomite of theoretical composition, and containing both idiomorphic and allotriomorphic crystals.

With the production of a pure dolomite, the rock usually becomes quite structureless and the crystals almost entirely allotriomorphic. No. 56, from the Hexenfels, is a good example of this type of dolomite.

Dolomite-crystals are sometimes quite clear and transparent. More generally, however, they are seen to contain cloudy matter; and this is generally orientated within the crystal, sometimes constituting a dark centre, sometimes being arranged in one or more zones parallel to the rhombohedral outline of the crystal. These cloudy centres and zones may originate in several different ways.

Prof. Watts has shown, in the case of the dolomites of the Carboniferous Limestone,¹ that this cloudy material is insoluble matter caught up and regularly arranged during the growth of the crystals.

My own observations indicate four additional causes:—

1. In some dolomites, staining with Lemberg's solution has shown that the cloudy matter is calcite.
2. In other dolomites, especially those of theoretical composition, there is little doubt that the cloudy matter consists of finely-divided dolomite, which does not stain with Lemberg's solution.
3. In some of the St. Cassian limestones the dolomites are zoned with cloudy chalybite, more or less altered to iron-oxide.
4. Occasionally, these cloudy areas, when examined under a high power, have been seen to be due to numerous minute cavities in the crystals. There is no direct evidence to show whether these cavities are original, or due to subsequent solution of certain parts which, owing to their physical state or chemical composition, were more susceptible to the solvent action of sea-water. Their irregular distribution in the parts of the crystals in which they occur is against the latter view of their origin.

Quite apart from the zoning in dolomite-crystals produced by this

¹ 'Geology of the South-Wales Coalfield, pt. ii: The Country around Abergavenny' *Mem. Geol. Surv.* (1900) pp. 34-36.

cloudy material, another type of zoning is occasionally seen¹ both in dolomites from Mango (Fiji), and also on a smaller scale in certain of the Tyrol dolomites. Before a rock is stained, it may appear to contain perfectly-homogeneous, clear, idiomorphic crystals of dolomite. Staining with Lemberg's solution shows, however, that the crystal is composite in character, and is composed of alternate layers of calcite and dolomite (less frequently chalybite forms one of the mineral-layers). The layers are in optical and crystallographic continuity, and the whole appears to form a single crystal.

Chemical Changes in the Limestones and Dolomites.

Compared with recent coral-limestones, these Triassic rocks present one or two interesting, if minor, points of difference :—

1. Only very minute traces of calcium-phosphate are found. In coral-limestones .2 per cent. is a fairly-common amount, and occasionally beds of phosphate are met with, as at Christmas Island. The circumstance that the earliest bird so far discovered is of Kimeridge age, is sufficient to account for the absence of beds of limestone altered to phosphate in the area of the Dolomites.
2. Recent coral-limestones show no trace of silicification. This is remarkable, in view of the fact that among the living organisms present in coral-reefs, siliceous forms sometimes constitute at least 1 per cent. of the whole. The colloid silica of which their skeletons are composed must be peculiarly soluble under the conditions existing in a coral-reef, for no trace of siliceous organisms has ever been found in a recent coral-rock. The same is true of the Tyrol limestones and dolomites, with the significant exception of the quartz-crystals occurring in the coral-section of No. 37. This quartz may represent the colloid silica of siliceous organisms, redeposited in the crystalline state.
3. In the Tyrol dolomites dolomitization is often more complete than in the case of any recent coral-limestone. From Christmas Island² and from the Funafuti boring, two dolomites which were analysed gave just over 43 per cent. of magnesium-carbonate; but, in general, a condition of stability ensued when the percentage of magnesium-carbonate amounted to about 40. Many of the Tyrol rocks are pure dolomites, containing 45.65 per cent. of magnesium-carbonate, but no rock has been found to exceed the latter amount.

¹ E. W. Skeats, *Bull. Mus. Comp. Zool.* vol. xlii (1903) pp. 117-18.

² *Ibid.* pp. 96, 102.

Formation of the Dolomites.

The most important chemical problems in Southern Tyrol are, perhaps, the following:—

1. The mode of origin of those wide-stretching and thick masses of dolomite, of which the Schlern Dolomite is the most conspicuous example.
2. A second problem is encountered in the attempt to explain the circumstances under which some areas, such as the Marmolata massif, escaped dolomitization, while most of the limestones of the same age are almost completely dolomitized.
3. The association of some of the dolomites of the Raibl Beds with gypsum-deposits suggests a different origin for these rocks.
4. The local dolomitization of some of the St. Cassian limestones along cracks in the rock would seem to require a special explanation.

