CORAL IN THE "DOLOMITES."

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CORAL IN THE "DOLOMITES" OF SOUTH TYROL.

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I.—General Character of the Scenery—The Interpretation of the Mid-Triassic Succession given by the "Coral Reef Theory."

AT the meeting of the British Association in Nottingham, in August of last year, a joint discussion on "Coral Reefs" was held by the sections of Zoology and Geology.[1] Prof. Sollas, in opening the discussion, referred to the "Dolomites of South Tyrol" as a country affording brilliant examples of Fossil Coral Reefs. He demonstrated this by sections taken from the well-known work of Mojsisovics, and showed several photographs of some of the more imposing dolomite mountains—Schlern, Langkofl, and Sella—which had been explained as reefs of Triassic age. In the course of the discussion, Dr. Hickson said he believed there were no corals in these so-called fossil reefs. Dr. Rothpletz corrected this statement, saying briefly that there were corals in the dolomite and limestone rock, along with other groups of marine animals, but that many of the sections shown by Prof. Sollas were incorrect. Prof. Bonney emphasized the ample evidence of Coral life in many parts of the district which he had visited.

I may be pardoned for recapitulating the part of the discussion bearing on South Tyrol, as I wish to state here the conclusions which I have formed with regard to Coral Reefs from my geological work in that neighbourhood. So far as South Tyrol gives countenance to one theory of the growth of Coral Reefs or the other, it supports in the main Murray's theory and not Darwin's. It displays striking analogies with the observations of recent reefs made by Agassiz in the West Indian and Caribbean Seas, by Dr. Guppy in the Solomon Islands, by Dr. Murray on the Barrier Reef of Tahiti and the Great Chagos Bank, by Prof. Semper in the Pelew Islands, by Dr. Rein, Dr. Sydney Hickson, and others. Some of the special points of correspondence may be indicated at once. Volcanic eminences formed submarine platforms in the Triassic ocean of South Tyrol, on which Corals built in Wengen and Cassian time. One special

[1] An account of the discussion is given in "Nature," October 12th, 1893.

ridge, south of Gröden and Enneberg, apparently the outermost at that time, formed the basis for a more or less continuous barrier-like chain of reefs, behind which (*i.e.* to the north) deposits collected of a different nature from the ordinary marine deposit of the Southern Ocean. These deposits include in their uppermost horizons the wonderful Cassian fauna of Enneberg, and probably the faunal conditions of the Cassian-Enneberg sea of Triassic South Tyrol may be justly compared with these of the Caribbean Sea at the present day. At a later Triassic period, in Raibl time, banks of reef-coral were formed on raised beds of ordinary submarine deposit. On the other hand there is every reason to suppose that in the particular periods of Trias in South Tyrol pre-eminent for the growth of Coral Reefs, the sea-floor was undergoing extensive movements of subsidence, subject to oscillation in the near vicinity of volcanic action. In the St. Cassian area, between the two main periods of Coral growth an interval of quiet subsidence intervened, marked in many places by the cessation of Coral growth and the accumulation of a marine deposit enclosing calcareous algæ.[1]

The Wengen and Cassian Coral Reefs of Gröden, Enneberg, and Upper Fassa have remained, with but rare exceptions, limestone. The actual thickness attained by the individual lenticular Coral Reefs or the Coral Banks is in no case very great, seldom more than 150 feet, and usually much less. The steep slope of the outer chain of reefs was mainly composed of volcanic rock with interbedded reef-limestones. As negative evidence it may be mentioned that the so-called "Dolomite Reefs," viz. the thick dolomite massifs of Schlern, Sella, etc., have originated as marine deposits and not Coral Reefs, probably calcareous in the greater part of their thickness, and only in their upper horizons originally dolomitic. The reef-like appearance assumed by these dolomite massifs is in small measure due to the variation in the character of contemporaneous Triassic deposits, but it is chiefly the result of the movements of the rocks in Tertiary time.

I have selected for the sketch-map[2] a long stretch of country between the Eisack Valley, with the Brenner railway on the west, and the Ampezzo Valley on the east. The map displays at a glance the characteristic physical features. Precipitous rocks, generally of a creamy or rose-tinted crystalline dolomite, rise to great heights above green swelling passes and grazing land, or sometimes descend at once into deep gorge-like valleys. The artistic sense scarcely knows which to love most—the romantic region of fir-wood and stream and human habitation, or the wild solitariness of the rocks beyond. Villages are perched midway between mountain and ravine, looking in some of the narrower valleys as if a push would throw them into the gap below. The simple Ladinian folk wander

[1] Mr. George Murray made the following observation in the Antilles:—"Many coralline sea-weeds living at greater depths than the Corals grow with a stout incrustation of carbonate of lime, and thus form great masses which seem to nearly rival the true Coral Reefs in bulk" ("Nature Notes," February, 1891).

[2] The Map will appear in the February Number with Part II. of this paper.

summer and winter among the rough winding paths and dilapidated huts, content to lead their cows and mow their hay. In the wider valleys the sun ripens hearty crops twice a year, and life flows on pleasantly, after a lazy Italian fashion. The barrenness of the dolomite mountain is such that even chamois rarely frequent their clefts and terraced table-lands; snow caps most of them during nine months out of the twelve, and is perpetual on the highest summits.

With the exception of a few scattered remnants of Jurassic and Cretaceous rock, the geological age of the deposits exposed throughout this country is Triassic. We are concerned with the history of Triassic deposit in South Tyrol, in the midst of which, we are told, there came a long epoch of Coral growth and reef-building. If this be true, the data of the geologist have a keen interest both for the geographer and the zoologist, whose duty it is to compare these fossil Coral Reefs with reefs now growing, and find corroboration or the reverse for the various theories which have been advanced regarding the growth of recent Coral Reefs. The chief data which geology determines, are the exact nature of the sedimentary rocks, the order in which they succeed one another, the fossil remains which they contain, and any particulars regarding the manner of occurrence of the fossils. That seems a simple enough commission, and yet in practice it is often very hard to execute, no part of it more hard in the Alps than that of determining the order in which the rocks succeed one another. For the sediments which were deposited by the great basins of water in Triassic time have since been folded and twisted and raised into entirely new positions in relation to one another. So that a rock which was once below is now alongside or even above its neighbour—or its fossils have been destroyed, or a volcanic invasion has taken place; in fact, endless accidents may have happened since Triassic time, and it requires much time and patience to unravel the mysteries introduced into a once simple succession. In a word, to be a good ancient geographer of the Trias, one must first be a wary stratigraphist.

We shall begin by quoting the succession of Triassic rocks in South Tyrol and the interpretation of it given by Mojsisovics[1]:—

Rhætic Beds.

Dachstein dolomite.

Raibl marls, sandstones, dolomite.

Coral Reefs of	Cassian Dolomite	thinning into contemp. deposits of	Cassian marls and limestones.
	Wengen ,,		Wengen shales and volcanic ash.
	Buchenstein ,,		Buchenstein limestones and ashy rocks.

Muschelkalk (Alpine) limestone or dolomite.

Werfen shales and thin bedded sandy limestones.

Permian Rock.

The actual part which these rocks take in the landscape may be briefly described. The so-called "Coral Reefs" rise as sheer precipices 2000–3000 feet high, or dwindle to nothing. The gaunt form of their cliffs is unbroken by familiar planes of bedding. Raibl marls draw themselves as a narrow band above them, and

[1] E. Mojsisovics v. Mojsvár, "Die Dolomit-Riffe von Süd Tirol und Venetien," Wien, 1879.

