17. *The WALDENSIAN GNEISSES and THEIR PLACE in the COTTIAN SEQUENCE.* By J. W. GREGORY, D.Sc., F.G.S., of the British Museum (Nat. Hist.). (Read February 7th, 1894.)

[PLATE XV.]

CONTENTS.

	Page
I. Introduction	232
II. The Cottian Sequence and Previous Literature thereon	236
III. The Gneisses	239
(a) The Paradiso Massif.	
(b) The Waldensian Gneisses.	
IV. Conclusions as to the Relations of the Beds	260
V. The Contact-Metamorphism	262
VI. The Origin of the Gneissic Structure	264
VII. The Age of the Waldensian Gneisses	267
VIII. Summary of Conclusions	274

Note.—This paper was originally sent in to the Geological Society on October 19th, 1892, but owing to the writer's absence from England the reading, and consequently the publication, have been delayed. No reference is therefore made to some recent papers on this and an adjoining part of the Alps, as they do not affect the argument.

I. INTRODUCTION.

THE Cottian Alps consist of three main lines of mountains occupying an area roughly triangular in shape, and forming the extreme western segment of the great curve of the Western Alps. They may be divided into three groups: the Northern Cottians, running E.N.E. and W.S.W. from Roche Melon to Mont Thabor; the Western, running from Mont Thabor S.E. to Monte Viso; and the Eastern, which completes the triangle by continuing the line of the Graians southward from Roche Melon till it joins the Western chain at its southern end. Of these three ridges the Northern and the Western form the main topographic chain, which connects the group of the Graians with the chain of the Maritimes. The arrangement of these two divisions of the Cottians is, to a large extent, independent of their geological structure. Thus Mont Thabor is composed of Carboniferous and Triassic rocks; south-east of this we leave the Triassic limestones at Monte Chaberton and pass to the gabbros and variolitic series of Mont Genève, which are certainly not earlier than the Upper Mesozoic: to these succeed the calc-schists and mica-schists, and then a vast series of gabbros, serpentines, amphibolites (epidiorites, etc.), and glaucophane-schists, which extend from Bric Bouchet to the Viso. Along most of these Western Cottians the direction of the mountains does not agree with the strike of their constituent beds; branches from the main chain run off along a north-and-south line and show the efforts of the forces of elevation to adapt themselves to the rock-masses which they were upraising. Such, *e. g.*, is the range that forks from the main chain

to the north of the Col de Traversette and runs from Monte Granero through Punta Manzol and Punta Agugliassa to Punta Plengh. This explanation does not, however, apply to the north-and-south ridges that form the main features in what Mr. Coolidge aptly describes¹ as "the very tangled and little known ranges around Césanne."

A comparison of the Eastern with the Western and Northern Cottians reveals several points of much interest. Thus the two latter are simple topographically and complex geologically; they include rocks of very different ages and characters, from the Upper Mesozoic or Eocene diabases of Le Chenaillet and the Jurassic limestones of Monte Chaberton to the old eruptives of Monte Viso; they have been upraised by earth-movements of considerable complexity, involving extensive foldings, inversions, and overthrust faults. The Eastern chain, on the other hand, is complex and inconspicuous topographically, having been cut across by the valleys of the Waldenses; but it is comparatively simple geologically. It is composed essentially of a series of schists and schistose rocks—possibly bent into an anticlinal, with a series of banks of coarse fresh augen-gneiss occurring along the axis of the fold.

It has been generally agreed that the rocks of the Eastern Cottians may be grouped into three series, a fundamental Laurentian gneiss (the 'central gneiss' of Zaccagna²) at the base, covered by a double set of schists, the Upper and Lower Archæan schists of Prof. Bonney³; these three correspond to the 'gneiss antiche,' the 'zona delle pietre verdi,' and the 'terreni cristallini stratificati più recenti' of Gastaldi.⁴ This classification and the view of the antiquity of the basal gneiss has been accepted by all recent writers on Cottian geology, including, in addition to those already quoted, Baretti,⁵ Lory, Sterry Hunt,⁶ Sacco,⁷ and Gianotti⁸; by all, in fact, since the abandonment of the old view of the Jurassic age of the whole series. This classification, moreover, is in harmony with the almost universal sequence of the pre-Cambrian schists. M. Michel-Lévy has referred⁹ to the identity in the threefold series in the Central

¹ W. A. B. Coolidge, *Alpine Journ.* vol. xiv. p. 336.

² D. Zaccagna, 'Sulla Geologia delle Alpi occidentali,' *Boll. R. Com. geol. Ital.* vol. xviii. (1887) pp. 346-417, pls. ix.-xi.

³ T. G. Bonney, 'Notes on Two Traverses of the Crystalline Rocks of the Alps,' *Quart. Journ. Geol. Soc.* vol. xlv. (1889) pp. 67-109.

⁴ B. Gastaldi, 'Studi geologici sulle Alpi occidentali,' pt. i. *Mem. descriz. Carta geol. Italia*, vol. i. (1871) pp. 1-48, pls. i.-vi.; pt. ii. *ibid.* vol. ii. (1874) pp. 1-61, pl. i.

⁵ Baretti, 'Studi geologici sul gruppo del Gran Paradiso,' *Atti R. Accad. Lincei*, ser. 3, *Mem.* vol. i. pt. i. (1877) pp. 195-313, 7 pls.

⁶ T. S. Hunt, 'Gastaldi on Italian Geology and the Crystalline Rocks,' *Geol. Mag.* 1887, pp. 531-540.

⁷ F. Sacco, 'La Géotectonique de la Haute Italie occidentale,' *Mém. Soc. Belge Géol. Pal. Hydr.* vol. iv. (1890) pp. 3-28, pl. i.

⁸ G. Gianotti, 'Appunti geologici sulla Valle di Chialamberto (Valle di Lanzo—Alpi Graie),' *Boll. Soc. geol. Ital.* vol. x. (1891) pp. 149-167, pl. v.

⁹ Michel-Lévy, 'Note sur la Formation gneissique du Morvan et Comparaison avec quelques autres régions de même nature,' *Bull. Soc. géol. France*, ser. 3, vol. vii. (1879) pp. 862-866.

Plateau of France, Brittany, and the Western Alps (Oisans), in Switzerland as at the Simplon, in Spain as in Cantal, in Germany as in the Eulengebirge and the Oberpfälzerwaldgebirge, and also in Canada. The same series, basal gneisses, then coarse gneissose mica-schists with amphibolites and upper less foliated schists and phyllites, can be followed even farther than M. Michel-Lévy has done; it occurs in China, as described by Richthofen,¹ and more recently by Vélain,² who has pointed out the close resemblance of the gneiss to that of the Simplon. In Brazil the same sequence occurs, on the authority of Hartt³ and Sterry Hunt; in Tasmania, as described by Thureau⁴; in India⁵ it is represented in the Sub-Himalaya by the central gneiss, the gneissose schists and foliated slate series, while in some places, as around Sikkim, the middle member of the 'Daling' series contains many hornblendic schists. In Scandinavia occurs the similar sequence of 'jern gneiss' (with magnetite), and 'gneiss gris à grenat,' or common gneiss with amphibolites, with overlying phyllites; in Finland the succession is the same, and Lucas⁶ compares it with that established by Profs. Gümbel, Groth, and Bonney in Saxony, the Vosges, and the Alps respectively.

In all these localities the sequence is fundamentally the same, the only variation being in the position of the amphibolites, though these are always confined to the two upper divisions.

While the accepted theory of the structure of the Cottians numbered among its advocates practically all recent writers on the subject, and as it was in harmony with this almost world-wide sequence, it appeared rash in the extreme to doubt its truth. Two previous visits to the area and a study of its literature and maps had, however, raised several difficulties which appeared insuperable. If the gneiss were the oldest rock in the district, why had it escaped the crumpling and contortion, the foldings and faulting to which the other rocks have been so extensively subjected? Why are its minerals so fresh when those of the schists around are so weathered and altered? Why does it happen that the mica-schists near the gneiss are generally so much coarser than at a distance, and so frequently garnetiferous? Again, if the gneiss is the oldest rock, why have none of the intrusive sheets and dykes of serpentine and amphibolites of the 'pietre verdi' series ever penetrated it? They cut through all the other rocks, from the Mesozoic limestones to the

¹ F. von Richthofen, 'China,' vol. ii. (1882) p. 706.

² Vélain, 'Géologie de la Chine,' Bull. Soc. géol. France, ser. 3, vol. ix. (1881) pp. 474-475.

³ C. F. Hartt, 'Geology and Physical Geography of Brazil,' 1870, pp. 550-551.

⁴ Thureau, 'Tasmania—West Coast, Progress Reports of Mines, no. 2: Mount Heemskirk and its Mineral Deposits and Mines,' Tasmanian Parl. Papers, 1881, no. 82; and Johnston, 'Geology of Tasmania,' 1888, p. 23.

⁵ Medlicott in 'Manual of Geology of India,' 1879, pt. ii. pp. 614, 616, 627.

⁶ R. N. Lucas, 'Notes on the Older Rocks of Finland,' Geol. Mag. 1891, pp. 173, 174; see also Sederholm, 'Studien über archaischer Eruptivgesteine aus dem südwestlichen Finnland,' Tscherm. Petr. u. Min. Mitth. vol. xii. (1891) pp. 98-100.

lowest mica-schists: they approach very close to the gneiss, but never enter it. Gastaldi's map¹ of the Paradiso, on the contrary, actually shows one broken across by the gneiss (fig. 2, p. 240). In reply to the enquiry as to whether any case were known of an intrusion of the 'pietre verdi' series into the central gneiss, Prof. Sacco assured me that such is impossible, as the occurrence of one of this series in the gneiss would prove that this belongs to the newer gneisses. Gastaldi, who fully recognized both the fact and its significance, boldly claimed² that this proved that the 'pietre verdi' rocks were not igneous but bedded sediments; if they were intrusive, he argued, they would certainly have somewhere cut the basal gneiss. There seemed, however, another alternative, viz. that the central gneiss may be newer and not older than the overlying schists; Gastaldi does not appear to have considered this explanation, which was not opposed to any of the facts known to me. Prof. A. C. Lawson's remarkable work on the geology of Rainy Lake,³ proving that the 'Laurentian' gneiss was there intrusive into the overlying rocks which have been correlated with the Huronian, showed the possibility of the truth of this explanation. Prof. Lehmann⁴ and Dr. Danzig's⁵ confirmation of Naumann's view of the intrusive nature and post-Archæan age of the Saxon gneisses and granulites, and Mr. Barrow's⁶ description of intrusive gneiss-dykes in Forfar, suggested the possibility that the intrusive nature of the gneiss might not be exceptional. Moreover, M. Michel-Lévy's⁷ demonstration that the protogine gneiss which forms the nucleus of Mont Blanc is an eruptive granite, and not a basal gneiss, showed that the same relation holds in at least one place in the Alps. There are, however, considerable differences between the protogine gneiss of Mont Blanc and the fresh gneisses of the Cottians, and as these mountain-groups belong to different Alpine zones, which are arranged on very different plans, I was not inclined hastily to apply conclusions from one to the other.

Impressed by these doubts, I was led to devote most of the time at my disposal for field-work during the summer of 1892 to a careful examination of the Cottian gneisses, in the hope that by working along the junctions some sections might be found that would settle the exact relations of the two series. At the same time it became necessary to settle the nature of the relation between the schists and

¹ Gastaldi, *Mem. descriz. Carta geol. Italia*, vol. i. (1871) pl. vi.

² Gastaldi, in letter to T. S. Hunt, *Geol. Mag.* 1887, p. 536.

³ A. C. Lawson, 'Report on the Geology of the Rainy Lake Region,' *Ann. Rep. Geol. Surv. Canada* for 1887, pt. F, 182 pp. and map.

⁴ J. Lehmann, 'Die Entstehung der altkrystallinischen Schiefergesteine, mit besonderer Bezugnahme auf das sächsische Granulitgebirge . . .,' Bonn, 2 vols., 1884.