The early views of L. von Buch on the origin of dolomite were formed as a result of the examination of the dolomites of the Tyrol, and they involved the ascent of heated magnesium-vapour from the outpourings of the Triassic volcanic rocks, which are found in association with the dolomites. Modern chemists would not agree with the chemical reactions involved in such a process, and, apart from this, the distribution of the dolomites has no causal relation to the distribution of the volcanic rocks.

The analysis by Silliman, of a dolomitized limestone from the raised coral-island of Makatea, led Dana to propound the view that sea-water constituted the source of the magnesium, and that it was probably introduced from the concentrated waters of the lagoon. This view forms the basis of the modern explanations of the formation of such dolomites.

In some of the Tyrol limestones examined by me, magnesium-carbonate is present in the rocks, in varying amounts up to 6 or 7 per cent., without leading to the formation of visible dolomite-crystals. In a paper published in 1903,¹ I quoted analyses from rocks at Christmas Island and elsewhere, in which limestones containing over 11 per cent. of magnesium-carbonate were similarly devoid of visible dolomite. Following Dana, I believe that the magnesium is introduced from the sea-water, and is absorbed by calcite up to 10 to 15 per cent. of its mass without any visible change of form, but above that amount the stable compound dolomite crystallizes out.² A similar result was obtained on analysing specimens from the upper part of the Funafuti borings.³

¹ Bull. Mus. Comp. Zool. vol. xlii (1903) p. 102.

² Mr. L. J. Spencer has described somewhat analogous behaviour in the mutual relations of copper and silver-iodides, Min. Mag. vol. xiii (1901) pp. 43-44.

³ J. W. Judd, 'Funafuti Report' Roy. Soc. (1904) pp. 373 *et seqq.*

In this case as much as 16 per cent. of magnesium-carbonate is present in the rock, and no dolomite-crystals can be traced. Prof. Judd gives a different explanation of the presence of so much magnesium-carbonate in the rock—an explanation depending on the relative solubilities of the two carbonates in sea-water. He quotes Gustav Bischof's and Högbom's experiments in support of the view that under atmospheric pressure calcium-carbonate is much more soluble than magnesium-carbonate. The skeletons of calcareous organisms contain in the living state a small amount of magnesium-carbonate, sometimes reaching 1 per cent. in amount. If, then, the rock composed of such organisms is attacked by water bearing carbon-dioxide in solution, calcium-carbonate will be dissolved more quickly than magnesium-carbonate, and the percentage of magnesium-carbonate in the remainder will as a consequence be raised, and may eventually reach 16 per cent. In this way, Prof. Judd explains the composition of the Funafuti rocks between the limits of 20 to 50 feet below the surface of the water.

This process of differential solution is one which no doubt coral-limestones undergo to a greater or smaller extent, and it is probably the correct explanation of the origin of the all but structureless limestones containing magnesium-carbonate in insufficient amount for the production of dolomite-crystals. Very extensive solution and removal of calcium-carbonate is needed, however, before the percentage of magnesium-carbonate in the residual rock is appreciably raised. Assuming the original limestone to contain 1 per cent. of magnesium-carbonate, an amount which is probably near the superior limit for the fresh organisms composing the rock, and further, assuming that only the calcium-carbonate is dissolved by carbonated water, 80 per cent. of the original rock must be removed by solution before the magnesium-carbonate in the remainder reaches 5 per cent., 90 per cent. must be dissolved before the magnesium-carbonate reaches 10 per cent., and over 93 per cent. before the magnesium-carbonate reaches 16 per cent. So extensive a removal of the original substance of the rock would largely destroy the structure of the organisms that it contained. In the case of the limestones from Christmas Island, Niue, and elsewhere, examined by me, in which magnesium-carbonate was present in the rock in amounts up to 11 per cent., the structure of the contained organisms was in general wonderfully preserved; and not only was there no evidence of solution in the rock, but on the contrary secondary calcite and secondary aragonite were deposited upon the organisms to a considerable extent. I was, in consequence, forced to the conclusion that in these limestones the magnesium-carbonate was introduced into the rock from the sea-water, resulting in the partial replacement of calcium- by magnesium-carbonate.