Dachstein dolomite, well stratified and often of very great thickness, builds the highest terraces and precipices. The Cassian, Wengen and Buchenstein sedimentary beds are exposed on the passes between "reefs," on their lower slopes, and over the large meadows which the people of the place call "Alpen." The Muschelkalk and Werfen series form the bed of the streams in the rapidly descending mountain valleys. It may be at once remarked that typical fossils have been found in all members of the succession. In the "reef-dolomite" fossil remains are extremely poor and scanty; plant algæ are got even more often than Corals, Gasteropods, or Bivalves. *Ammonites* occur, but usually in too meagre a state of preservation to be of much service in identifying the age of the rock.

Besides the layers of volcanic ash and lava which are interbedded with the Wengen beds, there is every here and there a massive looking volcanic rock, Augite Porphyry, which surprises the eye by its strong contrast to the dolomitic rocks. Everyone knows that Coral growth in our present seas is particularly luxuriant where volcanic action is occasionally felt, and this seems a strong argument in favour of the view which explains these Triassic dolomites as Coral limestones, largely magnesic, which were built in a volcanic sea of the far-away Trias period. The later conversion of such magnesic limestone reefs into pure dolomite also finds its parallel in recent reefs. So that the "Coral Reef Theory of the Dolomites" presents, as a theory, no problem which is not in harmóny with recognized facts, unless we except the enormous thickness attained by the reefs, and the occurrence on their upper surfaces and slopes of an appearance which Mojsisovics observed and called "overcast bedding."

A geological theory, however, stands by virtue, not of its probability argued from Nature's Present, but its absolute fitness to the facts observed in Nature's Past. And, when the same facts may bear two or even more explanations, the theory which is to stand in Science must fight for its position as the fittest survivor! We have to ask ourselves if the Coral Reef theory offers the only probable explanation of the dolomite cliffs. The mere occurrence of a couple of thousand feet of limestone or dolomite is part of the A B C of Geology, when taken as the accumulation of ordinary marine deposit. Dachstein dolomite is such a rock, and it still carries testimony of its origin in the numerous *Megalodon* bivalves and other fossils which it contains. Again, a considerable amount of variation in the thickness of any marine deposit might be expected, especially where volcanic eruption had previously disturbed the sea-floor and produced all degrees of inequalities by heaping up its ashy flows in some parts more than in others. But the special difficulty said to meet us in the case of the Cassian and Wengen dolomite of South Tyrol is, that rocks of 2000 feet in thickness rise quite suddenly from the midst of sedimentary earthy beds, and show certain curious appearances in relation to them. The dolomite rock seems to dovetail at its extremities into the marly and ashy beds, giving rise to strange anomalies in the geological succession, which could only be explained by regarding every case as one of contemporaneous deposition of different classes of rock very close to one another, so-called "Heteropism." Such difficulties can only be solved by stratigraphy, and to that we must turn for proof of the data on which the Coral Reef theory rests.

For the sake of clearness in writing, we prefer to use, instead of the triple term applied to the reef-dolomite by Mojsisovics, the single name given by von Richthofen, of "Schlern dolomite,"[1] from its characteristic occurrence at Schlern Mountain, south of the Gröden Valley.

II.—Normal Marine Formations of Mid-Trias in the Southern Alps—Submarine Volcanic Action in Upper Fassa and the neighbouring districts—The "Dolomite Reefs" of Enneberg and Ampezzo correspond to part of the Normal Marine Deposits of the South.

Whereas during the Wengen and Cassian period, volcanic activity was rife in the northern part of the area covered by the sketch-map, an accumulation of marine deposit apparently went on during a steady subsidence of the sea-floor over the southern areas. Great thicknesses of limestone and dolomite represent this period in the southern part of the South Tyrol, and in the Venetian and Bergamasker Alps. These are known in different localities as Esino limestone, Marmolata limestone, Schlern dolomite. The fauna is liable to great variation, but includes for the most part a typical assemblage of Mollusca, Echinoderms, Corals, and Gyroporellas (sea algæ). This we may regard as the *normal* oceanic formation of the mid-Triassic period in the Southern Alps.

In the Upper Fassa and Gröden, Enneberg and Ampezzo districts, intermittent outpourings of volcanic matter took place from one or more submarine craters, associated perhaps with the proximity of this part of the sea to pre-Triassic land of Palæozoic and crystalline rocks, and with Triassic earth-movement. Be that as it may, the southern rocks of Schlern dolomite, Marmolata and Esino limestones, were clearly collected in deeper waters than the contemporaneous deposits immediately to the north. This is nowhere better seen than at Schlern Mountain, where the deep-sea deposits on the south side of Schlern pass rapidly into the volcanic lavas and shallow-water deposits on the Seisser Alpe to the north. According to von Richthofen's original interpretation of this district, the upper part of the "Schlern dolomite" of Schlern was younger than any of the sedimentary beds on the Seisser Alpe, a stratigraphical fact of general import, which many geologists have since verified at this point.

Following an irregular line eastward and south-eastward, we may trace the same occurrence of stratigraphical facies. It takes place most suddenly where the Wengen lavas are thickest, *i.e.* in Upper Fassa. The dovetailing of the dolomitic and calcareous

[1] Schlern Dolomite. *Vide* von Richthofen, "Geognostische Beschreibung der Umgegend von Predazzo, St. Cassian und der Seisser Alpe," 1860.

strata with volcanic and marly beds which takes place along this volcanic zone is therefore perfectly comprehensible in the light of every-day facts of deposition. There is no need to call the massifs of Schlern, Rosengarten, Latemar, Marmolata, etc., "Coral Reefs," merely because a thin line of heteropic division may be traced between these two areas of Triassic rock in South Tyrol. Moreover, the local recurrence of volcanic activity during a prolonged period would explain the continuance of different conditions in adjoining districts. While a simple interpretation such as the above would explain one of the main features of Triassic geology in South Tyrol, it may be objected that it would not apply within the volcanic district itself, for it is in Enneberg and Gröden, more than in any other part of South Tyrol, that the curious suddenness of the "Reefs" strikes the eye.

As I have said in a previous paper,[1] every member of the Triassic succession in South Tyrol presents variations in its thickness when followed from place to place. More especially is this true of the beds from Muschelkalk to Dachstein Dolomite. The names Cassian, Wengen, and Buchenstein mark different horizons in a series of volcanic lavas, ashy and tufaceous marls, calcareous marls and limestones, which may, lithologically considered, be united as one series. This series represents, no doubt, the upward continuation of Alpine Muschelkalk much as the Partnach beds do in North Tyrol.[2] Zones may be followed in which certain fossil genera predominate in the number of individuals and species; but the palæontological facts give us not so much a clear succession of types as an index to the facial conditions which influenced the life of the period.

For instance, *Halobia Lommeli* is a fossil bivalve which is common in tufaceous beds both of Buchenstein and Wengen age; but in Buchenstein limestones the general character of the fauna is more like that of the Muschelkalk, whereas limestones of the Wengen age contain the remains of Corals and Echinoids like those in the next following Cassian deposits. Again, *Posidonomya Wengensis* is another bivalve which gradually outnumbers *Halobia Lommeli* in tufaceous beds belonging to upper horizons of Wengen beds, and it is a fossil which again and again reappears in Cassian time always associated with the same lithological character of deposit, and shewing but slight varietal changes in its outward form. It is one of these persistent types which saw the birth and destruction of innumerable shoals of less fortunate species and genera characteristic of the Cassian limestones.