⁵ E. Danzig, 'Ueber die eruptive Natur gewisser Gneisse sowie des Granulits im sächsischen Mittelgebirge,' *Mitth. Min. Instit. Univ. Kiel*, vol. i. (1888) pp. 33-79.

⁶ G. Barrow, 'On certain [Highland] Gneisses,' *Geol. Mag.* 1892, pp. 64-65; [see also *Quart. Journ. Geol. Soc.* vol. xlix. (1893) pp. 330-356.]

⁷ Michel-Lévy, 'Étude sur les roches cristallines et éruptives des environs du Mont-Blanc,' *Bull. Serv. Carte géol. France*, no. ix, 1890, 26 pp. and plates.

sediments of Gastaldi's 'pietre verdi' group. This subject will be dealt with in a subsequent communication by Mr. A. M. Davies, of the Royal College of Science, London, and myself. Mr. Davies gave me the great benefit of his assistance, as well as the pleasure of his company, during the examination of the gneiss. I must moreover express my thanks to Prof. Sacco for the opportunity of examining the rock-collections named by Sismonda at Turin; also to Dr. G. Giannotti, who guided us over the sections described by him on the south side of the Valle Grande at Chialamberto; to Signor Ing. Sommariva, to whom we are indebted for much information regarding, and the opportunity of a visit to, the Vonzo mines; and to Prof. Stevens, of Turin, whose kind help added much to the pleasure of a visit to the Valle Grande.

II. THE COTTIAN SEQUENCE AND PREVIOUS LITERATURE THEREON.

Even before Fournet's 'Mémoire sur la Géologie de la partie des Alpes comprise entre le Valais et l'Oisans'¹ and Lory's monograph, 'Description géologique du Dauphiné,'² had given a comprehensive view of the main features of the structure of the Cottians, it had acquired a somewhat extensive literature, dating from the works of Faujas St. Fond (1781), Robilant (1786), Morozzo (1793), and de Saussure (1796). We owe to M. Kilian³ a bibliography of the French side of the range, and to Prof. Baretta and Dr. Portis⁴ a similar work for the Italian; they are brought up to 1891 and 1881 respectively. It is, however, here unnecessary to refer to the earlier literature as, with the exception of the *absolute* age of some of the schists and sediments, there has been a general agreement amongst recent writers as to the *relative* age of the whole series. Lory, it is true, regarded the 'schistes lustrés' of Cesana as Triassic, a view recently put forward again on palæontological grounds, but he fully accepted them as younger than the underlying schists and both as newer than the gneiss.

The question of the relations of the gneisses and the schists has been twice discussed in recent years, and it is only necessary to refer to those two memoirs. In 1887 Zaccagna published his well-known paper 'Sulla Geologia delle Alpi occidentali,'⁵ in which he described in detail five sections across the Western Alps from Mont Blanc to east of the Col di Tenda. He recognized the following sequence:—

¹ Fournet, Ann. Soc. roy. Agric. Lyon, ser. 1, vol. iv. (1841) pp. 105–183, 483–560; vol. ix. (1846) pp. 1–112; ser. 2, vol. i. (1849) pp. 185–269, pl. i.

² Lory, Bull. Soc. Stat. Isère, ser. 2, vol. v. (1861) pp. 1–240, pl. i.; ser. 2, vol. vi. (1861) pp. 1–260, pls. ii., iii.; ser. 2, vol. vii. (1864) pp. 4–252, map.

³ Kilian, "Notes bibliographiques pour servir à l'histoire géologique des Alpes françaises—Le Dauphiné," nos. 1500–1566, An 26–27, 1890–91.

⁴ 'Bibliographie géologique et paléontologique de l'Italie,' 2^{me} Congrès Géol. Internat. Bologna, 1881, pp. 3–36.

⁵ Zaccagna, Boll. R. Com. geol. Italia, vol. xviii. (1887) pp. 346–417, pls. ix.–xi.

Miocene.

Eocene.

Cretaceous.

Jurassic.

Triassic. Grey, schistose, compact, and brecciated limestones, talc-schists with serpentines, etc.

Permian.

Carboniferous.

Pre-Palæozoic.	Zone of mica-schists, etc.	1. Calc-schists, mica-schists, quartzites, with saccharoidal limestones, tabular gneiss with syenites and granites.
2. Do. with serpentinous rocks, gabbros, diabase, and amphibolic, epidotic, and chloritic rocks.
3. Do. with massive diabase and porphyry.
	Zone of Central Gneiss.	Gneiss, augengneiss with white granite, talcose and micaceous granites (protogine of Mont Blanc).

With the Cainozoic and Mesozoic beds we have little to do; the important points are:—(1) that Zaccagna agrees with Gastaldi and some earlier writers that the whole of the true schists and the more normal sediments associated with them must be assigned to the pre-Palæozoic; (2) that he maintains that a definite sequence in them can always be established, and that the beds of ‘central gneiss,’ which Gastaldi and Baretto regarded as accidentally distributed through the schists, occupy a constant position at the base of the series. In his map he represents the ‘central gneiss’ as forming a continuous band from Bussoleno to Venasca, and in his section across the Southern Cottians shows it as occupying the axis of a great anticlinal. In his summary of conclusions he is very emphatic that “the central gneisses are not a mere lithological accident in the mass of mica-schists and other crystalline rocks, . . . but they hold a constant place in the series and form the base and the nucleus of the various ellipsoids of elevation.” Further, he maintains (pp. 415, 416) that “there does not exist a gradual passage between the crystalline rocks of the Alps and those of the fossiliferous series, as we ought to admit if we adopt the opinion of Lory, according to whom the Archæan calc-schists of the Cottian Alps and of the valley of the Arc represent a great part of the Triassic series.”

In complete accord with the views of Zaccagna upon these main points are those of Prof. Bonney, who in 1889¹ published his ‘Notes on Two Traverses of the Crystalline Rocks of the Alps.’ Bonney’s two most important conclusions were the fundamental unity of the sequence of gneisses and schists in the Eastern and the Western Alps and their Archæan age. He crossed the Cottians to the north of Zaccagna’s main section and concludes “that, broadly speaking, a stratigraphical succession can be detected in the gneisses and schists of the Alps, and that these rocks are of Archæan age.” He strongly opposed Lory’s view of the Triassic age of the ‘schistes lustrés,’ or calc-schists of Cesana, and attributed them to his Upper Archæan

¹ Quart. Journ. Geol. Soc. vol. xlv. pp. 67–109.

Fig. 1.—*Sketch-map illustrating the distribution of the Waldensian Gneisses.*

Scale: $\frac{1}{500,000} = \cdot 1267$ inch to the mile.

[For 'Crisolo' read 'Crissolo'; for 'Merciantiaira' read 'Merciantaira';
for 'Giordano' read 'Giordani.']

series. In regard to the gneiss, however, Prof. Bonney twice suggested,¹ from microscopical examination, that it is "not impossibly of igneous origin;" but he insisted on the remarkable coincidence between it and the Laurentian gneisses.²

Dr. Diener, in the admirable summary of the subject in his 'Gebirgsbau der Westalpen,' accepts (pp. 15, 16) the same threefold sequence; but he remarks (p. 33) that the evidence for Zaccagna's anticlinal is not conclusive, and shows that part of the 'schistes lustrés,' though in another district, are certainly Triassic.³

The work of both Zaccagna and Bonney was executed on the passes; failure, however, on previous occasions to obtain sufficiently satisfactory exposures on the closely cultivated, moraine-strewn flanks of the valleys, led me to trust mainly to the peaks and ridges and to follow the strike from north to south, in the hope of thus finding a series of clear exposures of the junctions.

III. THE GNEISSES.

Zaccagna, in the exquisite map attached to his memoir 'Sulla Geologia delle Alpi occidentali,' figures the gneiss as a continuous band from Bussoleno to Venasca, a distance of some 80 kilometres or 50 miles. I had, therefore, planned to start at the north end, work steadily south along the western margin of the gneiss, and return north along the eastern margin. The first day's work, however, showed that no such simple scheme as this was practicable. The gneiss may be found a short distance south of Bussoleno, forming a low bank, ranging along the base of the hills, below the villages of Fornelli and Combe; but on attempting to work south along the line of junction marked by Zaccagna, one soon left the gneiss and struck a wide stretch of mica-schists, with calc-schists on the north-western border. At two or three places to the south there are small exposures of dykes or banks of the gneiss, but we could find no trace of the great sheet of gneiss which Zaccagna's map had led us to expect. All along the line, the results were much the same; instead of the continuous band of gneiss, there appears to be really a series of disconnected masses. This is the case not only in the Bussoleno district, but as far south as the line of gneisses was followed; it is shown in the map of Vasseur and Carez, which in this respect appears to be more accurate than Zaccagna and Mattiolo's map. It seems, therefore, best to discontinue the use of the term 'central gneiss,' which has been applied in the area to many different rocks and moreover assumes the point in dispute. But as the gneisses are mainly exposed in the Waldensian valleys they may be appropriately called the 'Waldensian gneisses.' They may be divided into seven groups, each of which is perhaps best described separately:—

¹ Quart. Journ. Geol. Soc. vol. xlv. (1889) pp. 83 and 99.

² *Ibid.* p. 97.

³ Such is the case around Lago Paroird and Mont Brisé, 'Gebirgsbau der Westalpen,' p. 103.

1. Bussoleno-Susa. (Dora Valley.)
2. Palé. (Sangonetto Valley.)
3. Meano. (Chisone Valley.)
4. Angrogna Valley.
5. Pellice Valley.
6. Barge. (Giandole Valley.)
7. Crissolo. (Po Valley.)

Before, however, considering these, a digression to the exposure of gneiss nearest the northern end of the Cottians may well be made, in order to compare the rocks of the little-known Waldensian valleys with those of the classical massif of the Paradiso.

(a) The Paradiso Massif.

The Gran Paradiso has long been taken by geologists as the type of an Alpine massif in its simplest form, while it has been rendered classic by the descriptions of Desor, Gastaldi, and especially by the well-known monograph of Baretto.¹ The Paradiso belongs to the Graian Alps, but it is a member of the same Alpine zone as the Waldensian gneisses. It occurs immediately at the northern end of the Cottians, and consists of a series of gneisses and schists which,

Fig. 2.—*Reproduction of part of Gastaldi's map of the Paradiso.*

on the ground of lithological resemblance, have been correlated by Gastaldi and Baretto with the similar rocks farther south. The geology of the district has been fully described by Baretto, whilst in

¹ 'Studi geologici sul gruppo del Gran Paradiso,' Atti R. Accad. Lincei, ser. 3, Mem. vol. 2. pt. i. (1877) pp. 195-313, pls. i.-vii.

1892 Dr. Gianotti¹ and Prof. Chelussi² have added considerably to our knowledge of the south-eastern corner of the massif. From the works of these authors we know that the main part of the massif consists of a coarse augen-gneiss which passes into a granite at the centre and becomes finer grained around the margin; it is surrounded by schists, which are often intensely contorted and penetrated by a series of gabbros and 'pietre verdi.' Near the gneiss the strike both of the schists and greenstones is as a rule parallel to the margin; and the maps show the beds of 'pietre verdi' and limestone in the schists encircling the gneiss, in a manner which suggests that their strike is due to uplift around a central intrusion. Gastaldi admits that the ellipsoid of elevation of the Paradiso is due to the intrusion of the gneiss, but he maintains that this was in a solid state,³ and this is apparently accepted by most Italian geologists. Gastaldi, however, in the map previously quoted, of which part is here reproduced (see fig. 2), has shown one band of the 'pietre verdi' completely broken across by the gneiss in a manner that appears almost inexplicable for a solid intrusion. Though not inclined to place much reliance on Gastaldi's mapping, I thought it advisable to select this area for the examination of the relations of the gneisses and schists. A further advantage offered by this part of the massif was that the line of junction of the two had recently been precisely marked on a map to the scale of 1:25,000, issued by Dr. Gianotti in illustration of his paper on the mode of formation of the valleys around Chialamberto.