Prof. Judd suggests that the conversion of a magnesian limestone containing about 15 per cent. of magnesium-carbonate, into a rock containing 40 per cent. or more of that carbonate, may be due

to the operation of the forces of segregation, forces which are concerned in the formation of concretionary structures like the septaria in the London Clay and the 'doggers' in the Oolites.

Prof. Garwood,¹ in 1891, published the results of his investigations 'On the Origin & Mode of Formation of the Concretions in the Magnesian Limestones of Durham.' He showed that certain bands in the rock have practically the composition of dolomite, while in other layers, by subsequent solution, segregation of the calcium-carbonate has been set up, and concretionary structures are formed which consist mainly of calcium-carbonate. Prof. Garwood's results are interesting in this connection, because the effect of the segregative forces in the formation of the concretions is not the enrichment by magnesium-carbonate of a slightly-magnesian limestone, but the dedolomitization of a rock which formerly had almost the composition of a dolomite. Under other conditions than those obtaining in the Magnesian Limestone of Durham, it is quite possible that the calcium-carbonate may be removed altogether by solution, and that segregation of the remaining mass will give rise locally to the formation of dolomite. In some localities where dolomitic limestones are found, their occurrence is often of a patchy character, the dolomite disappearing horizontally and vertically in a short distance. It may very well be that some of these occurrences of dolomite could be best explained by a process of segregation, especially as in general the effects of the segregative forces (as exemplified by septaria and 'doggers') are of a quite local character.

In the Dolomites of the Tyrol, however, the dolomitization is not local, but on a very extensive scale. The Schlern Dolomite extends over many square miles, and in places exceeds 3000 feet in thickness, so that no local cause can explain its production over such large areas. The rock was without doubt originally a limestone, composed entirely of organisms, and was subsequently converted into dolomite. There can be no question that the magnesium was obtained from the sea-water. Chief interest is centred in the conditions under which this partial replacement of calcium-carbonate by magnesium-carbonate took place.

The Tyrol rocks are so completely dolomitized that they do not, of themselves, afford much indication of the conditions under which they were formed. Examination of specimens from upraised coral-islands, such as Christmas Island, the Fijis, etc., led me to the conclusion that the formation of dolomite can proceed in quite shallow waters.² In Christmas Island a band of dolomite occurs immediately below beds of calcium-phosphate, which cap the highest points of the island. These were low islets in the ancient lagoon, on which bird-droppings fell. The occurrence of dolomite immediately beneath these phosphate-beds points to its formation in superficial waters. Many of the Fiji islands are also dolomitized

¹ Geol. Mag. 1891, pp. 433-40.

² Bull. Mus. Comp. Zool. vol. xlii (1903) p. 125.

at their summits; some of their fringing-reefs, too, are dolomitized, while the raised fringing-reefs along the coasts of the Red Sea are also occasionally dolomitized. Dana was of opinion that magnesium was introduced into the rock from the waters of the lagoon during concentration. Many lagoons, however, are quite open to the sea, and concentration of the water is not possible in most of them; while, on the other hand, the outer parts of fringing-reefs facing the open ocean are sometimes dolomitized.

My view, then, is that the Schlern Dolomite originated first as a limestone, composed of organisms, in a slowly-subsiding area. Dolomitization of the limestone in superficial waters kept pace with the slow subsidence, so that the whole thickness of 3000 feet or more of rock was continuously and uninterruptedly converted into dolomite during the Triassic Period. Some areas in the Tyrol are only partly dolomitized, while others, like the Marmolata, are for the most part undolomitized limestones.

One important factor in the dolomitization of a limestone is the time during which the limestone is submitted to the conditions producing dolomitization. If it be true that dolomitization of submerged limestones takes place in shallow water, then the extent to which a limestone can be dolomitized will depend, other things being equal, upon the length of time during which the limestone remains in shallow water, that is, upon the rate of subsidence or elevation of the mass. Complete dolomitization will only be effected under stationary conditions in shallow water, or as a result of a very slow subsidence or elevation; while, conversely, a limestone which is raised or lowered comparatively rapidly, may undergo no dolomitization.