In the district of Upper Fassa there are true Augite Porphyry lavas of Lower Wengen age, which appear more or less interstratified with grits and tuffs. In the Enneberg districts, *i.e.* north of Upper Fassa, the lavas pass into black earthy tuffs and crumbling grits, in which the fauna is very limited and fragments

[1] "Contributions to the Geology of the Wengen and Cassian Strata in South Tyrol," by M. M. Ogilvie," Quart. Journ. Geol. Soc., vol. xlix. p. 47, February, 1893.

[2] "Ueber die Entwicklung u. Verbreitung der Partnachschichten," etc., by Dr. T. Skuphos, Jahrb. der k.k. Geol. Reichsanstalt, 1893, Bd. 43, p. 178.

of plants are of frequent occurrence. Mojsisovics has proved that these invasions came from a submarine volcano, probably in Upper Fassa, which "lay on the edge of the district of greater subsidence" to the south. "In Triassic time, as we are taught by the history of the Triassic reef masses, a certain protraction took place in the subsidence going on at the edge of the insular core of older rocks to the north as compared with a more rapid subsidence of the outer regions" (Mojsisovics, "Die Dolomit-Riffe von Süd-Tirol und Venetien," p. 525). We may naturally suppose that Augite Porphyry lavas formed irregular ridges on the disturbed sea-floor, more especially near the eruptive centre. From the beginning of this period we trace a marked difference in the deposits and fossil remains of the non-volcanic and volcanic areas respectively south and north of the Upper Fassa ridge, and even considerable variation within the shallow volcanic sea itself. A representation of the sea-floor in this period is given in Diagram I.

Corals found abundant "coigns of vantage" and were aided by Echinodermata to form communities of organic life, often prevented from farther growth by new volcanic invasions, but ever and anon settling down afresh. The remains of these form the "Cipit blocks" and "Cipit limestones," which were first observed by von Richthofen amid Cassian marls on the slopes below Schlern. Mojsisovics recognized similar limestones appearing intermittently over the whole area eastward. I have given special attention to the relations of these limestones with the contemporaneous rocks, and shall at once describe the more interesting results.

They, and not the mountains of Schlern dolomite, deserve the name of "Coral Reefs" in South Tyrol. They never attain any great thickness; generally in highly volcanic periods they formed mere isolated blocks composed of colonies of Corals and Echinoderms, and closely wedged amongst tuffy marls. In less volcanic periods continuous beds spread over a larger area—sometimes suddenly swelling out in lenticular fashion, sometimes perceptibly thinning into deposits full of other classes of animals. Stratigraphically considered, they occur as the equivalents of Cassian and Wengen strata, and in a less degree of Schlern dolomite and Raibl strata, and they follow certain fairly definite laws of distribution. Diagrams I. II. and III. represent successive stages in the history of the heteropic deposition in South Tyrol during this part of the Triassic era; Diagram IV. represents approximately the occurrence of Cipit Limestones in the contemporaneous series of rocks. In the Upper Fassa and Schlern districts the Cipit or reef-limestones occur at various horizons in the midst of volcanic earthy Wengen beds, or associated with sedimentary beds containing *Halobia Lommeli*, *Posidonomya Wengensis*, etc. They continue upwards in that district to the base of the Schlern dolomite, but are associated, north of the Schlern Mountain, in their higher horizons with characteristic Cassian fossils.

In Gröden Joch and in Enneberg, the Cipit Limestones do not make their appearance until the Wengen beds are giving place to

Cassian. The block-like structure observed in the Schlern and Fassa district becomes less prominent in Enneberg, and we are rather presented with thick unevenly bedded limestones full of *Cidaris* spines and Thecosmilian Corals, more rarely with Brachiopods and small Mollusca.

These are immediately succeeded in Enneberg by the great mass of thinly-bedded typical Cassian beds. The latter, therefore, correspond on Stuores meadows to the upper part of the Cipit Limestones of the Seisser Alpe and Sella Joch, and to some part of the lower horizons of Schlern dolomite at Schlern, and at Sella and Sasso Pitschi. Sometimes the outpouring of volcanic material, which was constantly recurring in Upper Fassa, caused the sudden disappearance of the rich fauna of Enneberg. During the short periods of disturbed deposition which then ensued, Echinodermata, even more than Corals, peopled the seas.

Thin beds of Limestone were thus formed at intervals amid tufaceous sediments of Cassian age, but the main thickness of Cassian beds in Enneberg is composed of soft marls and limestones full of the remains of Brachiopods, Mollusca, and many species of non-reef-building Corals. This fauna lived, I believe, in an inner area of quiet water, secluded from the Southern Ocean by the Cipit reefs and volcanic rocks, some deeper channels being left free.

Whereas the Wengen and Cassian beds retain their tufaceous character, in greater or less degree, throughout the whole district of Enneberg, they show it much less in the corresponding deposits of Ampezzo. Fine, unfossiliferous shales and clays take the place of the tufaceous grits, and although Corals and Sponges occur in hard limestones of Cassian age, they are seldom in sufficient magnitude to form any appreciable reef-like thickening. The same is true of the northern or "Abtey" part of Enneberg, and of the deposits of Seeland Valley and Misurina, north-east of Ampezzo. Hence Cipit-Limestone building flourished most in the volcanic areas of Gröden and Upper Fassa. I observed, however, in the higher horizons of Cassian strata at Ampezzo thick, reef-life extensions of Limestones, mostly one mass of the spines of *Cidaris Hausmanni.* They form bands of rock between softer beds, and are present as well in the undisturbed series below the Schlern dolomite of Lagazuoi as in the disturbed succession near the small Lago Majorera to the east (close to the Falzarego road). The stratigraphical facts afford evidence that the Cassian marls are both in Enneberg and Ampezzo succeeded by a dolomitic rock, and never conformably by fossiliferous Raibl sandstones and marls. As might be expected from the occurrence of an upper palæontological zone of Cassian beds in the Ampezzo districts (Upper Cassian—*vide* M. M. Ogilvie, *loc. cit.* pp. 46, 47), the dolomite rock which succeeds Cassian strata did not everywhere begin to be deposited at the same time.

In the south-west, where a true marine formation had been continued throughout the Wengen and Cassian period, the deposit has only sometimes a stratified appearance. Mojsisovics has ascribed some parts of the Latemar and the mountains still further west to a lagoon formation; but he describes a large, originally continuous, dolomite mass, "with the Schlern for the most northerly, and the Piz, near Sagron, for the most southerly point," as an immense Reef. The Marmolata Mountain and the Mount Alto de Pelsa "are two important continuations of this mass, jutting out in peninsular fashion into the eastern district" (*vide* "Horizontal Extension of the Dolomite Reefs in Lower Wengen Time," Mojsisovics, *loc. cit.* p. 482). In the case of Schlern, where the upper part of this rock is stratified and the lower apparently unstratified, we are told that the lower part is Coral Reef, the upper part is lagoon deposit. But in many portions of this western "Reef," it has been proved that the remains of algæ and mollusca form the important part of the deposit. Whether stratified or unstratified, there is no reason why the Schlern dolomite of this Western "Reef" should not be regarded throughout simply as a lagoon and marine formation. In no single case has it been proved that reef-coral continuously built vertical cliffs of Coral rock during the mid-Triassic period of subsidence represented by Esino limestone, Schlern dolomite, etc.