The central gneiss has been so well described macroscopically by Baretta⁴ and microscopically by Chelussi⁵ that there is no need here to say more than that around the margin it is typically a coarse augen-gneiss with felspar 'eyes' often 2 inches in diameter, and with all the minerals remarkably fresh.

In the centre of the massif the gneiss, as we are told by Baretta⁶ and Gianotti,⁷ passes into a normal coarse-grained granite, without any trace of foliation. At the actual contact with the surrounding schists the gneiss becomes much more finely foliated and the large felspar 'eyes' disappear. The junction, however, is unfortunately generally covered by moraine, and actual contact is rarely to be seen. Above the level upland valley, on the lower edge of which stands the hamlet of Vonzo, the stream of the same name runs for some distance along the line marked on Dr. Gianotti's map as the junction

¹ G. Gianotti, 'Appunti geologici sulla Valle di Chialamberto' (Valle di Lanzo—Alpi Graie), Boll. Soc. geol. Ital. vol. x. (1891) pp. 149-167.

² I. Chelussi, 'Studio microscopico di alcune rocce della Valle di Chialamberto in Piemonte,' pt. i. Giorn. Min. Crist. e Petrogr. vol. ii. (1891) pp. 196-210; pt. ii. *ibid.* pp. 270-277.

³ Gastaldi, Mem. descriz. Carta geol. Italia, vol. ii. (1874) p. 58.

⁴ Baretta, 'Gran Paradiso,' Atti R. Accad. Lincei, ser. 3, Mem. vol. i. pt. i. (1877) pp. 208-211.

⁵ Chelussi, *op. supra cit.* pt. ii. Giorn. Min. Crist. e Petrogr. vol. ii. pp. 270, 271.

⁶ Baretta, *loc. supra cit.*

⁷ Gianotti, *op. supra cit.* p. 153.

of the two series ; no exposure of this can be here seen *in situ*, but some of the boulders on the banks and in the bed of the stream do show the actual junction.

Fig. 3 shows one of these cases : the boulder consists of a mass of fine-grained gneiss including two masses of the 'pietre-verdi' series ; the foliation of the gneiss flows round the inclusion, which shows clear contact-alteration to a depth varying between $\frac{1}{4}$ and $\frac{1}{2}$ inch. The gneiss is finer in grain than any we could find there *in situ*, but other boulders showed a passage from gneiss having characters identical with this to the normal coarse-grained rock. Microscopic examination completely demonstrates that the gneiss belongs to the central mass. Half an inch from the contact the gneiss is clear and colourless, and all the minerals are remarkably fresh ; the main mass of the rock is formed by a water-clear quartz-felspar mosaic,

Fig. 3.—Inclusion of 'pietre verdi' in the gneiss of the Vonzo Valley.

[Reproduced from a photograph.]

the constituents of which are often united in pegmatitic intergrowths. The quartz has a well-marked circular polarization ; the orthoclase is occasionally idiomorphic, and Carlsbad twins occur ; these crystals also show signs of corrosion. Oligoclase occurs only as a few rounded grains. The mica is white and occurs in long blade-like crystals, most of which lie along the planes of foliation ; a few, however, are scattered irregularly through the quartz-felspar mosaic.

Adding the letter Φ to indicate foliation, and the bracket $\sim$ to show simultaneous crystallization, the formula for this rock, according to M. Michel-Lévy's system,¹ would be :

$$\Gamma\Phi\alpha\gamma \overline{F_5} \overline{ma_1a_1g}.$$

The rock is therefore a muscovite-granitoid gneiss.

Near the actual junction of the two rocks occur many flakes of chlorite which have doubtless been formed by the alteration of fragments of the 'pietre verdi'; a few corroded and broken garnets, showing optical anomalies due to strain, also occur. The contact-line is irregular, the gneiss having cut into the included block; this is now so altered that it is not easy to say what was its original constitution. The principal constituents are rounded grains of plagioclase, small, strongly dichroic crystals of green hornblende, and some irregular grains of glaucophane; these are scattered through a mass composed of rounded grains of epidote. A little zoisite and some patches of titanoferrite are also present.

The green included fragment is, therefore, an altered basic igneous rock and may be called a glaucophane-epidiorite.

Farther up the valley of the Vonzo the gneiss leaves the river and runs due north, below the chalets of Culet and west of the crag below the Capella della Madonna di Ciavinis. No section showing the junction could be found, but close to it the 'pietre-verdi' series is very contorted and along it loose blocks of garnetiferous amphibolite and glaucophane-schist are very abundant; these both probably indicate contact-alteration.

The junction of the two series is, however, much better shown on the south side of the Stura Valley, along a line to which we were guided by Dr. Gianotti; the sections occur on both sides of the steep Vallone Verso, north of the hamlet of Ortiero. In descending the valley for some distance below the main bridle-path one crosses the ordinary 'pietre verdi' series; the rocks of this series then become much contorted and garnetiferous, and 40 feet lower down pass into a crushed decomposed rock crowded with large garnets; immediately below this is a fine-grained gneiss-rock which Dr. Gianotti called a 'talcose gneiss' and accepts as the transition-rock between the gneiss and the schists. The talcose gneiss passes gradually below into the normal augen-gneiss. The actual junction here is clear, but it is not easy to be sure of its exact nature, as there has been a certain amount of slipping and squeezing out of the soft decomposed garnet-rock.

¹ 'Structures et Classification des Roches éruptives,' Paris, 1889, pp. 29-30, 37-38.

Γ = granitoid.	F_5 = apatite.	a_1 = orthoclase.
α = granitic.	F_6 = zircon.	q = quartz.
γ = pegmatoid.	m = white mica.	k = kyanite.
		e = epidote.

The brackets are used for extraneous materials caught up by a rock during its intrusion.

The talcose gneiss macroscopically resembles that in contact with the epidiorite in the Vonzo Valley, and subsequently described from Mustione and elsewhere in the Eastern Cottians. It appears to be a gneiss which has absorbed much basic matter from the schists; while the fact that the garnet-rock above it is crushed and decomposed is also a result of the contact-metamorphism.

On the opposite side of the Vallone Verso similar amphibolite-schists can be seen, on the edge of the platform on which stand the hamlets of Casa Girot and Casa Ortiero. Below them occurs a bed of quartzite which strikes towards the gneiss. The latter is well shown in a few small quarries; the uppermost of these is immediately below the quartzite, here altered to a quartz-schist. The gneiss is fine-grained, and in this condition it can be traced up to within 5 metres of the quartzite. In a second quarry, a little below the first, the gneiss is coarser and typically augen, characters which become more prominent as it is followed farther down the hillside.

The schists and the quartzite here dip 23° south-east with a strike of 32° south of west (magn.), whereas in the lower quarry and in numerous exposures farther down the cliff the foliation of the gneiss has a strike of 10° south of west (magn.). The gneiss below the quartz-schists contains none of the 'talcose' (or chloritic) material which occurs in it when in contact with the 'pietre verdi.'

The general conclusion to be drawn from these facts seems to be that the gneiss is here intrusive, as shown by the contact-metamorphism in the 'pietre-verdi' series, and the alteration of quartzites into quartz-schists; and also by the transgressive junction of the gneiss from its contact with the 'pietre verdi' to the quartzite.

The actual junction could not be clearly traced, as the hill-slope is here covered with brushwood, but in the absence of any evidence of a fault the strikes certainly favour an intrusive junction. On the north side of Chialamberto I had hoped for clearer evidence of this nature; but I failed to find the 'terreni cristallini superiori' that Gastaldi figures on either side of the band of 'serpentino, eufotide, ecc.' which his map shows in contact with the gneiss on the north-east of Chialamberto. Nevertheless, there is some evidence of a transgressive junction along the course of the stream at the base of Monte Bellavarda, opposite Madonna di Ciavinis. The foliation, as measured by Mr. Davies, runs 13° north of west, and along a line at an angle of about 75° with this (i. e. 62° south of west) a definite succession of the beds can be recognized; this includes ordinary amphibolite-schists, amphibolite with felspar-grains and nodules, and talcose amphibolite-schist. In this series, moreover, occur some masses of altered serpentine, the field-relations of which resemble that common to the peridotites of the Cottians. The rock consists of fairly large crystals of brown bastite, with very well-marked schillerization; the outlines are irregular and surrounded by an altered structureless zone, which still maintains its optical continuity with the central nucleus. These crystals are enclosed in a light-green serpentinous mass, crowded with needles and radial

clumps of tremolite. A few grains of olivine still remain. The rock was therefore originally a saxonite, though the rhombic pyroxene was probably hypersthene rather than enstatite. The mass occurs intruded in some chlorite-schists belonging to the 'pietre-verdi' series; its sudden western termination may be due either to its having been cut off by the gneiss or to the original peridotite segregation not having extended far in that direction.

We were glad to find that Signor Ing. Sommariva, of the Vonzo mine, had arrived at the same conclusions—as to the intrusive nature of the gneiss—as we had; the mine lies near the contact of the two rocks in a synclinal, which he believed to have been formed at the time of the gneissic intrusion.

(b) The Waldensian Gneisses.

1. *Bussoleno—Susa*.—The town of Bussoleno is situated on both banks of the Dora Riparia in the midst of a wide tract of moraine and alluvium, which here separates the Grand' Uja and Punta Lunel continuation of the Northern Cottians from the northern end of the eastern range. The mountains on both sides of the valley are mainly formed of mica-schists; but an extension of the calc-mica-schists of Cesana runs along the base of the south side of the valley as far east as the gorge of the Giordani, south-west of Bussoleno. From this point a low bank of gneiss forms the foot of the hill-slopes for some distance towards the east, and is extensively quarried below the villages of Combe, Fornielli, and Meitre. A similar rock, no doubt an extension of the same mass, occupies a corresponding position on the north side of the valley extending from Foresto di Susa to Grange. These are the northern exposures of the Waldensian gneiss, and Zaccagna has figured them as spreading over a wide extent of ground south and south-east of Bussoleno,¹ and thence extending in one unbroken line as far south as Venasca. It was therefore natural to strike from Bussoleno towards the south-west, to the line marked by Zaccagna as the junction of the gneiss and the schists.

One soon found, however, that it was not possible to apply that geologist's map too literally, and that a large extent of his 'central gneiss' is really occupied by mica-schists, calc-schists, and even 'pietre verdi.' Thus the foot of the hill-slopes at Capella Santa Parnella, about 1 kilometre south-west of Bussoleno, is formed of calc-mica-schists, in places garnetiferous; the foliation of the schists here dips 45° to the north-east, and strikes north-west and south-east. Higher up the slopes the calc-schist is succeeded

¹ There is a slight discrepancy here between the lettering and colouring of Zaccagna's map. According to the former, the gneiss extends as far west as Chiomonte, and it forms the whole of the basins of the Giordani and of the lower part of the Scaglione; the colouring, however, marks the western termination of the gneiss about 1 kilometre to the east side of the Scaglione, the course of which is thus wholly on the schists; the colouring is no doubt the more correct.

by a great thickness of brownish mica-schists, which can be seen in numerous crags around Combe, Fornielli, Tignaj, and Meitre; thence they can be followed along the hills southward to Giordani, and up the Gerrardo Valley. We found them from Giordani all along the line of a traverse across country past Pinetti, Cervelli, Condé, Travers à Mont, and Pois to Mustione.

Fig. 4.—*Sketch-map showing the distribution of the Waldensian Gneisses in the Bussoleno district.*

Scale: $\frac{1}{100,000} = \cdot 6336$ inch to the mile.

[For 'Gerrande' read 'Gerrardo'; for 'calc-schist' read 'calc-schist.']

The 'central gneiss,' on the other hand, appears to have a very restricted distribution, being limited to the bank stretching from below Fornielli past San Basilio to below Meitre. The foliation of the gneiss here strikes about due east-and-west, with a dip of 75° north. A second bed occurs intercalated in the schists east of Giordani; it can be seen on the right bank of a stream just above the village. Better exposures are seen as a line of low crags, above the road from Giordani to Fornielli; at the foot of this the path turns to Tignaj, which leaves the main road just north of Giordani.