The problem is certainly complicated by other considerations. Among these, an important question is the extent to which the rock is permeable to sea-water. The growing part of the reef just below the surface is generally very porous, and admits of the free penetration of sea-water, and sometimes the older part of the limestone is also sufficiently porous to admit of the introduction of water throughout its mass. Perhaps more generally, however, that part of the structure upon which the living reef rests loses its porosity, and is converted into a dense limestone by the filling-up of the cavities by detrital material, or the fine mud produced by the partial solution of the loosely-consolidated upper part of the rock. Since the conversion of such a limestone into dolomite is effected by an interchange between magnesian salts in sea-water and the calcium-carbonate of the rock, it follows that the production of a compact rock is one of the factors which shields a limestone from dolomitization. Prof. Branner has adopted this view, in order to explain the local character of the dolomitization of the Brazilian reefs.¹

I think that the varying power of sea-water to dissolve limestones is another factor in the question of the formation of dolomite. This power depends mainly upon the amount of carbon-

¹ Bull. Mus. Comp. Zool. vol. xlii (1904) p. 265.

dioxide dissolved in the water, or liberated on the decay of the organisms composing the rock. Probably the interchange of magnesian for calcium-salts is most readily effected at the moment of solution of the calcium-carbonate of the rock. If this be so, the carbon-dioxide slowly liberated on the decay of plants and animals would help to determine the introduction of magnesium. We should, in that case, expect that unstable forms like the corals would be more rapidly affected than organisms the skeletons of which are built of calcite; and among the calcite-forms we should expect those to be most dolomitized which contain the largest quantity of organic matter in their tissues. Examination of thin sections of coral-limestones affords evidence in favour of this view, since aragonite-forms, like the corals, and *Halimeda* among the calcareous algæ, contain much organic matter in their tissues, and are the first organisms to suffer dolomitization and loss of structure. Among the calcite-organisms, too, we find that forms such as foraminifera and echinoderm-spines, containing little organic matter in their skeletons, resist disintegration and dolomitization longer than *Lithothamnion* and *Lithophyllum* among the calcareous algæ.

So far, the evidence given of the distribution of dolomite in limestones of organic origin points to the change having taken place in shallow water, while contributing causes are porosity of the limestone, slow upheaval or subsidence, and the presence of carbon-dioxide in the water, to serve as a solvent for part of the limestone. What, however, are the precise conditions governing the change from limestone to dolomite in the case of great rock-masses, and the exact chemical reactions which take place, it is very difficult to say. Chemists are not all in agreement as to the relative solubilities of the two carbonates in carbonated water, and it may be that the reactions which take place in pure water are modified in sea-water. There is, however, considerable evidence to show that under atmospheric pressure calcium-carbonate is more soluble than magnesium-carbonate. Similarly, there is no doubt that, when dolomite is subjected to fresh water containing carbon-dioxide at a pressure of about 5 atmospheres, the magnesium-carbonate is dissolved and the calcium-carbonate remains almost unaffected. This, indeed, was the process formerly employed in the production of Epsom salts from magnesian limestone. It would appear to follow, then, that at some pressure between 1 and 5 atmospheres carbonated water will dissolve the two carbonates in molecular proportions, and under saturated conditions the double carbonate, dolomite, may be deposited. In this connection it may be stated that Mr. Stanley Gardiner has quoted experiments showing that dolomite is more insoluble in carbonated water than either calcium-carbonate or magnesium-carbonate alone.¹ The change from calcite to dolomite involves a considerable shrinkage in the bulk of the rock, amounting to about $\frac{1}{11}$ th of the original mass. In view of this contraction, it is quite in accordance with

¹ Proc. Camb. Phil. Soc. vol. ix (1898) p. 496.

the well-established 'principle of least work' to find that this change is facilitated by an increase of pressure.

Translated into depths, the limits may be expected to lie between the surface and 150 feet below it, and probably nearer the upper than the lower limit. The solid matter in solution in sea-water consists of 78.32 per cent. of sodium-chloride, 1.69 per cent. of potassium-chloride, 9.44 per cent. of magnesium-chloride, 6.40 per cent. of magnesium-sulphate, 3.94 per cent. of calcium-sulphate, and traces of bromine, iodine, etc. What we require to know are the conditions under which the magnesium-chloride and sulphate present in such considerable amount in sea-water will react with the calcium-carbonate dissolved by carbon-dioxide and in contact with the mass of the limestone. Dr. C. Klement's experiments¹ demonstrate that this reaction can take place under pressure, and at a temperature of about 100° C. He subjected calcite, aragonite, and aragonitic organisms to water saturated with sodium-chloride and magnesium-sulphate, enclosed under pressure in a sealed tube, and heated for one or two days at a temperature of 90° to 100° C. The resultant action was a selective one. The calcite took up only a trace of magnesium-carbonate, aragonite absorbed 38 per cent., and corals and other aragonitic organisms over 41 per cent. The chemical instability of the aragonite was here the determining factor in the rapidity of the interchange. It is possible that, if the calcite had been exposed to the conditions of the experiment for a much longer period, the introduction of magnesium-carbonate would have proceeded farther, and probably the action would have been accelerated if the calcium-carbonate had been brought partly into solution by carbon-dioxide. The high temperature no doubt quickened the chemical changes, which probably proceed more slowly at the temperature of ordinary sea-water.