This typical calcareous or dolomitic rock in the south-west of the district succeeds in the northern and eastern areas, in greater or smaller thickness, the volcanic series and the marls and limestones of Wengen and Cassian age, gradually succeeding the upper horizons of the series towards Enneberg and Ampezzo. The so-called Schlern dolomite "Reefs" of these areas can never be said to be contemporaneous with the marls at their own base unless, as in the case of the Schlern Mountain, denudation has allowed the rock to remain standing over such an extensive area that the dolomite of one portion is contemporaneous with the marls underlying the dolomite further north. To express the same fact somewhat differently, the fossiliferous marls and limestones of Enneberg were not laid down against Coral cliffs, but form a deposit belonging to a definite palæontological horizon, and succeeded by a dolomitic or calcareous rock of marine or lagoon formation. For this dolomitic or calcareous rock between the fossiliferous deposits of ascertained Cassian and Raibl age in the Enneberg and Gröden district, it is best to preserve the name of Schlern dolomite,[1] as no sufficient faunal distinction has yet been carried out between different horizons of the said dolomitic rock in the south-western area of its complete development.

I must refer the reader to my sections and maps already published for further proofs of the conformable succession of Schlern dolomite on the Cassian beds in Enneberg. I shall now recapitulate the main conclusions which may, I think, be drawn from what I have already stated:—

1. The frequent occurrence of Coral remains in the "dolomite" country is a fact, often repeated, but somewhat vaguely applied, bearing with it no evidence whatever of the Coralline origin of the "dolomites" themselves.

[1] Schlern dolomite: In using the expression "dolomitic or calcareous rock" I wish to take nothing for granted as regards the original or subsequent dolomitization of the rock. This question is outside the immediate interests of the paper.

2. The Coral remains occur sometimes in isolated blocks, sometimes in large clumps of rock perforated by *Thecosmilia* species of Coral, and often full of fragments of Echinoderms. These blocks or clumps occur in the midst of fine volcanic mud, or the calcareous and dolomitic matter of the contemporaneous marine sediment, and form more or less continuous beds with lenticular reef-like expansions. The name they go by is "*Cipit Limestones,*" and they vary from 10 feet to 150 feet in thickness.

3. "Cipit Limestones" are of episodal occurrence throughout the mid-Triassic era, appearing at entirely irregular horizons of all Triassic strata between the Muschelkalk and Dachstein dolomite. At the same time, in the area under discussion, there is one horizon pre-eminent for the interbedding of Cipit Limestones, that is, the Cassian.

4. In its lithological character and faunal distribution, the Wengen and Cassian period shows marked heteropism. While in deeper seas algæ grew and Mollusca prevailed, there was, not far from the island coasts of the mid-Alpine core of rocks, a zone of submarine volcanic eruption. Lavas and ashes were swept intermittently over the sea-floor. Along the hem of this volcanic girdle communities of Corals and Echinoderms settled and formed a series of small barrier reefs (Cipit Limestones), frequently interrupted in their growth by fresh lavas. On the outer, seaward side, marine deposits continued to increase in thickness over a sinking basin; on its inner side, at first only a few mud-loving species of *Halobia, Posidonomya,* etc., could exist, but later the Cassian fauna enjoyed a varied and rapid development, and lived on good terms with the Reef-fauna of the Cipit Limestones.

5. The fossiliferous marls and Cipit Limestones of Cassian age in Enneberg are succeeded by a calcareous and dolomitic rock, which is of the same age as the upper horizons of the calcareous and dolomitic marine deposits of mid-Triassic age in the south and south-west. Taking one or two parallel lines of section north and south through the inner Cassian belt of deposit, we find that Schlern dolomite succeeds, in the west or Gröden area, an extremely irregular submarine relief of volcanic, sedimentary, and reef-rocks of Wengen and Cassian age; in the Enneberg area it succeeds reef-rocks and the famous fossiliferous Cassian marls of Stuores meadow; in the Ampezzo and easterly regions it succeeds reef-rocks and fossiliferous marls, belonging to a somewhat later palæontological zone, Upper Cassian.

6. Contemporaneous faulting and volcanic action were the cause of mid-Triassic heteropism in South Tyrol.

Hence, so far as positive evidence goes, the Coral rocks of South Tyrol in the Wengen and Cassian period are not the majestic mountain massifs of dolomite, but much less obtrusive, lenticular masses of limestone. And one general law may be said to govern the Wengen and Cassian period in Gröden, Enneberg, and Ampezzo, a wandering north-eastwards of the Wengen and Cassian fauna (including the special reef-fauna of the Cipit Limestones) consequent on the cessation of volcanic activity along the immediate southern boundaries of the Cassian-Enneberg sea, and the increasing subsidence of these areas. During the subsiding movement, sea algæ and large Mollusca pressed northward. The shallow-water Cassian-Enneberg fauna, no longer enjoying the same favourable conditions as before, retreated into more and more limited localities and gradually gave place to its lineal descendants, the shallow-water fauna of Raibl times. This transitional period paved the way for the complete recovery of normal conditions in Fassa, Gröden, and Enneberg. As Mojsisovics has said, South Tyrol in Raibl times "participated once more in the general movements of Alpine areas."

III.—Transitional Dolomitic Era—Extremes of Rock-Facies in Raibl Times.

The Raibl period was the natural sequel of the variable and unequal movements which prevailed over Alpine areas in Permian and pre-Raibl Triassic time. Many basins formerly open were then enclosed; rauchwackes and beds of dolomite and gypsum were interbedded with fossiliferous deposits. Whereas, in some places, the dolomitic nature of the deposit is confined to special horizons, in the South Tyrol "Dolomites" it may almost be said to reign throughout. This makes it all but impossible to say when Schlern dolomite ends and Raibl beds begin. In the present incomplete state of our knowledge with regard to the heteropism of the Raibl series throughout the whole Alps, I have judged it best to begin the Raibl horizon at any particular place with the first appearance of a distinctly Raibl fauna, even although that fauna may not have been proved to correspond to the acknowledged lowest fauna of Raibl age in distant parts of the Alps.

To return for a moment to the succession of Schlern dolomite upon the Cassian beds of Enneberg, I found that, where Schlern dolomite rests on Cipit limestones, it has at its base a conglomeratic appearance, as if Cipit blocks had been imbedded in a beautifully fine white or reddish dolomitic mud, instead of the dingy brown and black tufaceous sediments. This is the case in several places, *e.g.* upon Pordoi and Sella Jochs, where there is no evidence of unconformity. Again, where the dolomite succeeds the thin-bedded marls and limestones of Cassian age, it does so conformably; but one and the same bed is at some parts calcareous and fossiliferous, at other parts dolomitic and unfossiliferous. Seeing that this holds good at various horizons in Lower as well as Middle Trias over the whole area of South Tyrol, we need find nothing remarkable in it from the point of view of the stratigraphical succession. Indeed, I have only mentioned these observations as an indication of the particular mode of transition from conditions of deposition favourable for the Cassian fauna to those in which the Raibl fauna was enabled to make an occasional appearance in the South Tyrol dolomites. At a very little distance above the base of Schlern dolomite all signs of Coral life disappear, and the deposit looks a homogeneous rock, although always retaining local variation in the degree of its dolomitism. At this stage the rock often shows typical Oolite structure. As regards the presence or want of stratification, it has as little to do with the question of the Coral Reef origin of the dolomite as the amount of magnesic salts in the rock—stratification is present and absent in one and the same "Reef."