One kilometre south of this another gneiss-bed crops out on the right bank of the Gerrardo Valley, opposite where R. is marked on the map. It occurs here as a bed, some 25 feet wide, which appears to be a dyke; the junction with the surrounding gneissoid mica-schist is irregular: the only evidence of contact-metamorphism which we noticed is that the adjoining gneiss is garnetiferous.

These three gneisses appear so strikingly similar in their lithological characters that in all probability they are part of the same original rock.

The gneiss at the quarries below Meitre, when examined microscopically, is seen to consist in the main of a water-clear quartz-felspar mosaic, which forms large white 'eyes,' around which curve lines of long blade-like crystals of white mica. The quartz shows well-marked undulatory extinction: it is often pegmatitically associated with the felspar. Apatite and zircon both occur in the mosaic. The felspar is sometimes idiomorphic, and crystals of it are seen completely enclosed in quartz.

The formula for the rock is therefore :

$$\Gamma\Phi\alpha\gamma \quad \overline{F_{56}a_1m} \quad \widetilde{a,q},$$

and the rock is a muscovite-gneiss.

The dyke in the Gerrardo Valley agrees with this in the main. The principal differences are the small proportion of orthoclase, many of the crystals of which show a zonal regrowth. Moreover the micas are in thicker crystals, and there are a good many eroded crystals of kyanite; a few grains of the last-named mineral occur in the Bussoleno gneiss.

The formula is therefore :

$$\Gamma\Phi\alpha\gamma \quad \overline{F_{56}(k)a_1} \quad \widetilde{ma,q},$$

and the rock may be regarded as an aplite.

We were unfortunate in not finding in this district any very clear sections showing the junction of the main mass of the gneiss and the schists; but around Fornielli there appears to be a gradual passage from the normal gneiss to one rendered coarsely 'augen' by numerous inclusions of quartz-nodules. At the upper end of Fornielli, in a chestnut grove on the south side of the main road, there is an exposure of white gneiss with similar quartz-nodules and impregnated with calcareous matter. Close to this the mica-schists are seen *in situ*; they are crowded with garnets near the junction, while the adjoining schists are strongly contorted.

Though it is not possible to prove the actual connexion of the three gneisses, it seems highly probable that they are part of the same massif; the section on the following page (fig. 5) shows their field-relations upon this view. The three rocks agree very closely in composition, as is shown by their formulæ, and in the freshness of their minerals in contrast to those of the rotten, decomposed rocks in which they are intercalated; the only differences between them are just those which might be expected between an intruded mass and its apophyses. In this case the Susa and Fornielli exposures represent the massif exposed by the erosion of the Dora Valley.

2. *Palé*.—Between the gneiss-dyke in the Gerrardo Valley and the next exposure seen at the Col de Vento, the rocks along the line traversed were wholly of the gneissoid mica-schist; these occur along a line from Pinetti, Cervelli, Condé, Travers à Mont, Pois, round the flanks of Punta Rossa and south along the Rio di Gravis to Mustione and the Col de Vento. South and west of this line

there appears to be a great extension of the upper schists with 'pietre verdi,' with gabbros, serpentine, amphibolites, and variolites. The true Col de Vento is on the mica-schists, but immediately south of it is a dyke of gneiss intrusive into the 'pietre verdi' series: a narrow and not very easy gully leads to a small col which crosses the ridge at a height of 2290 metres. This runs along the junction, the gneiss forming the north wall and the serpentine the south. The serpentine¹ is greatly schistified and contorted, while the gneiss has a somewhat greenish colour, doubtless due to the absorption of the neighbouring material. At the upper end the gully forks, and in the northern branch the gneiss can be seen in contact with a much altered limestone belonging to the schist series. The gneiss between the two branches of the gully is much decomposed. Close by the summit of the right-hand branch the gneiss crosses the gully and forms the south wall, and the rock is there still fresh.

Between the top of this gully and the Col de Vento is a band of limestone which is cut into by the gneiss, and the junction is well shown on the south wall of the northern fork of the gully. The

Fig. 6.—*Junction of gneiss and limestone in a gully north of Col de Vento.*

accompanying figure shows the actual junction and the way in which the limestone-bedding ends off against the intrusive gneiss. The limestone is altered at the contact: the microscope shows it to consist of a clear twinned calcite, some small rounded masses of untwinned calcite, and numerous small crystals of dolomite. These are all included in what appears to be a crushed calcareous groundmass; in this some authigenous blade-like crystals of white mica are further evidence of alteration.

In connexion with the Col de Vento gneiss-dyke it is necessary to consider a boulder which occurs beside the path a little below Mustione, of which a sketch is reproduced in fig. 7, p. 250. This shows two fragments of the 'pietre verdi' series included in gneiss; both inclusions are distinctly altered on the margin, the larger to a depth of 1 inch, and the smaller to $\frac{4}{5}$ inch. The gneiss belongs to the

¹ 'Serpentine' is here used as a general term for any altered peridotite. This rock was probably a lherzolite, as the microscope shows the presence of both rhombic and monoclinic pyroxenes, and of a little oligoclase; these are included in a light-green serpentine groundmass containing many needles and prisms of tremolite; some of the latter are sufficiently large to show the hornblende cleavages.

type of talcose gneisses, and is of a faint green colour; this no doubt it has acquired from the absorption of some of the 'pietre verdi.' The microscope shows it to consist of the usual pegmatitic quartz-felspar mosaic with bands of white mica; the dark colour of hand-specimens is seen to be due to inclusions of an indeterminate opaque material, which appears reddish-brown by reflected light. A series of broken and corroded garnets, often showing double refraction, also represents material collected from the surrounding schists. The foliation of the gneiss flows round the included fragments, like a true fluxion-structure. Though we did not find similar inclusions *in situ* at the Col, the exact resemblance of the gneisses leaves little doubt that it was derived from the dyke which we examined, or from a similar one.

Fig. 7.—Gneiss, with included fragments of the 'pietre verdi' series at Mustione.

South of the gneiss, along the northern arête of Punta Costabruna, the serpentinous schists (probably an altered lherzolite) rise into a sharp crag; south of this, the mica-schists recur again, and these form the summit. On the eastern side of the pass and ridge a long gradual slope of meadow-land extends down to the Sangonetto Valley, and consequently there are no exposures. The gneiss, however, occurs extensively developed on both sides of this valley; on the north it forms the ridge of Monte Salancia, from the crags of the Rocca del Moutone to Monte Luzera (the Punta Siudre of the $\frac{1}{100,000}$ map). On the south side it forms the northern arête of Rocca Rossa, see fig. 8, p. 251. The gneisses of the two sides of the valley are at first separated by the schists, a wedge of which appears to extend into the gneiss, as far as the 1500-metre contour, down the Poirent Valley (a tributary of the Sangonetto). East of this point, as far as Dirotto, all the exposures seen were of gneiss. Still farther down the valley widens, and, as we had no time to leave the road, we could see no rocks *in situ*.

Unfortunately lack of time prevented any attempt at a precise determination of the boundaries of the gneiss, even if such be possible; but it seems most probable that the dyke at the upper Col de Vento is an offshoot from the great mass of gneiss about Palé.

Fig. 8.—Sketch-map of the gneiss exposures round Col de Vento.

Scale : $\frac{1}{50,000} = 1 \cdot 267$ inch to the mile.

[For 'Sangoretto' read 'Sangonetto'.]

3. *Meano, Perosa, and Chisone Valley.*—On Zaccagna's map the gneiss band is shown to cross the Chisone Valley between Meano and Roure; two unnamed streams are marked as traversing the gneiss, and these occupy the positions of the Borsetto on the south side of the Chisone and the Balma on the north. Meano is itself placed as on the extreme eastern margin of a granite which here separates the schists and the gneiss. Eastward from Meano to Pinerolo the whole valley of the Chisone is coloured as schist. There are, however, at S. Germano, large quarries of a pale coarse gneiss, which seems to be a typical 'central gneiss.' But in this part of the valley the chances of actual junctions are very remote; and, as Prof. Bonney has already described the rock and remarked on its possibly intrusive nature,¹ it did not seem necessary to stop to examine it.

After leaving Perosa Argentina the road rises gradually, and there are no exposures worth mentioning, though the hills on either side are clearly of mica-schist; $1\frac{1}{2}$ kilometre distant, however, a quarry in the pale-coloured gneiss occurs on the northern side of the road.

¹ 'Two Traverses, etc.,' Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 83.

The microscopic structure of the rock has been described by Prof. Bonney (*op. supra cit.* p. 104); the only addition that I would desire to make to this is in regard to the presence of the large number of dark segregations. These are often at least 4 inches wide and 12 to 16 inches long; the longest diameter of the fragments is always parallel to the foliation.

On the opposite side of the river the gneiss is much better seen in some larger quarries, while on the eastern margin of the mass a certain amount of evidence as to the junction is obtainable. The gneiss forms an irregular bank occupying the axis of an anticlinal: the schists on the east side dip 10° W.S.W., while in the cliff below the ruined castle of Brandonegna they dip 10° N.W. At the foot of the cliff the gneiss is fairly coarse, but when traced towards the junction it becomes finer, and it is not easy in the field to fix on the exact line of separation between the gneiss and the gneissoid mica-schists which overlie it. The microscope, however, leaves no doubt of the distinctions between the igneous and the clastic rocks.

The igneous gneiss near the junction is finer-grained than that seen in the quarry on the opposite side of the river; it differs from the gneisses that have been previously described from Bussoleno and the Gerrardo Valley by the presence of a good deal of biotite in addition to the white mica. Epidote in small rounded grains is also abundant. This and the micas are included in a groundmass of a water-clear quartz-felspar mosaic, which was the last constituent to solidify. The formula may thus be written:

$$\Gamma\Phi\alpha\gamma F_{\epsilon}(e)\overline{Mma}, \widetilde{a_1q};$$

and so the rock is a typical Waldensian gneiss with some foreign inclusions.

An examination of one of the most gneissoid of the adjoining mica-schists shows several marked differences. The materials in this belong to two very different sets. There are some quartz and zoisite aggregates which doubtless represent broken-down plagioclase; they are included in an indeterminate granular material, which contains many small authigenous flakes of white mica. These represent the original constituents of the mica-schists, now completely metamorphosed by the intrusion of the second group of constituents. There are thin bands of fresh granulite, composed of quartz, orthoclase, and some white mica.

The formula for this rock is:

$$\Gamma\Phi\alpha\gamma (zqx)\overline{F_{\epsilon}ma}, \widetilde{a_1q}.$$

It is probably due to the injection of the schists by gneissic materials, similar to those cases around the protogine intrusion of Mont Blanc which have been described by M. Michel-Lévy.

The brown schists recur to the west of this narrow band of gneiss, and before attaining Meano a cliff is passed in which they are

almost vertical, with an E.S.E. strike; a well-marked band of fault-breccia here indicates a fault. Thence westward no sections occur on the road until reaching La Balma, where, beside the mule-path at the west end of the village, there is a crag of the ordinary brown gneissoid mica-schist dipping 42° to 23° west of north. The same schists extend up the Balma Valley to halfway between the confluence of the Balma and the Forcho and the talc-mine at Roussa; then they recur above the mine, where an amphibolite occurs in them; they also form the lower slopes of the Rocca Rossa, and thence they can be followed to the south side of the Col Roussa, and southward to the summit of Monte Bocciarda. Near the Alpe di Bocciarda, however, banks of the central gneiss crop up from the pastures, and appear to extend east towards the Punta Sarasina and the Monte Uja. The actual junction here is hidden by pastures, and an attempt was therefore made to descend to the south in the hope of finding it exposed. The head of the Comba di Bocciarda is close to the junction, and a small galena-mine may mark the exact position; owing to the steepness of the descent, however, and a mist that prevented our following the junction, we saw nothing but gneissoid mica-schists, with some amphibolites, till we reached the 1300-metre contour. The Roc del Pelvo, which rises above the stream from the base of the great cliff down which we had scrambled, is a sharp pyramid of gneiss and affords clear evidence of intrusion. The foliation of the gneiss dips 45° N.N.E., while the strike is E. 27° S.; 20 yards from the junction with the gneiss the schists to the north are almost horizontal, but at the contact they are sharply bent upward and are much altered. The gneiss at the junction is impregnated with lines and fragments of dark-coloured included material. Microscopic examination shows that the rock is a normal Waldensian gneiss. It differs from that described from Bussoleno by the presence of much extraneous matter occurring as lines and rolled-out fragments. Most of the included material is indeterminable, but flakes of chlorite and some rolled, broken, and slightly doubly-refracting garnets may be recognized. The inclusions farther from the contact are rarer and more altered; they consist in the main of green and brown hornblende and numerous small garnets; there are numerous idiomorphic but corroded crystals of orthoclase in the gneiss. The adjoining schists present the same characters as that above the gneiss in the section south of the Chisone; the rocks consist of bands of chloritic and amphibolic material separated by thin seams of granulite.