While, in general, dolomitization takes place as a result of the interchange of magnesium- for calcium-carbonate, the question arises whether it is ever deposited directly from solution. Perhaps most chemists are unfavourable to this view of its formation, and direct experiments bearing to some extent on this question have in general produced negative results. Dr. Sorby found that magnesite, and not dolomite, was formed by the action of magnesium-sulphate upon calcium-carbonate under high pressure. There is, however, mineralogical evidence in favour of the view of direct deposition of dolomite. The lining of calcite-crystals by an outer zone of clear dolomite, described by me² as occurring in sections from Mango (Fiji), and also noticed in some of the sections of Tyrol dolomite described above, is difficult of explanation, except on the hypothesis that the dolomite was deposited from solution in optical continuity with the calcite. It sometimes happens that one crystal is built up of successive zones, alternately calcite and dolomite. As these crystals are but rarely recognized in thin sections, it is clear that they were not formed under the conditions

¹ Tschermak's Min. & Petr. Mitth. n. s. vol. xiv (1895) pp. 531 *et seqq.*

² Bull. Mus. Comp. Zool. vol. xlii (1903) pp. 117-18.

governing the general dolomitization of the mass of the rock. It may be that they were formed in cavernous parts of the rock, more or less shut off from the free passage of the sea-water; and, indeed, these crystals are sometimes found lining the walls of cavities. Dr. C. G. Cullis, in the mineralogical report on the Funafuti boring,¹ describes and figures a somewhat analogous case, of the deposition of the two minerals in alternating coats lining the walls of cavities, in a way that simulates on a microscopic scale the appearance of the structure of an agate.

It would appear from this that the composition of the solution or its physical state varied from time to time, in such a way as to lead to the alternate deposition of dolomite and calcite. Possibly, in these restricted areas, the sea-water becomes saturated with calcite and the double carbonate in turn, and the conditions of equilibrium may resemble those investigated by Prof. Van't Hoff and others in connection with the Stassfurt salts and similar deposits. Besides this peculiar and local formation of dolomite by direct deposition from solution, in the Tyrol we have to consider two other modes of occurrence of dolomite in some way resembling that just described. Some of the St. Cassian Limestones which immediately underlie the massive Schlern Dolomite of the Sella and Sett Sass, for example, contain in general only a small amount of magnesium-carbonate and usually show no visible dolomite.

In both these areas, however, microscopical examination shows that in places certain parts of the groundmass of the rock contain very minute dolomite-crystals. These are generally confined to the neighbourhood of some crack in the rock. No doubt, in this case, carbonated water, passing through the Schlern Dolomite above, dissolved some magnesium-carbonate, and, traversing the cracks in the St. Cassian Limestone below, deposited its magnesium-carbonate as small crystals of dolomite. Occasionally, these minute crystals are zoned with layers of calcite, and in one case with the isomorphous carbonate chalybite.

In the Raibl Beds overlying the Schlern Dolomite local dolomites are found, and these are sometimes intimately associated with beds of gypsum, in such a way as to leave little doubt that movements of upheaval during the Raibl period led to the enclosure of limited areas or lagoons, and caused the concentration of the sea-water and deposition of the calcium as gypsum and the magnesium as dolomite.

We have then, within the area of Southern Tyrol, to deal both with local and regional dolomitization. The mode of occurrence of some of the dolomites of the Raibl Beds, and the very partial and local dolomitization of the St. Cassian Limestones, makes it easy to suggest a probable explanation of their origin. The great problem of the origin of the Schlern Dolomite is, as has been seen, a more complex one, and a complete solution of all the difficulties will only be found when the chemical problems involved have been more fully investigated.

¹ Roy. Soc. (1904) p. 410 & fig. 44.