In the highest horizons of Schlern dolomite there is infinite irregularity in the relations of fossiliferous and unfossiliferous beds; these horizons have been proved palæontologically to belong to the Raibl period. In them Corals and Echinoderms reappear again in some abundance in the Gröden and Enneberg districts. Dolomitic shales may be regarded as the typical sediment, giving place locally to sandstones and limestones, in which strand-faunas and plant-remains are imbedded. In one or two places Corals formed thin reef-like extensions over preceding plains of algal and marine origin. The fauna everywhere has many reminiscences of the Cassian fauna, but has marked local as well as zonal characters. Thanks to the occurrence of a few leading Molluscan types of wider distribution in Raibl strata, one or two horizons of time are clearly identifiable in the succession. Life was often made impossible, and brightly-coloured magnesian marls silted up large basins. Dolomitic mud and rauchwackes accumulated, or beds of dolomite or gypsum were separated from the water in inland seas and lagoons of what seems to have been a South Tyrol "Raibl" Archipelago. The best example of the heteropism in Raibl times is afforded by Schlern Mountain, where the stratigraphical relations of the fossiliferous well-known "Schlern plateau" Raibl beds have been carefully worked out by von Wöhrmann.[1] He says: "At one place we have a fauna exceptionally rich in individuals, in others we find the same horizon represented by a Coral bank, or by ferruginous marls wholly unfossiliferous, etc. These contrasts cannot be explained merely by the irregularity of the sea-floor, which is readily recognizable through the rapid increase or diminution in thickness of the strata; we are bound to accept current action in addition, making the relations locally so favourable that a numerous assemblage of Bivalves, Gasteropods, and other organisms were able to thrive within narrow spacial limits (for instance, the immediate neighbourhood of 'Schlern-klamm') without spreading into the surrounding area" (*loc. cit.* p. 219). I have had experience of very similar facts at Sella, Sett Sass, and Lagazuoi. On Sella, as at Schlern, a Coral-bearing dolomite of no great thickness appears amid the dolomitic shales on the plateau. Again, on visiting the top of Lagazuoi, I found unfossiliferous beds of a hard dolomitic sandstone, perfectly white, above the Schlern dolomite. From the occurrence of similar beds on the Sella massif, I took them to be of Raibl age, but followed along their dip to the north-east and saw their gradual passage into ordinary-looking yellow sandstones, with numerous fossils which proved to be the typical Raibl fauna of Travenanzes Valley. As the Travenanzes horizon is palæontologically younger than that of the Schlern plateau deposits, some part of the dolomite of Lagazuoi must in reality be of the same age as the fossiliferous Raibl beds of Schlern age. Thin beds of Cipit Limestones, like those of Cassian age, but much harder and whiter, occur at Valparola and Falzarego interbedded with the Travenanzes fossiliferous horizon.

Enough has been said to show that some of the anomalies of "Schlern dolomite" fall in the Raibl period, which has not been included by Mojsisovics in the Coral Reef epoch. Yet the heteropism of the Raibl strata adds to, and takes away from, the apparent thickness of the dolomite "reefs." It will be remembered that a younger or Upper horizon of fossiliferous Cassian strata is present in Ampezzo, which is absent in the Fassa and Gröden districts, and we know now that the upper part of the Schlern dolomite rock is

[1] Von Wöhrmann, u. Koken. "Die Fauna der Raibler Schichten vom Schlern Plateau." Zeitschrift d. D. Geol. Ges. 1892.

contemporaneous with fossiliferous Raibl beds. Going a step farther, we can see that by thinning off the dolomite both at its upper and lower horizons, it would be probable enough, especially in the Ampezzo area, that fossiliferous Raibl strata should rest on fossiliferous Cassian strata. According to Mojsisovics, this is actually the case. My reasons for not adopting this view have been already stated (Quart. Journ. Geol. Soc. 1893, pp. 64–69). It is true that in these valleys the Schlern dolomite becomes comparatively thin, and it looks like the dolomite rock interbedded at higher horizons of Raibl strata. But even if the dolomite rock were wholly or in part contemporaneous with fossiliferous Raibl strata elsewhere (*e.g.* the Schlern plateau strata), this would in nowise afford evidence in favour of the Coral Reef theory, but only of the familiar fact of Raibl heteropism. The important feature is that the dolomite bears no evidence of Coral building, and is no thinning-out prolongation of a "reef"; but is here and elsewhere in the Cortina valleys an independent horizon of dolomite above the Cassian fossiliferous beds—it is, therefore, not Cassian "reef-dolomite." The varying relations of Cassian, Schlern dolomite, and Raibl strata are represented in Diagram IV.

The Raibl deposits pass quite gradually into the overlying true marine deposit, Dachstein dolomite, with which an important faunal link connects it. Several species of the bivalve *Megalodon* appear in the highest Raibl strata, and this is the predominating genus in Dachstein dolomite. There are dolomite shales of Dachstein age undistinguishable from those of Raibl age, and dolomitic marls make their appearance now and then in true Dachstein horizons.

The two rocks, Schlern dolomite and Dachstein dolomite, are so much alike that one experiences in the field the utmost difficulty in distinguishing them. The characteristic Dachstein bivalves so common in some parts of the rock are entirely absent in others. Here we see an easy loophole of misconception in working out the stratigraphy of this area. How frequently it has given rise to error becomes apparent on comparing the maps or sections of different authors who have surveyed in the district!

An impression will now have been gathered of my opinion with regard to heteropism in the "Dolomites." Beyond doubt that exists, and to a very large extent; it alone explains the succession of Triassic rock in the "Dolomites." There are also reef-like communities of Corals, and of other fossil organisms, changing with the actual depth of the water and the character of the surrounding sediment. The Corals have but their fair share, along with other groups of marine life, in the thickness of any one formation, and just as important as the organic causes of heteropism are the inorganic. Most of all, the clear presentation of two epochs is necessary—the one is the volcanic period of Wengen age, when so many inequalities were introduced into the relief of the sea-floor and differential movements were set up in the basin of that part of the South Tyrol Triassic sea; the other is the Raibl period, and what it tells us of the culminating point in an age of unequal deposits and especially fluctuating conditions of level over these "volcanic" areas.

IV.—Apparent "Reef-Formations" in the "Dolomites" largely result from the particular history of Earth-movements in that area—Occurrence of Vertical and Inclined Planes of Fault in the "Dolomites"—Overthrusts—"Overcast" Bedding—Effects of Weathering.

Gradually the waters of the Rhætic and the great Jurassic ocean advanced over Alpine areas and the deposits of the Triassic Archipelago lay sleeping at unknown depths below a heavy weight of marine accumulations. The South Tyrol Trias and younger deposits alike shared in the tektonic movements which passed over the Alps during the long geological "days" of Mesozoic and early Tertiary time; but probably it was not until the Tertiary mountain-making period that the series of deposits was affected by tearing or sliding movements.

Tertiary movement begins a much more difficult chapter in the past history of the South Tyrol dolomites than the period of Triassic deposition. And we might be content to omit it entirely from present consideration, were it not that it produced many results in South Tyrol which cannot be dissociated from the "Coral Reef" question. It has left its symbols indelibly written on the rocks of the country, symbols as strange and as impossible of interpretation for the early school of geologists as ever were the ancient characters on the colossal monuments of Egypt and Syria for the unpractised eye. And when we learn to read, one of the first Miocene symbols in the "Dolomite" spells "*R e e f*" and is, being translated, *reduplication and faulting of rocks.*

The presence of a great number of vertical faults within the areas of Enneberg and Ampezzo has been already proved, also the influence of those in complicating the geology of the district and producing apparent reef-structure as at Sett Sass (Quart. Journ. Geol. Soc. 1893, pp. 58–77). I wish now to refer to inclined fault-planes. Mojsisovics first hinted at their occurrence in the dolomites,[1] *e.g.* "on the slopes towards the Duron Valley a partial overturning, or perhaps more correctly, over-thrusting of Werfen shales over Muschelkalk dolomite seems to have occurred. The exposures along the road leading from the Duron Valley up Col Rodella scarcely permit of any other explanation. *At the edge of the Rodella Fault-block Melaphyre dykes occur south-west of Col Rodella*" (*loc. cit.* p. 189; the *italics* are mine).