A manganese vein which has been worked occurs along the junction of the gneiss and schists, on both sides of the valley. There are no slickensided surfaces or other evidence of a fault, and the whole aspect is that of an intrusive igneous mass. This is clearly demonstrated by the contortion and metamorphism of the adjoining schists, and the inclusions in the gneiss.

In regard to the possible existence of another bed of intrusive gneiss farther west, between Castel del Bosc and Roure, I am unable to express a definite opinion. Zaccagna and Mattirol's map marks the

south-eastern limit of the gneiss as crossing the main valley at the confluence of the Balma and the Chisone; we went for some little distance beyond this point, and failed to find anything but the brown mica-schists. If the gneiss does, however, occur, it cannot be continuous with that of the Bocciarda and the Pelvo, or we should have seen it in our traverse to the north. Abundance of the gneiss, however, occurs on a talus slope to the south-west of Castel del Bosc, by the first fork after crossing the Chisone, along the bridle-path leading to the hamlet of Garner. Erratics of the same rock are found on the grass slopes west of the summit of Punta Medio Muret, and probably indicate its occurrence somewhere along the ridge between this peak and Punta Raccias; but a dense cloud prevented any search for the rock *in situ* at this point. With these exceptions the whole of the rocks crossed between Castel del Bosc and Perrero were of the schist series, with intrusive amphibolites and interbedded limestones and dolomites. The last are well seen in some crags on the south-eastern ridge of Punta Medio Muret, between the summit and the point marked 2004 metres; the dolomite is much contorted, and is associated with some mica-schists containing enormous garnets. The actual summit of Punta Medio Muret is made up of the gneissoid mica-schist which so often occurs in the neighbourhood of the intrusive gneisses. Between Castel del Bosc and Garner the schists have a prevalent east-and-west strike; but between Massello and Perrero the strike has worked round to W. 30° N.

Near Perrero occur several large beds of amphibolite, as at a crag above Maniglia and east of Quin, which is apparently intrusive along the strike. A similar rock, probably an epidiorite, is worked for road-metal at a quarry $\frac{1}{2}$ kilometre east of Perrero. It occurs here in a position on which Zaccagna has marked 'central gneiss.' There did not seem to be any evidence of the existence of that rock at this point. There is a good exposure of mica-schist, richer in mica and paler in colour than is usual, at the sharp bend of the road about 1 kilometre from Perrero; here a foot-bridge crosses the Germanasca and a bridle-path leads south to Grangette and Poet Soprano, as far as which all the exposures noted were of the coarse gneissoid mica-schist. Above the latter, large garnets become abundant; farther up, where the path bends round the flank of Bocca del Cavalupo at a part where it runs level for some hundreds of yards, there is an amphibolite which is clearly intrusive into the gneissoid mica-schists. The path thence rises to the ridge between Rocca Bianca and Bocca del Cavalupo, which it crosses by a col at the height of about 2025 metres.

From this point we kept south along the main ridge as far as Punta Cornour. The whole line is marked by Zaccagna as 'central gneiss,' and it is therefore advisable briefly to refer to the main types of rocks which compose it. At the col between Rocca Bianca and the Bocca del Cavalupo, the rock is a pure white, massive, crystalline, saccharoidal limestone, which has been there quarried for the kilometre-posts on the new military road. The limestone is

inclined to the north, and is overlain by mica-schists which form the 2051-metre point north of the col; the band thence rises, and is succeeded by masses of dolomite intensely folded and contorted and with beds of 'pietre verdi,' probably of a clastic origin, caught in between the limestone masses. The beds here strike 35° N. of W., while the thrust has come from approximately W. by S. Along this ridge, in spite of the intense foldings of the rocks, there is little evidence of any definite schistosity, and the actual summit of Rocca Bianca (2379 metres) is of a rock with foliation so imperfect that in the field we called it a micaceous grit; judging, however, from the great extent to which the quartz-grains are seen to be corroded, when examined under the microscope, this rock is probably a quartz-porphyry. South of the Colletta Bianca the rocks become more schistose and belong to the 'pietre verdi' series with numerous quartz-veins. The summits of Cima del Liste and Punta Bruta, however, mark a return to a less foliated series, being formed of a micaceous grit or schist breaking into large flat slabs, with a general strike north and south, at one place working to 10° E. of N.; the dip is 13° west. Farther south the strike is 10° W. of N., with a westerly dip of 16° . Associated with these evenly-foliated schists there are, on the south face of Punta Bruta, some interstratified thin green beds which probably represent layers of volcanic ash. There are also numerous blocks of a green rock in the same schists; they range from about $1\frac{1}{2}$ to 3 feet in length, and in their present form are lenticular; the long axes are in the plane of foliation, the lines of which bend round the blocks. Microscopic examination shows them to consist of garnets, chlorite, tremolite, and epidote; they represent altered blocks of a basic igneous rock, and their association with what is possibly a bed of volcanic ash led us in the field to consider the possibility of their being ejected blocks. The microscopic evidence neither confirms nor conclusively disproves this hypothesis.

In many places along this ridge between the Bocca del Cavalupo and Punta Cornour the rocks are either not foliated, or the foliation, such as it is, is coincident with the bedding; this is probably the case also with the rock which includes the eclogite-blocks. In the 'roches moutonnées' around Lagho d'Envoi, a charming little lake in a glaciated rock-basin, we have clear evidence that such is not always the case, as the vein there has been intensely contorted, before the foliation of the rocks; the foliation here has the normal strike of 10° W. of N., with a westerly dip of 16° . Around the flanks of Capello d'Envoi the schists become coarser and the limestones are schistified.

Evidence for the same independence of the foliation and stratification is seen in the view of Punta Cornour from Tredici Laghi. A massive bank of white rock (probably dolomite) may be observed interstratified between masses of the 'pietre-verdi' series; the white rock dips to the west, but the foliation dips much more sharply and crosses the bedding at a high angle.

Near the summit of Punta Cornour, the large garnets and the

crushing of the schists indicate a region of greater disturbance than in the Cima del Liste area.

Boulders of the central augen-gneiss occur on the northern face of the Punta Cornour, and this, combined with other facts subsequently noted around Bobbio Pellice (5 kilometres south), led me to think that this is probably an outcrop of the gneiss to the south. Ill-health, however, prevented an examination of the ground in this direction.

4. *Angrogna Valley*.—We had thus crossed from Perrero to the highest point between the Germanasca and the Pellice valleys, keeping along the line coloured by Zaccagna and Mattirolo as ‘central gneiss,’ without seeing the slightest traces of this rock, except for the single boulder on the Punta Cornour. Limestones, dolomites, grits, and some quartz-porphry rendered slightly schistose, were the main rocks met with. The north-and-south traverse was therefore discontinued, and we then descended the Angrogna Valley towards the east in the hope of finding on its flanks some further exposures of gneiss, which it was possible that Zaccagna might have accidentally represented too far west.

Nevertheless, from Passo Roussa as far east as Gaisset, the only rocks seen were schists with interstratified beds, of which some are apparently intrusive amphibolites and others clastic green rocks. At Gaisset, however, a mass of fine-grained and locally foliated gabbro crosses the valley and forms a massive hill on the north side of that chalet; before crossing the stream near Pra del Torno, a dyke of compact dark-green porphyrite crops out across the path. Below Pra del Torno the normal mica-schists recur, and they are at first garnetiferous. Farther from the gabbro massif the schists are finer and less crystalline, and opposite the bridge at the angle of a sharp bend of the river, nearly 1 kilometre S.S.W. of Pra del Torno, the schists are comparatively unaltered and anthracitic.

A little farther round the curve a sharp crag, Rocca Roccaglie, overhangs the path to the north, and this is cut through by dykes of white aplite; a much finer exposure occurs in some rocks which here interrupt the course of the stream.

The main rock is a member of the ‘pietre-verdi’ series; the commonest variety is a rock which is probably an altered andesite, cut through by a fine-grained gabbro dyke. Both rocks have been subsequently invaded by a complex of intrusive aplite-veins (see fig. 9, p. 257). The aplite or granulite-veins vary in width from a few inches to 4 feet; and the coarseness of the rock varies with the width of the dykes. Microscopic examination shows that the rock consists in the main of quartz-felspar mosaic, with some larger eroded crystals of orthoclase and a foliation determined by bands of white mica. Its formula, excluding accessory minerals and some foreign material absorbed from the surrounding rock, is:

which is that of the typical gneiss of the district.

The evidence of this exposure is unquestionable. There can be no doubt of the intrusive character of the dykes, nor that these are composed of an acid rock in which all gradations can be traced from a compact aplite or granulite to a fairly coarse, well-foliated gneiss. It appears that the dykes are an offshoot from a large mass below, which has not been exposed; its existence can be inferred from the elevation of the overlying beds into an anticlinal, as is shown by the photograph here reproduced.

East of the exposure which has just been described, along the path through Angrogna to Torre Pellice, the beds all consist of the ordinary mica-schist, dipping south-east.

Fig. 9.—*Veins of gneiss (aplite) in the 'pietre verdi' series, Angrogna Valley.*

The aplite-veins run obliquely upward across the right-hand lower corner; one occurs just above the lower margin and below the oblique series.

5. *The Pellice Valley.*—According to Zaccagna's description and map,¹ the 'central gneiss' crosses the Pellice Valley near Bobbio Pellice; it occupies the area between the Rio Subiasco and the Rio Cruello, the town being on the eastern margin. At Bobbio the main valley is occupied by moraine, and the hill-slopes are so wooded and cultivated that no exposures could be found; to the west, however, a small footpath (named the Via Podio) branches from the Villanova bridle-path and ascends through some orchards to the

¹ 'Sulla Geologia delle Alpi occidentali,' Boll. R. Com. geol. Ital. vol. xviii. (1887) p. 384, pl. xi.

north. Five minutes' walk along this, in a field north of the path, there is an exposure of a pale-coloured, foliated, fine gneiss. The rock is worked here, and the quarry is known to the peasants as the 'Rocca Bianca.' The actual junction cannot be seen, but brown mica-schists can be found at a little distance above and below it. The foliation dips about 20° west, and is approximately the same as that of the surrounding schists. In the Cruello Valley there are numerous blocks of gneiss scattered about the lower part of the stream; as this is followed to the north, the schists become coarser and very contorted. The valley, however, is closed by two vertical side-walls and a waterfall, which may mark the junction with a northern mass of gneiss. But the path towards Malpertus shows only the ordinary mica-schists, and the peasants whom I asked could not tell me of any place where the gneiss occurred, except at Rocca Bianca; and as they all immediately recognized the specimens from that quarry, some value may be attached to their evidence.

All, therefore, that can be safely asserted about the gneiss here is that it occurs as a thin sheet or dyke, which is probably only an offshoot from a mass to the north, between Bobbio and Cima Chiapis, though it is possible that it is not at all or but slightly exposed on the surface.