VIII. SUMMARY OF CONCLUSIONS.

1. Recent work on modern coral-reefs has extended our knowledge as to the chemical composition of the rocks of which they are built up, especially as to the general absence of insoluble residue in the limestones.

2. The study of the relative proportions of the organisms composing coral-reefs and the alterations which they undergo has shown that corals generally play a subordinate part, and that calcareous algæ, foraminifera, and other organisms form the bulk of the rocks composing the reefs.

I have applied this information in the examination of collections from the much-debated area of the Dolomites of Southern Tyrol.

3. I find that many of the dolomites are devoid of insoluble residue, and that where residue is present it can be generally attributed, as in the raised reefs of Fiji, etc., to association with contemporaneous volcanic rocks.

4. Examination of thin sections of the rocks shows that the limestones have undergone mineralogical and chemical changes similar to those which have affected the limestones of modern reefs, and that similar organisms are represented in the Tyrol Dolomites, allowing for the loss of structure due to more complete dolomitization.

5. That the Schlern Dolomite of Southern Tyrol probably represents Triassic 'coral-reefs,' using the term in the modern, more extended sense.

6. With regard to the origin of the dolomite-masses, it is shown that the general conditions favourable to their formation were:—

- (a) Shallow water between 0 and 150 feet in depth, and corresponding to a pressure of 1 to 5 atmospheres.
- (b) The presence of carbon-dioxide in comparative abundance, causing the partial solution of the limestones and the possibility of chemical interchange with the magnesium-salts in sea-water.
- (c) Porosity of the limestones, allowing of the percolation of sea-water through the mass of the rocks.
- (d) Sufficiently-slow subsidence or elevation to render the change from calcite to dolomite complete.

7. Locally, dolomite is deposited directly from solution in confined areas or cavities in the rock, while some of the Raibl Dolomite associated with gypsum was formed by the concentration of sea-water in land-locked areas.

EXPLANATION OF PLATES X-XIV.

[The rock-sections are preserved in the Author's private collection, but numbered hand-specimens of the rocks from the Dolomites have been deposited at the British Museum (Natural History). The Author is indebted to his friend, Mr. Franklin T. Barrett, for the photographs from which these Plates have been prepared.]

PLATE X.

- Fig. 1. Slightly-dolomitized limestone (No. 100), from the Sella. $\times 11$ diam. Sporadic rhombohedra of dolomite are scattered through the rock, which contains badly-preserved calcareous algæ, foraminifera, and other organisms. (Stained with Lemberg's solution.)
2. Dolomitized limestone (No. 32) from the Marmolata. $\times 32$ diam. Some of the dolomite-crystals are allotriomorphic; but those projecting into calcite are well-formed, and show cloudy zones. (Stained with Lemberg's solution.)

PLATE XI.

- Fig. 1. Dolomite (No. 10), from the Schlern. $\times 32$ diam. Dolomitization is so nearly complete that no calcite remains, and the large majority of the dolomite-crystals are allotriomorphic. A few crystals with cloudy centres exhibit, however, rhombohedral outlines.
2. Oolitic and partly-dolomitized St. Cassian Limestone (No. 77) from St. Cassian. $\times 50$ diam. The oolitic grains are well-preserved, show both concentric and radiating structure, and include foraminifera and fragments of other organisms. Minute rhombohedra of dolomite occur in the calcite-matrix, but do not extend into the oolitic grains.

PLATE XII.

- Fig. 1. Buchenstein Limestone (No. 88), from the Gader Gorge. $\times 230$ diam. A limestone containing zoned crystals, consisting of calcite and dolomite in alternate layers, which are in crystallographic continuity. The calcite-layers are stained with Lemberg's solution, and appear dark in the illustration.
2. Transverse section of a coral (No. 109), from the St. Cassian Limestone of Sett Sass. $\times 18$ diam. The original aragonite and the minute structure of the coral remain. The stages in the conversion of calcareous mud into clear crystalline calcite are also shown. To this change the preservation of the coral is probably to be attributed.

PLATE XIII.

- Fig. 1. Part of No. 109, more highly magnified. $\times 240$ diam. The middle line of the septa is shown, as also prismatic crystals of secondary aragonite, formed in crystallographic continuity with the coral-fibres, which project from the walls of the coral into the space between the septa.
2. Dolomite (β), from the stream at Bad Ratzes. $\times 30$ diam. The dark areas probably represent septa of a coral, the structure of which has been largely destroyed by dolomitization. The lighter dolomite-crystals in the matrix show cloudy zones.