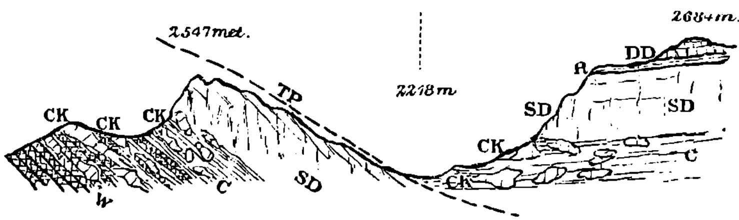
I drew attention to the occurrence of fault-planes with extremely low hade in the Dürrenstein Mountain, and again in the Buchenstein Valley, north of Arabba; but, as the subject was a large one, and as I had not then completed my survey of the Buchenstein and Sella districts,[2] I avoided treating it within the scope of my previous

[1] At the British Association Meeting in Edinburgh, July 1892, Prof. Lapworth, towards the close of his Presidential Address to the Geological Section, referred to the country of the dolomites as one which he believed would be found to be cut by a great many overthrust fault-planes.

[2] I hope soon to publish a geological map of the district between Sella Joch and Wolkenstein on the West, and Cortina d'Ampezzo on the East, surveyed to scale 1 : 25,000; and to give along with it a complete statement of my results.

paper. The planes at Dürrenstein hade south, the plane I referred to in Buchenstein was an overthrust fault-plane hading north. Dr. W. H. Salomon published a preliminary note[1] of his survey in the district of Marmolata Mountain, south of the Buchenstein and Cordevole Valleys, in which he reports that two overthrust fault-planes occur on the southern slopes of Marmolata hading north.

I shall at present confine myself to one typical example of the occurrence of an overthrust plane and its explanation of an apparent "Reef" in the district personally surveyed. The example selected is Sasso Pitschi (see accompanying section), a dolomite summit south of the Sella massif. It is a reef-like mountain, standing up from the



DD = Dachstein dolomite.
R = Raibl Marls.
SD = "Schlern dolomite" and limestone.
TP = Thrust-plane.
CK = Cipit limestone.
C = Cassian strata.
W = Wengen strata.

midst of Wengen beds on the Pordoi Joch. As will be seen from the description given by Mojsisovics (*loc. cit.* p. 238) the interbedding of Cipit Limestones with tufaceous rocks is peculiarly characteristic. The dolomite rock contains, especially at its base, remains of Corals and Crinoids. *Ammonites* also have been found in the dolomite. I find it impossible to consider the succession on Pordoi Joch undisturbed. On the south side, the Wengen lavas dip N.N.W. (20°–30°) and the conformable series of Cipit Limestones (Wengen and Lower Cassian age) and Schlern dolomite beds dip in the same direction at a rapidly increasing angle. The rocks on the north or Sella side are, on the contrary, remarkably horizontal, but where the terrain descends from Sella Mountain to Pordoi Joch, the strata dip slightly southward and south-eastward, *i.e.* outward from Sella (a dip which the strata exposed on the lower half of Sella massif continue to have all round its eastern side). On Pordoi Joch, therefore, we are presented with a repetition of the Cipit Limestone and the dolomite strata, owing to the passage of an overthrust plane of low hade, above the Sasso Pitschi rock. The thrust-plane hades northward and cuts away the dolomite rock of Sasso Pitschi, both in its eastward and westward extension below the Cassian beds of the

[1] Dr. W. H. Salomon, "Ueber den geologischen Bau und die Fossilien der Marmolata," Verh. der k.k. geol. Reichsanstalt, 7th March, 1893.

Sella block. This fault affords to my mind a simple explanation of all the appearances associated with "Coral Reef":—

1. That Sasso Pitschi appears to "rise out of Wengen beds."
2. That the dolomite rock of Sasso Pitschi has a steep cliff edge to the south, and a gentle slope to the north.
3. That it thins out on Pordoi Joch, except on the western side, where it *appears* to pass conformably under the dolomite rock of Sella massif.
4. The "overcast bedding with northerly dip" said to be observed on the northern slope of Sasso Pitschi.

This last-mentioned appearance is clearly shown at Sasso Pitschi, and is by no means the only case in which I believe it to be the result of fault movement. The thrust-plane observed at Sasso Pitschi may be followed with N.N.E. outcrop close under the cliffs of Sella to Pian de Sass, where it also explains the seeming anomalies of the succession. If we now proceed to mend this broken section according to the natural succession of the district, we have a fair representation of the particular volcanic zone from east to west, already referred to (see Diagrams I.–II.). Here, where we are on the borderland of the actual passage of Wengen and Cassian strata into their deeper sea equivalents, the main thickness of these beds is composed of volcanic lavas and tufaceous deposits. The Cipit Limestones and the Sasso Pitschi "dolomite" may of course be regarded as the direct continuation northwards of the upper part of the Marmolata deposit of limestone and dolomite, continued further north over Sella, Gardenazza, etc. This is an example perfectly analogous, therefore, with the case of the heteropism at Schlern Mountain, on its southern and northern sides, and the Seisser Alpe. There is scarcely any thickness of the Cassian horizon present below the Schlern dolomite of Sasso Pitschi; the Middle Cassian or "Stuores" zone partly developed as "Cipit Limestones" on the Sella slopes, passes to the east and north-east into the thin-bedded fossiliferous marls of Enneberg, and reaches a later palæontological development on these meadows than below Sella and Sasso Pitschi.

I have dwelt at some length on this example, because it shows again the tektonic nature of some of the difficulties hitherto professedly explained by the "Coral Reef theory." We must in every case clearly decipher the twofold nature of the difficulties in South Tyrol, for, as we have seen both at Sett Sass and at Sasso Pitschi, the battle is only half fought with a knowledge of the Triassic period. In the latter case, Sasso Pitschi, the heteropism of the Wengen and Cassian strata, together with the conformable succession of "Schlern dolomite," are the stratigraphical truths observed at Pordoi Joch. The tektonic fact is the overthrusting from the north of the system or "block" of strata belonging to the Sella massif along a plane formed in this southern part by the cut and tilted ends of the strata belonging to the fault-block of Sasso Pitschi and Cima Rossi. It is not necessary for the purpose of the present article to follow farther the course of this thrust-plane, or to describe in detail others which exist in the districts of Enneberg and

Ampezzo, Buchenstein and Upper Gröden. For the Pordoi overthrust is not an isolated occurrence, but one of several inclined planes of fault which pass through strata of all ages in this part of the "Dolomite Alps." Above Pian de Sass, on Sella Mountain, an overthrust fault passes through Dachstein dolomite, and just north of the Boe Spitz (the highest ridge of Sella) a fault plane with reversed hade has raised Dachstein Dolomite against Jurassic strata. The direction of these faults is S.S.W.—N.N.E., and they afford the most perfect analogy with the main faulting which has taken place in districts west and south-west. Suess says, in summing up the observations of faults in the Southern Alps (east of the Judicarian fault): "Long flexures have occurred passing locally into faults, which, running parallel to the Judicarian line, have let down the strata on the eastern side, and have caused overthrusting to the east, or more correctly from a W.N.W. direction towards E.S.E. These extend from the Judicarian line as far as the left side of the Etsch below Peri. Further, similar flexures have occurred which run more or less parallel with the Asta faults, lie south of these, and have let down the strata on the south, and sometimes overthrust them to the south. Some of the Judicarian faults swing round in sharp curves, in the proximity of the Etsch Valley, into the direction of the Asta faults" ("Das Antlitz der Erde," Bd. I. pp. 334–335). It is just such a swing-round that the inclined fault-plane of Pordoi and Sella shows, and I may state generally that the faults of Sella may be grouped with the Judicarian system, whereas those of Gröden Joch, of Buchenstein Valley, and, in short, the faults in this area which pass through anticlines of the deeper lying Triassic strata, belong to the Asta series. No hard and fast distinction can be drawn between these systems; they pass into one another and form one complicated system of movements, which may be proved even in the small district of Enneberg to have affected the positions of both Triassic and Mesozoic rocks.