A more extensive exposure in the Pellice Valley occurs on the south bank east of Villar Pellice; the rock is here a coarse augen-gneiss, with the minerals as usual all strikingly fresh and pale. It is worked in a number of quarries, the line of which is connected by a series of crags which stand out above the soft schists and talus. Being unfortunately compelled to leave the Pellice rather hastily, we were unable to examine the field relations of this band of gneiss. It must therefore be here also left doubtful whether the rock is anything more than an intrusive sheet. The northern slopes of the Pellice Valley all appear to be made up of the schist, and there is therefore seemingly no connexion between the gneiss on the southern bank of the Pellice and the outcrop in the Angrogna Valley.

6. *Barge*.—Gastaldi has described the occurrence of the 'central gneiss' at Barge, and has inferred therefrom that it is a continuation of the same rock seen farther west near Ostana, here brought up to the surface by a fold. Zaccagna, however, whose Section II. crosses the country a little north of this town, does not admit the occurrence of the gneiss there. The rock is one of the pale-coloured, coarse augen-gneisses, exactly similar to that which he has elsewhere described as 'central gneiss.' The foliation dips S.W., as does also that of the mica-schists which succeed it to the west: I had not, however, the time to search for a junction, and indeed should hardly expect to find one that would be at all satisfactory.

After passing the 788-metre point the schists dip eastward, but they subsequently become horizontal, and at a sharp bend in the road at the 833-metre level the schists are black and dip south-west.

7. *Crissolo*.—Zaccagna's main section through the Cottians crosses the valley of the Po at Crissolo and thence continues east-

ward, traversing the band of 'central gneiss.' That geologist has described the sections along this line with much care. Hence it was natural that I should expect to discover much closer agreement with the facts than in regions to the north, where the lines must have been hastily and diagrammatically sketched in. I therefore turned to the valley of the Po in the hope of finding the gneiss exactly where Zaccagna has placed it in his map. In this I was not disappointed: the gneiss can be seen in numerous roadside exposures between the hamlet of Calcinerè, west of Paesana, and the western end of a gorge due south of Crampetti. The gneiss forms steep, barren, craggy slopes, easily distinguishable from the softer and more fertile schists.

The section which best shows the relations of the gneiss and the schists occurs on the south bank of the river near a footbridge, at the upper end of a gorge east of Crissolo. The base of the hillside here is of coarse augen-gneiss, which is covered by the schists. The normal schist at more than 20 feet from the gneiss is a thin-bedded lead-coloured rock, with some interstratified amphibolites.

As we approach the gneiss the schists become coarser, till they form a gneissoid mica-schist—such as is generally observed near the contact with the Waldensian gneisses throughout the Cottians. The lead-coloured schists contain much material that can be identified as having been originally clastic grains; as we approach the gneiss this lessens in amount and water-clear quartz-felspar mosaic becomes the chief constituent. This is associated with numerous garnets, and some muscovite, epidote, and chlorite; there is also some indeterminate material which represents the less altered part of the original rock. Still nearer the gneiss the garnets disappear, but some earthy grey zoisite-aggregates represent the original constituents of the 'pietre verdi'; the bulk of the rock is formed of white mica, orthoclase, and quartz-orthoclase mosaic.

In addition to this contact-metamorphism, further proof of the intrusive nature of the gneiss in this section is afforded by some dykes of aplite which strike off from the gneiss; these are best seen where they cross some bands of amphibolites which occur in the schists. Owing to the great difference in the chemical composition of the aplite and the amphibolites, the junction between them is much sharper than that between the aplite and the mica-schists; it is very irregular, sending small projections into the amphibolite in a way that clearly shows the intrusive nature of the former. Unfortunately, it was not possible to trace the aplite-dyke into the gneiss, as the junction was hidden by moraine matter, and it was not even possible to be absolutely certain that the amphibolites were *in situ*. Their occurrence as blocks along a definite narrow line, however, rendered it highly probable, and any doubt was removed by the discovery at the foot of the slope of a large boulder of mica-schist containing a vein of amphibolite.

There is, moreover, a marked discordance between the strike of the gneiss and that of the schists, which, in the absence of any evidence for a fault, affords further proof of intrusion.

IV. CONCLUSIONS AS TO THE RELATIONS OF THE BEDS.

Prof. Bonney has recently insisted on the great difficulties in the way of geological mapping in the Alps,¹ and though in the Eastern Cottians there is not much difficulty from snow or glaciers, the great extent of the moraines and vineyards in the valleys, and of the pastures on the higher slopes, prevents any detailed mapping of much of the area. The ruggedness of the country, the depth of the valleys, and the lack of accommodation add further obstacles to the investigation by causing so much of the time to be necessarily spent in walking to one's field of work.

It was impossible, in the short time available for field work, to prepare any detailed map of the geology of the area, or even to follow, as I had intended, the whole length of the junction of the gneiss and the schists. This has been rendered less necessary by the clearness of the sections at some points. A rough sketch-map of the area is appended, on which the main facts have been inserted (see fig. 1, p. 238), and it is perhaps advisable here to summarize briefly the evidence afforded by the foregoing descriptions.

As has been already remarked, according to the generally-accepted theory, the 'central gneiss' is the lowest of a three-fold series of Archæan rocks, and its position at the base of the series is due to its being the oldest of the three, the others having been deposited upon it. Against this view the evidence now presented is fairly conclusive. It will be generally admitted that if this be true, a strong unconformity must occur between the schists and the gneiss; in support of this, it is only necessary to refer to the map of Gastaldi reprinted on p. 240 and to his sections, such as that from Roche Melon to Lanzo² or at Monte Resta³; the section of Dr. Gianotti⁴ shows the same for the neighbourhood of Chialamberto.

With such an unconformity it is incredible that no fragments or pebbles of the gneiss should occur in the schists. The latter are a very extensive series of deposits, and contain several beds of conglomerate, such as that at Tredici Laghi and under Punta Bruta. But in no case do fragments of the 'central gneiss' occur in them; a section of the Tredici Laghi conglomerate in the schist series shows that the pebbles consist of a felspar-zoisite aggregate with numerous crystals of rutile and some small flakes of biotite. These pebbles are very dusty, and their outlines are rounded as if by crushing; they are set in a matrix of a water-clear mylonitic mosaic of quartz and felspar, which contains long blade-like crystals running round the inclusions. The evidence of the slide is not conclusive, but the rock appears more probably to have been formed by the crushing of a felspar-conglomerate than of an augen-gneiss.

At not one of the sections examined was there any evidence of

¹ Bonney, 'On the Crystalline Schists and their Relation to the Mesozoic Rocks in the Lepontine Alps,' *Quart. Journ. Geol. Soc.* vol. xli. (1890) pp. 187, 188.

² Gastaldi, 'Studi geologici sulle Alpi occidentali,' *Mem. descriz. Carta geol. Italia*, vol. ii. (1874) pl. i. f. 2.

³ *Ibid.* vol. i. (1871) pl. v.

⁴ Gianotti, *op. jam cit.* pl. v.

the derivation of the schists from the gneiss, or of any erosion of the surface of the latter.

In regard to the possible alternative theory of the gneiss being faulted up through the schist, the evidence is also strong, though it is again all negative. The absence of any slickensides or fault-rock along the junctions, the sharpness of the junction where the gneiss adjoins rocks of dissimilar composition and its indefinite nature at places where the gneiss and the schists are of similar chemical composition, and, finally, the great irregularity and complexity of the faults and thrust-planes that would be necessary to account for the field relations of the two, all combine to dismiss this hypothesis.

The positive evidence, however, as to the relations of the two series is fairly complete. It may be divided into four groups.

1. Contact-Phenomena. (a) *In the Gneiss.* Zaccagna has remarked on the fact that the 'central gneiss' passes into a true granite when at some distance from the junction,¹ a fact which he noted in the valleys of the Pellice and the Chisone; Baretto has described the same in the Paradiso massif.² We may, therefore, to some extent regard the foliation as a marginal structure, such as that which is not uncommon around unquestionably intrusive granites.³

When the rock is examined close to the junction, it can be gradually traced from a coarse to a fine gneiss. This may be seen around the Paradiso massif, as below Casa Ortiera, at Fornielli, near Bussoleno, on the banks of the Chisone, $1\frac{1}{2}$ kilometre above Perosa, and is especially well shown at the junction in the Po Valley below Crissolo; at this locality the fine gneiss passes into a compact aplite. In other places the margin of the gneiss has incorporated sufficient of the neighbouring schists to considerably affect its general character; in extreme cases the gneiss has been altered into a greenish talcose gneiss, as near Chialamberto and Perosa.

(b) *In the Schists.* The alterations here vary greatly, according to the nature of the rocks with which the gneiss is in contact. When the rock is a quartzite it is converted into a quartz, as at Casa Ortiera; amphibolites and epidiorites are converted into glaucophane and hornblende-schists, while the mica-schists are rendered gneissoid at the contact and richly garnetiferous farther from the actual junction. Sillimanite, kyanite, cordierite, and other minerals are also developed, while a band of an intensely altered, decomposed rock often occurs along the actual contact-line; this is especially well shown south of Chialamberto and in the Po Valley opposite Ostana.

2. Included Fragments. Around the margin of the Paradiso massif, as along the Vonzo Valley, in the gneiss of the Roc del

¹ Zaccagna, 'Sulla Geologia delle Alpi occidentali,' Boll. R. Com. geol. Ital. vol. xviii. (1887) p. 379, and elsewhere.

² Baretto, 'Gran Paradiso,' Atti R. Accad. Lincei, ser. 3, Mem. vol. i. pt. i. (1877) pp. 208, 210, 214.

³ See Rosenbusch, 'Mikroskop. Physiogr. d. Massigen Gesteine,' 2nd ed. (1887) vol. ii. p. 41.

Pelvo at the end of the Bocciarda Valley, at Mustione, etc., fragments of the amphibolites of the mica-schist series are included in the gneiss; the contact-alteration on the margin of the inclusions, and the flow of the gneiss around them, prove that they are fragments of the schists caught up by the molten rock.

3. Apophyses from the Gneiss. Opposite Ostana in the Po Valley, near Bobbio in the Pellice Valley, and below Pra del Torno in the Angrogna Valley, dykes of aplite, which present all the characters of apophyses from the gneiss, break through the schists; in the last case quoted a complete passage can be traced from the fine-grained aplite to a well-foliated gneiss.

4. Transgressive Junctions. Cases of these are the contact of the gneiss at Bussoleno with the calc-schists and gneissoid mica-schists; of the gneiss on the south side of the Valle Grande with the 'pietre verdi' series, quartzites, and mica-schists; at the upper Col de Vento, where it works across from the serpentine to the calc-schists and dolomite; the discordance of the strike of the second series around Crissolo, where, according to a manuscript map prepared and kindly lent to us by Dr. Gianotti, the gneiss transgresses from the mica-schists to the calc-schists.

5. The up-tilting of the schists at their contact with the gneiss at the Roc del Pelvo, and the irregularity of the line of junction of the two rocks—when specimens showing it are examined under the microscope—are further proofs of the intrusive nature of the Waldensian gneisses.

V. THE CONTACT-METAMORPHISM.

The normal phenomena of contact-metamorphism are well shown around the Waldensian gneisses, and the development of new minerals has sometimes taken place on an extensive scale. Among others the following have thus been formed: quartz, white mica, biotite, orthoclase, microcline, oligoclase, garnets, kyanite, epidote, zoisite, and sphene. The extent to which this has proceeded varies enormously; thus the quartzites of the Valle Grande have been converted into quartz-schists along only a very narrow band; at the Roc del Pelvo, in the Comba di Bocciarda, new minerals have been developed for merely a short distance from the gneiss, while the alteration around the dykes of the Angrogna Valley only affects the neighbouring rocks over a breadth varying from $\frac{1}{2}$ to about 2 inches. In other places, as in the Po Valley, the rocks have been intensely altered for 50 feet from the margin. There is, however, nothing in this to justify the charge of capriciousness often made against contact-metamorphism: it may be selective metamorphism, but good reasons can be found to explain the selection.