PLATE XIV.

- Fig. 1. No. 112. Schlern Dolomite of Sett Sass. $\times 11$ diam. Transverse section of organisms (*Gyroporella*?), the structure of which has been destroyed by dolomitization. The dark crystals defining the outer margin of the organisms have originated by the extrusion of impurities during the process of recrystallization.
2. Insoluble residue from partly-dolomitized coral (No. 37), from the Giau Pass. $\times 250$ diam. The insoluble residue consists entirely of very minute, doubly-terminated crystals of quartz, showing occasional distortion and striation on the prism-faces.

Profs. Døelter & Hørnes¹ recorded two analyses of rocks from the Marmolata, near the Fedaja See, in which the insoluble residues amounted to .06 and .03 per cent. respectively. The analyses indicate that the massif, as a whole, is very free from insoluble residue, and is for the most part not dolomitized.

The Sella.

The specimens were collected in sequence from the northern slopes of the Sella Mountain, on descending from the Gröden Pass towards Colfusco. No. 101 was taken from a block fallen from the upper part of the mountain; No. 99 from near the junction with the subjacent St. Cassian Limestone; while No. 98 represents a specimen of the St. Cassian Limestone, analysed for comparison with the dolomitized rock above it.

No.	CaCO ₃ . <i>Per cent.</i>	MgCO ₃ . <i>Per cent.</i>	Insoluble residue. <i>Per cent.</i>	
* 101	55.7	44.3	...	* Not in place.
102	79.3	20.2	0.46	
100	80.5	18.2	1.26	
99	81.7	17.4	0.93	
98	88.2	8.2	3.53	

Taking the results in ascending order, we find that the amount of insoluble residue, which is high in the St. Cassian Limestone, falls on ascending the Dolomite Series, the uppermost specimen being devoid of residue.

On the other hand, the percentage of magnesium-carbonate rises from 8 in the St. Cassian Limestone to 44 in the dolomite of No. 101, the intermediate specimens being dolomitic limestones. Profs. Døelter & Hørnes² recorded an analysis of a dolomite from Schloss Wolkenstein, west of the Gröden Pass, which contained .11 per cent. of insoluble residue.

The St. Cassian District.

Lavarella.

No.	CaCO ₃ . <i>Per cent.</i>	MgCO ₃ . <i>Per cent.</i>	Insol. res. <i>Per cent.</i>	
82 ...	54.7	45.3	.033	The three specimens were collected, in descending order, from the dolomite-mass of Lavarella, east of St. Cassian. It will be seen that insoluble residue is practically absent, and that the specimens are dolomites of theoretical composition. An analysis of a St. Cassian Limestone (No. 76), from the slopes below Lavarella, shows considerable residue and over 10 per cent. of magnesium-carbonate.
81 ...	54.7	45.3	.013	
83 ...	55.5	44.5	.013	
76 ...	84.1	10.2	5.73	

¹ Jahrb. d. k.-k. geol. Reichsanst. vol. xxv (1875) p. 319.

² *Ibid.* p. 320.

FIG. 1. $\times 11$ DIAM.

No. 100

FIG. 2. $\times 32$ DIAM.

No. 32.

FIG. 1. $\times 32$ DIAM.

No. 10.

FIG. 2. $\times 50$ DIAM.

No. 77.

FIG. 1. $\times 230$ DIAM.

No. 88.

FIG. 2. $\times 18$ DIAM.

No 109.

FIG. 1. $\times 240$ DIAM.

No. 109.

FIG. 2. $\times 30$ DIAM.

No B.

FIG. 1. $\times 11$ DIAM.

No. 112.

FIG. 2. $\times 250$ DIAM.

No. 37.

DISCUSSION.

The PRESIDENT said he felt that the Fellows, after listening to the Author's presentation of the work which he had done in great detail in the Tyrol and also in the laboratory, would agree that the Council had made a wise choice when they had made the first award of the Daniel-Pidgeon Fund, 'to be used in whatever way may in their opinion best promote geological original research,' to the Author.