By reason of these faults, the dolomitic rock has sometimes been so placed with regard to the earthy deposits below or above as to look like an independent reef from the midst of sedimentary rocks of its own age. Or it has been doubled upon itself, and thus, apparently, attains a much greater thickness. The harder rocks of Schlern and Dachstein dolomite have sometimes been pushed into new positions over the slipping substratum of earthy rocks without themselves undergoing much relative change of position or perceptible evidence of strain, except when complications are introduced by minor thrusting and faulting along the main planes. I hope to find out from specimens collected if any degree of internal change in the crystallization of the rocks may be due to thrust-strain. Visible signs of this strain are given by the "overcast bedding" at Sasso Pitschi and on the east side of Sella.

The appearance called "overcast bedding" is not always a concomitant of a thrust-plane, but is sometimes occasioned by the outward dip of the dolomite strata from the mountain. The weathering of the rock then produces a characteristic effect, *e.g.* on the west side of Dürrenstein, where the strata dip west; on the north side of Sett Sass, where they dip north; on the east side of Sella, where they dip east, etc., etc. Another form of "overcast bedding" is produced in the Cassian strata. The tufaceous or marly beds surrounding Cipit Limestone are worn or washed away more rapidly than the Limestones which gradually fall over and strew the steep slopes below the dolomite rocks. This is also a common reason why the reef-limestones predominate more, to all appearance, in the neighbourhood of the cliffs than on the less steeply inclined gradients of the "Alpen" or meadows.

A curious and particularly pleasing appearance is produced where a mountain slope of Schlern dolomite has been gradually denuded by snow and ice, wind and weather, of its Raibl "robe of many colours." Patches of greenish or reddish marls, from the size of a bean to the roof of a house, are left upon the pure crystalline whiteness of the dolomite. The sunlight sends its gleams upon it till the cold rock is lit with life, and the shimmer that runs through the leaves of an autumn forest is not more beautiful. All the more strange is the contrast to the Alpine climber when he reaches the top and finds on the other side of the mountain a giddy precipice of apparently unbedded rock. We cannot wonder that the idea of steep Coral cliffs facing the broad ocean and shelving inwards into calm bays and lagoons has long held its own in the mind of many as a fitting theory of the origin of such wonderful mountains! Beside it, any other explanation pales, and seems beset with endless complications.

For no sooner does one realize the main laws attending Tertiary movement in the "Dolomites" (a series of wide folds running, roughly speaking, east and west; anticlines segmented by steep fault-planes which meet and intercross as at Gröden Joch, or by overthrust fault-planes as in the Buchenstein Valley; synclines sinking unequally in many detached pieces, *e.g.* the Tofana and Kreuzkofl massif, Sett Sass, etc.), than new difficulties present themselves.

V.—Complete Harmony of the Geology of Enneberg in South Tyrol, with recognized methods of Alpine Mountain-making.

Since the main folding and overthrusting and East-West faulting took place, these planes of fault and the strata through which they passed have continued to suffer from movements of a vertical nature and usually in transverse direction (*cf.* Vacek's observations on North-South faults in the Etsch basin). For example, I have already referred to an important thrust-plane in the Buchenstein Valley. It may really be better called an east and west direction of overthrust faulting, for the main thrust is made up by the coincidence of several minor overthrusts, and it breaks eastwards into a number of diverging overthrusts. The whole series of faulting is cut off just west of the Arabba stream by a vertical fault of considerable throw, extending north and south, and letting down the Sella block in the west. This fault passes through the western limits of the Prelongei and Stuores meadows, while the Buchenstein over-thrust lies on the southern. Another important North-South fault occurs between Cherz and Varda, in the Buchenstein Valley, again letting down the western flank. What do we find now on the northern and eastern limits of Prelongei? Northward, the squeezed and shattered anticline of Gröden Joch passes across the meadows and is cut off by the north-south vertical fault traced southward from Heilig-Kreuz.[1] The mountains of Kreuzkofl and La Verella are let down to the east of this fault until Dachstein dolomite reaches almost the same low contours as it does at the Sella massif (eastern side), and at Sett Sass. We see, therefore, that the Cassian strata of Prelongei are pressed like a pliable plug into the midst of an ancient arena of cross-movements. And in this light the theory that the fossiliferous Cassian deposits collected in a basin more or less surrounded by high Coral cliffs of Sett Sass, Sella, Lagazuoi and Gardenazza, sinks into insignificance, for here we have something much grander! These are the processes of ages which have given us our grand Alpine Chains. The meadows of Enneberg have in *this* history one which will bear comparison with the proudest tales of Switzerland. They give us their trophy of miniature forms of mid-Triassic life; they give us also an insight into Nature's methods of mountain-making, on a miniature scale it is true, but following natural law as inevitably as did the spirals of their thousand Gasteropods, or the delicate intricacies within their myriad Brachiopods.

I must for one moment refer to the latest volcanic eruptions which took place, presumably also in Triassic time, in the districts of Predazzo and Monzoni (Fleims and Fassa Valleys). The innumerable dykes of the district often penetrate Wengen lavas and Schlern dolomite, and are said to be limited to a certain radial distance from the chief centres of eruption. The northern limit given, viz. Rodella, Canazei, and Marmolata, for the occurrence of intrusive porphyry in rocks younger than Lower Wengen, must, however, be extended to include the meadows of Prelongei, for in them I found intrusive sheets penetrating high horizons of Cassian strata,[2] and producing contact-metamorphism in sedimentary beds above and below. At Gröden Joch,[3] and in the Buchenstein Valley, dykes of porphyry occur in Lower Trias and Wengen horizons. Where they pass through Upper Muschelkalk, they have converted it *in situ* into a brecciated rock, or sheared it into shaly layers. Both on Gröden Joch and on the Buchenstein cliffs the porphyry is exposed in the main fault-lines which cut through these two anticlines of older Trias. In the Buchenstein Valley, above Varda, the volcanic rocks are hopelessly mixed up with the overthrust beds of Lower and Upper Muschelkalk and Buchenstein strata, but they are absent

[1] *Vide* Q.J.G.S. 1893, "General Map," p. 70, where the important faults in the Prelongei district are drawn.

[2] Q.J.G.S. 1893, *loc. cit.* p. 18, Map A.