The variation in the extent to which this action has proceeded around the Waldensian gneisses seems to depend on two main factors,

—the bulk of the intrusive rock and the nature of the beds with which it has come in contact. Thus, as illustrations of the former, we may refer to the very thin contact-zone around the Angrogna dykes, which are apparently but tongues intrusive into the schists, so that no continued flow of molten matter ever occurred through them. The dyke at the upper Col de Vento is larger and probably rose to a considerable height above the present level of the ridge; a wider zone has therefore been affected. Around the gneiss massifs the contact-metamorphism is much more strikingly developed; here the extent varies according to whether the gneiss meets the schists as a vertical wall, as it does in the gorge of the Comba, or forms a low bank upon which the schists rest, as in the valleys of the Po and the Dora and in the Paradiso massif on the south side of the Valle Grande. In the latter cases the contact-metamorphism is most strongly marked because the schists then acted, to use the conventional illustration, as a ‘piecrust’; they were in contact with the gneiss over a wide area, and through them the heat given off by the consolidating rock was slowly conducted.

The second condition which determines the extent of the metamorphism is the nature of the rock in contact with the gneiss. Where this is one of the amphibolites or other rock of the ‘pierre verdi’ group, the junction is sharp and definite; where the older rock is of a comparatively simple composition, such as a quartzite, it may be rendered more schistose, but few secondary minerals have been developed in it. At places where the gneiss has been intruded into a rock of a similar composition, such as mica-schist, a much greater change has been effected; the mica-schists have then been rendered gneissoid, and it is often difficult in the field to determine the exact line of separation between the two rocks. Thus, in the sections on the south side of the Chisone, east of Meano, we were not at all sure—in the field—of the exact position of the contact; the microscope, however, at once enables the two to be separated.

M. Michél-Lévy has pointed out similar features in the contact-phenomena of the gneiss of the Central Plateau of France. Thus he shows¹ that, where the gneiss (or foliated granite) occurs in great mass and is intruded into rocks which are also acid in character, they are united by a passage-zone combining the characters of the two rocks. When, on the other hand, the mass of intrusive rock is comparatively small, as in a dyke, or where it cuts through rocks of a very different chemical composition, then the contact is very sharp.²

In concluding this section it may be remarked that the contact-metamorphism affords additional evidence as to the conditions under which the gneisses consolidated. Considering the massiveness

¹ Michel-Lévy, ‘Compte-rendu de la Course du 19 août, de Semur à Saulieu, par la Motte-Ternant,’ *Bull. Soc. géol. France*, ser. 3, vol. vii. (1879) pp. 852, 853.

² *Id.* ‘Compte-rendu de la Course du 19 août, d’Avallon à Chastellux,’ *op. cit.* p. 845; ‘Compte-rendu . . . à Alligny, Goie, Pensières,’ *ibid.* p. 872 and ‘Compte-rendu . . . de Semur à Saulieu . . .,’ *ibid.* pp. 853, 854.

of some of the intrusions, the contact-alterations are comparatively slight, and we have no such striking changes as those to be seen around the Biella porphyries, for example. This therefore suggests that the rock when intruded was not at a very high temperature, but in the viscid condition of a mass that has undergone partial consolidation. This is in full agreement with the evidence of the fluxion-structures. It is probable that most if not all of the true fluxion-gneisses were formed under similar conditions, and we cannot therefore expect contact-metamorphism so extensive as that produced by the intrusion of rocks, all the constituents of which were molten at the time of injection.

VI. THE ORIGIN OF THE GNEISSIC STRUCTURE.

(a) *The Igneous Gneisses*.—Before Darwin's¹ discussion of the subject in 1846, the view of the origin of the foliated rocks by original sedimentation had been universally held. Though the objections Darwin advanced have now been generally recognized as insuperable, the theory long flourished and lingers yet. In its stead have been substituted the agencies of dynamo-metamorphism, fluxion in semi-viscid consolidating rocks, and a more local combined fluxion and concretionary action. The first of these is that which is most widely applicable and is the real cause of the parallel foliation of rocks of very different composition over wide areas, *i. e.* of all cases of regional metamorphism. But that this is not a universal explanation is now admitted. Thus it has long been known that many intrusive rocks which are normally granitic in structure become foliated around the margins and in the apophyses which run off from them. Prof. Rosenbusch,² for example, clearly recognizes gneisses thus formed as well as those due to dynamo-metamorphic action. So also do MM. Michel-Lévy and Barrois.³ In England the same theory has been extended to cases previously regarded as due to dynamo-metamorphic action. Thus it has been applied by Prof. Bonney and General McMahon⁴ to the foliated gabbros of Cornwall, by the latter author⁵ to certain gneissose granites of the Himalaya, by Prof. Bonney and the Rev. Edwin Hill⁶ to the banded gneisses of Sark, and by Sir Archibald Geikie⁷ to many Archæan gneisses. Further illustrations could easily be added, but this is

¹ Darwin, 'Geological Observations on South America,' 1846, chap. vi.

² Rosenbusch, 'Mikrosk. Physiogr. Mass. Gesteine,' 2nd ed. vol. ii. (1887) p. 41.

³ Barrois, 'Le Granite de Rostrenen, ses Apophyses et ses Contacts,' Ann. Soc. geol. Nord, vol. xii. (1885) p. 105.

⁴ 'On the Crystalline Rocks of the Lizard District,' Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 483-491. (Further references given in footnote, p. 489.)

⁵ 'Note on the Foliation of the Lizard Gabbro,' Geol. Mag. 1887, pp. 74-77.

⁶ 'On the Hornblende-Schists, Gneisses, and other Crystalline Rocks of Sark,' Quart. Journ. Geol. Soc. vol. xlviii. (1892) pp. 125-127, 132-137. Note by Prof. Bonney, *ibid.* pp. 145, 146.

⁷ In discussion of Prof. Bonney and General McMahon's paper, *op. cit.* vol. xlvii. (1891) p. 499.

sufficient to show that an eruptive- or fluxion-foliation is well established.¹

Representatives of both the metamorphic and the fluxion-gneisses occur in the Cottians; thus the gabbros (or zobtenites) of Monte Viso are due to the deformation of massive gabbros, while the augen-gabbro-gneiss along the margin of the gabbro intrusion at Le Chenaillet, on Mont Genève,² appears to be clearly due to fluxion in a viscid rock near the contact.

We have then to consider which of the two explanations must be applied to the Waldensian gneisses. The field evidence at once suggests that the structure in these is a contact-fluxion. The fact that the rock is foliated on the margin, while often granitic in the centre of the massif, is not by itself conclusive. The stress of subsequent earth-movements might readily set up a deformation along the line of contact of two dissimilar rocks. But the evidence of the dykes is free from such doubts; the foliation is there parallel to the walls, and is frequently at a high angle to that of the neighbouring schists. The dykes often have an irregular course through the schists, but the foliation in them remains quite independent of that of the surrounding rocks. This appears to show conclusively that in these cases, at least, the foliation is a contact-fluxion, and has no connexion with the dynamo-metamorphism of the district.

Microscopic examination shows the identity of the structures in the apophyses and the massifs. In both the phenocrysts present true erosion-structures, as well as some which—like those from the Republic of Colombia discussed by Kuch³—may better be explained as due to pressure-deformation. In both, the micas and other constituents are distributed along lines of flow around the larger crystals. Finally, there is no evidence of the production of secondary minerals, such as invariably accompanies dynamo-metamorphism sufficiently powerful to produce a molecular rearrangement of the constituents.

(b) *The Clastic Gneisses*.—If gneiss be defined simply as a foliated rock consisting of quartz, orthoclase, and mica, then there are in the Eastern Cottians numerous rocks to which this name must be applied: they were clastic rocks—now altered by the intrusive Waldensian gneisses. These have been previously referred to as gneissoid mica-schists, and one has already been described on p. 259. That one serves as a convenient type, because all stages can be traced to it from a lead-coloured schist of undoubtedly clastic origin.

¹ Cases of foliation due to a kind of concretionary action on an enormous scale are probably exceptional and local. Such, however, appears to be the explanation of the foliation of some of the basic igneous rocks on the north-west coast of Lake Superior, which the writer hopes shortly to describe.

² Cole and Gregory, 'The Varicolitic Rocks of Mont Genève,' *Quart. Journ. Geol. Soc.* vol. xlv. (1890) p. 303.

³ Rich. Kuch, 'Petrographie—pt. i.: die vulkanischen Gesteine,' in Reiss & Stübel's 'Geologische Studien in der Republik Colombia,' 1892, p. 61.

The differences between the clastic and the fluxion-gneisses may be very conveniently expressed in diagrammatic form by M. Michel-Lévy's formulæ. Thus, adding the letter Φ to signify foliation, the following will be the formula¹ for this clastic gneiss or gneissoid mica-schist:—

$$\Phi\alpha \overline{F_1 c a_2}^1 \quad \overline{F_2 a_1 q m}.$$

The formula for the mica-schists of the same section, where comparatively unaltered, will be:—

$$\Phi\alpha \overline{F_2 M q} \quad \overline{q z m}.$$

These may be compared with that for a fluxion-gneiss:—

$$\Gamma\Phi\alpha\gamma \overline{F_2 a_1} \quad \overline{\widetilde{m a_1 q}}.$$

The question therefore inevitably arises, what use is to be made of the term 'gneiss,' as the rocks included under this name comprise those formed by three different modes of origin? That the term should be used to denote a type of structure, instead of composition, is shown by the general use of such names as gabbro-gneiss. The question now is whether the term should be restricted to the igneous or clastic varieties. Different answers have been given, according to which rock was the prevalent one in the district studied. Thus M. Michel-Lévy,² working among the clastic gneisses of the Central Plateau and Brittany, urges the necessity of limiting the term to these, whereas Prof. Lehmann, working among the granulitic gneisses, urges that all the altered sediments should be excluded.

In the case of so old a term, it is useless to attempt to determine the matter by the Morison's Pill of priority. It therefore seems advisable to retain the word in a general sense, and add some prefix to denote the nature of the origin of the rock.

Consequently the writer suggests the appended classification of gneisses, separating those in which foliation is an original structure from those in which it has been secondarily produced; the latter series may be subdivided according to the nature of the original rock. The following table summarizes the classification and terms proposed:—

A. Metamorphic.	{ Altered igneous rocks or Metapyrigen ³ -gneisses.
	{ „ sediments or Clastic gneisses.
B. Igneous.	Fluxion-gneisses.

¹ c =chlorite; a_2 =actinolite; z =zoisite; F_1 =sphenes; F_2 =garnet.

² 'Note sur la Formation gneissique du Morvan et Comparaison avec quelques autres régions de même nature,' Bull. Soc. géol. France, ser. 3, vol. vii. (1879) pp. 870-871.

³ From *πυριγενής*, formed by fire.

VII. THE AGE OF THE WALDENSIAN GNEISSES.

In Part IV. of the present paper the evidence has been summarized to show that, whatever may be the age of the gneiss, it is younger and not older than the surrounding schists. If, therefore, we wish to fix a minimum age for the rock, it is necessary first to determine the age of the schists. This question has been twice discussed in recent years by Prof. Bonney and Signor Zaccagna, who both agree with Gastaldi, Baretta, and other Italian writers; to these must be added the name of Prof. F. Sacco,¹ who, in a recent paper, accepts the Laurentian and Huronian correlation of the beds.