Prof. JUDD congratulated the Society upon the valuable results secured by the first award of the Daniel-Pidgeon Fund, and at the same time complimented the Author on the lucid and effective manner in which he had marshalled his facts and arguments. He bore testimony to the great skill and patience with which the investigation had been carried out. He further ventured to express the hope, that the founder of this Fund would feel satisfied as to the success of the means which she had adopted to carry out the wishes and perpetuate the memory of her late husband. With respect to the arguments of the Author, he pointed out that the very important conclusion, that coral-rocks yield only minute traces of insoluble residue, was established not only by the Author's own analyses, but by those of several other chemists, including Mr. Stanley Gardiner. That other calcareous sediments contain a sensible proportion—1, 2, 3, or more per cent.—of insoluble residue is proved by the analyses of the *Challenger*-materials and many investigations of later date. The Author, by an application of the method described in the Funafuti Report to the classic dolomite-district of the Tyrol, had given a confirmation of the value to geologists of this crucial test concerning the origin of limestones. In addition, he had supplied a number of observations bearing on the very difficult chemical problem of dolomitization, which could scarcely fail to be of service in its ultimate solution.

Dr. E. F. ARMSTRONG remarked that, in the course of Prof. Van't Hoff's Stassfurt investigations, with which he had been associated, the problem arose as to the order in which salts would separate out from sea-water. It was a question whether dolomite existed as a true chemical compound, or was merely an intimate mixture of magnesium- and calcium-carbonates. In view of the great number of double salts known to exist, the former hypothesis seemed at least plausible. So much being granted, the problem next arose as to the conditions which governed the separation of dolomite from solution. Here, perhaps, pressure was a more important factor than any other variation that could be suggested. The Author had drawn attention to material containing a small percentage of magnesium-carbonate, but showing no evidence of dolomitization. One explanation might be that, owing to some variation in pressure, or other causes, not dolomite but magnesium-carbonate pure and simple had been deposited from solution; and it would be interesting to know whether this could be distinguished by microscopic methods from calcium-carbonate. It was noticeable, in this connection, that the uppermost rocks in the Funafuti borings, where

the pressure was consequently lowest, yielded the smallest percentage of dolomite.

Dr. C. G. CULLIS said that it was very satisfactory to find that the Author's investigations had led him to conclusions which were, in the main, harmonious with those already arrived at, along other lines of evidence, by such eminent geologists as Baron F. von Richthofen and Dr. E. von Mojsisovics, namely, that these great limestone-masses of Southern Tyrol represent the denuded remains of Triassic atolls and coral-reefs, and that the peculiar lithological characters of the rocks, as well as the distinctive physical features of the region, were merely expressions of this fact. The Author had been led to this conclusion by observing the great similarity which the rocks presented, in their chemical composition and detailed microscopic characters, to those which enter into the constitution of recent coral-reefs. From what he himself had seen of the microscopic character of coral-reef rocks, as exemplified by the cores of the Funafuti boring, he was glad to be able to confirm this resemblance, which in many cases is so striking as to make it almost impossible to avoid the conclusion that, notwithstanding their great difference in age, the two sets of rocks must have come into existence under substantially the same conditions.

Referring to the explanation of dolomitization, in terms of the relative solubility of calcium- and magnesium-carbonates under varying pressures, which the Author had suggested, he hoped that this would secure the favour and support of chemists. Speaking from recollection, he could not recall any fact or phenomenon presented by the dolomitization of the Funafuti rocks which did not find a satisfactory interpretation in the light of this simple but ingenious explanation. It seemed to him to provide the key to a problem which had puzzled geologists since the days of Leopold von Buch.

Mr. DIXON referred to the evidence that some dolomite in the Carboniferous Limestone of Pembrokeshire and Caermarthenshire is associated with shallow-water conditions.

Prof. WATTS drew attention to the probably shallow-water dolomites near Charnwood Forest, and to the base of the Carboniferous Limestone in Ireland, frequently either a dolomite, or a conglomerate or grit cemented by dolomite. He further pointed out that, although the Author had made an extremely-important comparison between the dolomites of Southern Tyrol and coral-limestones, and had shown that both of them lacked insoluble residue (which was a common ingredient in calcareous deposits), the comparison could not be followed to its logical conclusion until other calcareous sediments, such as those of the Gulf of Mexico and the Gulf-Stream areas, had been thoroughly examined.

The AUTHOR thanked the previous speakers and the Fellows present for their generous reception of his paper, and, in reply to Dr. Armstrong, stated that microscopical examination of limestones containing 10 or 12 per cent. of magnesium-carbonate failed to show the presence of magnesite as recognizable crystals.