[3] Cf. von Richthofen, *loc. cit.* p. 133, etc., who notes the occurrence of intrusive rocks at Gröden Joch.

in the highly-folded succession of the same rocks below the thrust-plane, at Ruaz, or in the series of radiating faults below Pieve. Further detail I cannot give in these pages; I would only indicate the natural considerations which suggest themselves with regard to the age of the intrusive sheets. Two hypotheses may be stated:—(1) The intrusions of Augite Porphyry in these cases may be of Triassic age, exposed along with the Triassic rocks through which they penetrated, by later faulting and erosion. Since they, as well as the lavas of distinctly Wengen age, often occur along the path of faults, it would seem that the Judicarian-Asta system of faults followed largely ancient lines of weakness, which had been marked by the outbreak of lavas in Triassic time, or intrusions of porphyry of uncertain age. (2) The idea that the intrusions may have been associated with Tertiary movements in the Alps is not supported in Enneberg, but rather the evidence shows that at this period the volcanic rocks, both contemporaneous and intrusive, behaved as a compact, united mass, along with the sedimentary rocks.

The Buchenstein Valley finds its tektonic continuation in the Pordoi and Rodella district, where, as a previous quotation shows (p. 53), the facts appear to be in the main analogous. If we now compare the great "Eruptive Fault" of Fleims and Fassa, we find that by its throw at Sattel Joch, the northern wing of the fault is Lower Trias, faulted to the same level as Schlern dolomite on the south. The "Eruptive Fault" changes in its relations at Viesena, but it may be traced east and west through the country to a considerable distance from the actual eruptive centres. Here and there along its main line or its radiating branches, dykes of porphyry and melaphyre occur, just as in the fault-lines further north. I should think there could be little doubt that these great longitudinal fault-lines, together with the parallel Villnös fault in the north, were developed under the same general conditions, and were for the most part of pre-Tertiary origin. These faults have all been important planes of movement since Mesozoic time. Tertiary faults in some places coincide with, or cross at varying angles, lines of Triassic disturbance. Where areas already considerably faulted have been affected in this way, the ultimate results may seem conflicting. More especially might this be expected in the Fassa or Rodella districts, but no such complication would gainsay the striking analogy which the "Eruptive Fault" of Fassa presents in its main tektonic aspects with the faults of Buchenstein and the Gröden Joch.

VI.—Conclusions with regard to Coral Formations in the Dolomites.

We are now in a position to examine more closely the points of agreement and difference which Coral formations in the Dolomites present with the various theories of Coral-reef growth. Mojsisovics[1] has clearly shown to what a great extent variation in

[1] Mojsisovics, "Dolomit-Riffe," etc., pp. 505–510, and more especially for general tektonic relations, chap. xvii.

the rate of subsidence and the depth of the sea-floor has influenced mid-Triassic deposit in South Tyrol. Rothpletz, in his most recent work,[1] has discussed the entire question and brought forward the importance of submarine banks of sediment. While I have attempted to indicate an irregular sea-floor in Diagrams I. to IV., I designed those diagrams mainly to show one or two other facts of almost equal importance: (*a*) that coralline "Cipit Limestone" and Coral Dolomite form comparatively small thicknesses of interbedded rock and not the main body of the mountain masses; (*b*) that Corals began to grow in Wengen time on a submarine volcanic ridge on the northern edge of a great area of subsidence, and travelled inward and northward in Cassian time; (*c*) that extensive banks of Coral were formed in scattered localities during the Raibl period of shallower water and Dolomite deposit.

The Coral-blocks and lenticular "Cipit Limestones" were, therefore, to begin with, members of a submarine barrier-ridge, and never were strand-reefs. There was, from early Wengen time, an inner protected part of the sea whose bed, so far from being deepened in the way indicated either by Murray or Guppy, was constantly being shallowed by the rapid accumulation of shore sediment and the intermittent eruption of porphyry and lava. The movement was one of subsidence, proved by the fact that the Corals moved northwards, or inwards, in the later Cassian periods, and gave place, along the old Fassa-Gröden barrier, to the formation of marine Calcareous deposit. Probably occasional stationary intervals retarded the subsidence of this inner sea, and were, so far, favourable for Coral-growth. Several authors have called attention to the evidence of the action of currents in those areas. The vicinity of land is proved by the frequency of plant remains everywhere in the Wengen sediments. In the Cassian strata of Enneberg these are very rare; on the other hand, in the Ampezzo district, fragments of stems and leaves are common at certain horizons of Cassian and also of Raibl strata, and were not unlikely swept here by some wide river-channel from the north-west. The area of depression, south of the Fassa-Gröden barrier, extended also considerably westward; it was a basin in which, during Permo-Triassic time, volcanic activity was never long absent.

Comparing now the conditions existing in the West Indies at present, the resemblance is most striking. We read from Langenbeck[2] that barrier-reefs "have built on the outermost edge of extensive banks of sediment which have been heaped up along the whole North Coast of Cuba by sea-currents" (*loc. cit.* p. 18); and again, "It is exactly this difference in the degree of subsidence which produces the contrasts (so very characteristic of the north-west part of the Caribbean Sea) between great oceanic depths and

[1] Rothpletz, "Ein geologischer Querschnitt durch die Ostalpen," Stuttgart, 1894, pp. 52–67, "Ist der Schlerndolomit ein Korallenriff-Bildung"—a full discussion of the question.

[2] Dr. R. Langenbeck, "Die Theorieen über die Entstehung der Koralleninseln und Korallenriffe und ihre Bedeutung für geophysische Fragen." Leipzig, 1890.

relatively shallow portions of the sea, the two abutting almost directly on one another, united by steep slopes" (*loc. cit.* p. 24). In the Australasian Archipelago we find essentially similar physical and natural phenomena—in the Philippine Islands, the Solomon, Pelew, and Fiji Islands, etc. There too, reef-Corals show special favour for submarine ridges and plateaux in the immediate proximity of areas of strongly-marked subsidence, and very generally where volcanic agencies have recently been, or still are, active. Everyone conversant with the literature of recent Coral-reefs will recall abundant testimony of the co-operation of the same great geophysical forces which influenced the Triassic seas of South Tyrol, and made them locally suitable for the existence of beds of reef-Coral and the development of a rich fauna.

Guppy and other observers have stated that during "negative," or shallowing movement, Corals grew seldom in reef-like fashion; they tended rather to spread laterally and form extensive banks, or even terraces. This is admirably illustrated by the Coral-banks of the Raibl period. Their mode of occurrence reminds one, too, of the "Coral Oolite" beds of Jurassic deposits. The Coral rock formed in South Tyrol in Raibl time is not Limestone; it is a member of a highly Dolomitic series and is itself Dolomitic. It must be remembered that the Dolomitism of the Raibl-Dachstein period is by no means confined to South Tyrol, but is a common feature in greater or less degree in the Alps and in Keuper deposits elsewhere. The volcanic eruptions of Predazzo and Monzoni have been attributed to the early part of the Raibl period. This would conform with the local oscillations of level in neighbouring areas and the temporary "back-flow" of the water. The Pelew and Fiji Islands and the Sandwich Islands yield again good cases of analogy.

Darwin's theory demands fairly constant equipoise throughout a long geological age between the rate of growth of reef-Coral and the rate of subsidence of the reef-basis. There is *not* satisfactory evidence in favour of this in South Tyrol; my special survey in a part of the district seems to me to justify, without doubt, the position of those authorities who have contended that the immense thicknesses of "Schlern Dolomite" rock were an ordinary marine deposit and not "Coral-reefs."

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The Map is contoured at Heights of 1000 - 1500 and 2000 Metres.

DIAGRAMS ILLUSTRATING "CORAL IN THE DOLOMITES OF SOUTH TYROL," BY MISS MARIA M. OGILVIE, D.Sc.