Élie de Beaumont and Fournet held that the schists were Jurassic, but their arguments were not in accord with modern methods; their view has, however, been again expressed recently by Prof. Stanislas Meunier² in a map in his 'Géologie Régionale de France.' Lory, on the other hand, assigned the 'schistes lustrés' to the Trias; this he taught in 1861, and reaffirmed in his latest utterances.³ He originally assigned⁴ this age only to the calc-schists that form the upper part of the series, but ultimately found it impossible to separate these from the lower mica-schists, and thus carried his line of Trias as far east as the junction with the Waldensian gneisses near Susa. This view was based on his mistaken identification of the whole of the 'Calcaire du Briançonnais' as Liassic; the lowest carnoules and dolomites of these are now universally admitted on palæontological grounds to be Triassic.⁵ The schists below them are, therefore, either Palæozoic or pre-Palæozoic. Lory would no doubt have accepted this change; he would have argued that all the evidence which made him originally assign the 'schistes lustrés' to the system immediately preceding the limestone series was quite unaltered, and that this simply involved calling the schists Carboniferous or Permo-Carboniferous instead of Trias. This would, of course, be a mere matter of detail, and would not affect the principles involved in the discussion.

It therefore becomes necessary to consider what are the oldest unaltered fossiliferous rocks in the district, and what are their relations to the Cottian schists.

Along the eastern side of the Cottians the oldest fossiliferous beds are the Pliocenes, along the extreme edge of the crystalline area;

¹ 'L'Age des Formations ophiolitiques récentes,' Bull. Soc. Belge Géol. Pal. vol. v. (1891) Mém. pp. 60-95.

² Paris, 1889, p. 430.

³ 'Sur la Constitution et la Structure des Massifs de Schistes cristallins des Alpes occidentales,' Congrès Géol. Internat., 4^{me} Sess. Londres, 1888, Comptendu (1891), pp. 86-103.

⁴ Bull. Soc. Stat. Isère, ser. 2, vol. vii. (1864) p. 94 (§ 298); *ibid.* vol. v. (1861) p. 88 (§ 43).

⁵ See Diener, 'Gebirgsbau der Westalpen,' pp. 18, 19.

but in the Maritime Alps representatives of all the principal systems, from the Carboniferous upwards, occur on both flanks of the main chain. Traced north from the Apennines and the Maritimes, the Carboniferous beds can be followed with some interruptions along the western slope, through Briançon to the base of Mont Thabor. Of the age of these beds there can be no question; they have been described by Fournet, Lory, Zaccagna, and more recently by Kilian: they are not very fossiliferous, but the plants recorded¹ from Monestier de Briançon, Puy St. Pierre, Chardonnet, Col de Buffer, etc., are sufficient to precisely fix their age. The Carboniferous is overlain by a series of rocks described by Zaccagna as Permian, which are doubtless a portion of the Poikilitic series; these beds in several places distinctly overlap the Carboniferous and unconformably overlie the calc-schists. Thus, in Zaccagna's section from St. Paul across the Monviso to Rocca Cavour, the Carboniferous beds are not included, but Pointe de Mary is capped by Permian beds, resting unconformably on the calc-schists. The basal conglomerates of the Permo-Triassic series overlie the schists and contain numerous fragments both of them and of the igneous rocks with which they are associated. The Carboniferous rocks, however, are in no place found in superposition to the schists, nor are fragments of the latter met with in the former; Kilian has, therefore, suggested the view that the schists are probably of Carboniferous age and represent the altered eastward continuation of these. He says "le terrain houiller disparaît à l'est d'une ligne Modane-Briançon-Saint-Paul, et semble céder la place aux schistes lustrés."²

This view has been strongly opposed by Bonney and Zaccagna, who agree in assigning the whole of the schists to the pre-Palæozoic. Prof. Bonney has given³ a section across the pass of Mont Genève and the Col de Sestrières, in which he limits the Mesozoic series to the upper part of Monte Chaberton, including in the Archæan the whole of the base of the mountain below the level of the Italian forts on the road from Cesana to Clavières, and all the hills on the east side of the Dora Valley.

During the present year, however, the search for radiolaria which has been stimulated by the remarkable results obtained by Issel, Parona, and Pantanelli in Liguria, has been rewarded by a discovery by Prof. Parona which has thrown an entirely new light on the whole question. This is no less than the occurrence of a radiolarian schist, or 'phthanite,' or cleaved radiolarian mud included in the calc-schist series. Prof. Parona⁴ has described the stratigraphical relations of this rock, which occurs interbedded in some green and

¹ Lory, Bull. Soc. Stat. Isère, ser. 2, vol. vii. (1864) pp. 26, 27.

² W. Kilian, 'Notes sur l'Histoire et la Structure géologique des Chaînes alpines de la Maurienne, du Briançonnais et des Régions adjacentes,' Bull. Soc. géol. France, ser. 3, vol. xix. (1891) p. 580.

³ Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 80.

⁴ C. F. Parona, 'Sugli Schisti ilicei e radiolari di Cesana, presso il Monginevra,' Atti R. Accad. Sci. Torino, vol. xxvii. (1892) pp. 306-318.

reddish siliceous schists on the south side of Monte Cruzeau, and close beside the great mass of serpentine cut through by the road from Fenestrelle to Cesana. The point at which the beds occur is on a line between the great mass of Triassic limestone that forms the Gran Roc and Roc del Boucher, with some smaller exposures of the same rocks marked by Vasseur and Carez north of Monte Cruzeau. It seemed probable, therefore, that the fossiliferous phthanite might be really a member of the Trias series folded in with or faulted down into the schists. Prof. Parona does not consider this hypothesis in his paper, and I therefore thought it advisable to examine the area independently. Before doing this, however, I examined part of the Roc del Boucher limestone and its basal graphitic beds, and worked three times over the Triassic series of Chaberton; but in neither could I find any trace of the phthanite. Nor is there any evidence that would suggest an infold of the Trias in the schists at this point. Moreover, in working along the Fenestrelle road from Cesana, a few thin bands of a similar phthanite and siliceous schists are found to occur interbedded in extremely typical calc-schists.

[Dr. Brugnatelli has announced his intention of describing fully the stratigraphical relations of the phthanites (Parona, *op. cit.* p. 306). I did not therefore attempt to trace the beds to the north, and prefer to leave any further description till after Dr. Brugnatelli's memoir has appeared. I must apologize to him for having possibly to some extent anticipated his conclusions, but it appeared absolutely necessary to insert these remarks in the discussion of the age of the schists.]

I was consequently compelled to abandon the hypothesis which I went to Cesana expecting to be able to prove, and can see no escape from the conclusion that the radiolaria are of the same age as the calc-schists.

It is somewhat unfortunate that the only fossils found, or which are likely to be found, are radiolaria, because their evidence as to the age of the deposits in which they occur is very unsatisfactory. The radiolaria are also in a very imperfect condition of preservation, but no doubts as to their authenticity can be entertained, as Prof. Nicholson and Dr. Hinde both express themselves quite satisfied with the evidence of the slides prepared from the material which I collected. Dr. Rust, who has examined slides lent by Prof. Parona, not only identifies the fossils as radiolaria, but suggests that they are possibly Tithonian in age; the stratigraphical evidence is, however, conclusive against the latter opinion.¹

Prof. Parona has figured a good number of the radiolaria, and has been able to determine the presence of 21 genera and even to identify 7 species. It is probable that better indications as to the age of a radiolarian fauna will always be obtained by the comparison of lists of genera than of species; more reliance must be placed on the general facies of faunas than on the number of species common to

¹ Parona, *op. cit.* p. 316.

the two. The Cesana radiolaria include two genera peculiar to the Palæozoic, though there are some previously known only in the Mesozoic. Prof. Barrois¹ has recently announced the discovery of a pre-Cambrian radiolarian fauna; the members of this, according to M. Cayeux, all belong to the Monosphæroidea. The Cesana fauna is, however, much more specialized than this, and includes such comparatively advanced forms as *Rhopalastrum*. The Ordovician fauna described by Dr. Hinde² all belongs to the Spumellaria, with the exception of some doubtful species; and, moreover, of this subclass only the two orders Beloidea and Sphæroidea are represented. The Cesana fauna appears of a more recent type than this, and Rust and Parona would even place it in the Mesozoic. It includes six genera of Nassellaria, while the Spumellaria are represented by the Prunoidea and Discoidea, in addition to the Sphæroidea.

Few geologists would be likely at present to argue that the mere presence of fossils in a bed is sufficient to disprove its Archæan age; but the general aspect of the radiolarian fauna is strongly in support of the view of the Palæozoic, and even of the Upper Palæozoic, age of the Cesana schists, a view which was so strenuously urged by Lory (though with a slight difference in nomenclature), and has been re-suggested by Kilian from purely stratigraphical considerations.

We must, therefore, conclude that the Waldensian gneisses are later than beds which are probably Palæozoic and may possibly be Carboniferous. This gives the maximum age. The statement has been made that pebbles of the 'central gneiss' occur in the conglomerates of the Cretaceous; I am not aware that this has been asserted by any competent petrologist, and as so many different rocks have been included under this name, it is probable that some fragments of the gneissose mica-schists have been mistaken for it. Dr. Giannotti, however, assures me that pebbles of the gneiss occur in the Miocene at Lauriano, and the accuracy of his identification cannot be questioned, though other geologists have failed to confirm it. Gastaldi also says³ that specimens of all the rocks of the Alps occur in the Lower Miocene. This settles the latest possible date, at least for the Paradiso.

The basic igneous rocks which cut through the schists would limit the date more closely, if it could be proved that they are all of one age. The Clavières serpentine is later than the calc-schists through which it cuts, and is pre-Triassic, as fragments of it occur in the conglomerates at the base of the dolomites; and this serpentine is far more likely to belong to the basic series in the schists than to the Upper Mesozoic basic series of Mont Genève. None of the pre-Triassic basic rocks cut the gneiss, though they approach

¹ Ch. Barrois, 'Sur la Présence de Fossiles dans le Terrain azoïque de Bretagne,' Comptes Rendus Acad. Sci. vol. cxv. (1892) p. 326.

² G. J. Hinde, 'Notes on Radiolaria from the Lower Palæozoic Rocks (Llandeilo-Caradoc) of the South of Scotland,' Ann. Mag. Nat. Hist. ser. 6, vol. vi. (1890) pp. 40-59, pls. iii., iv.

³ Gastaldi, Mem. descriz. Carta geol. Ital. vol. ii. pt. ii. (1874) p. 59.

very close to it. We may, therefore, conclude that the gneiss is later than the earlier basic series. But, until it can be determined at what period in the Palæozoic era that series was intruded, this line of argument only confirms the previous conclusions without rendering them more precise.

For a more definite determination of the age of the Waldensian gneisses reliance must be placed on the indirect evidence afforded by a study of the main dislocations of the district. It is now generally admitted that the mountains in this part of the Alps have been formed by elevations at very different epochs, from the Carboniferous (or, according to Prof. Sacco,¹ from the pre-Cambrian) to the Pliocene. The evidence for, and the influence of, the different movements, have been recently discussed by Kilian,² Haug,³ and Diener.⁴ The pre-Permian movements appear to have been unimportant in this district, as Diener has pointed out, though Zaccagna lays much stress upon them.

The main earth-movements of the Cottians may be divided into six groups:—

1. The east-and-west fold of the Northern Cottians, which has caused the anticlinal separating the gneiss of the Paradiso from that of the Eastern Cottians.

2. The north-and-south faults to which are due the valleys of Turras, and the uppermost part of the Dora Riparia.

3. The east-and-west compression to which is due the narrow north-and-south chain from Bric Bouchet to the Monviso.

4. A series of powerful thrusts from the west, which has pushed the Trias on to the calc-schists—as in the north-eastern spur of Monte Chaberton and in the Roc del Boucher, and has contorted the dolomites to the north of Rocca Bianca.

5. An enormous gabbro-intrusion (possibly laccolitic) which forms the Punta del Lagho, Monte Tre Denti, Monte Robinet, and Monte delle Plate, which now occupies the centre of a great circular amphitheatre, $2\frac{1}{2}$ miles in diameter, formed of the schists of Rocca Rossa, Rocca Vergia, Rocca del Mortai, and doubtless also the Costa di Plantin and Costa Ciarmagrande.

6. The intrusion of the Waldensian gneisses.

¹ F. Sacco, 'La Géo-tectonique de la Haute Italie occidentale,' Bull. Soc. Belge Géol. Pal. vol. iv. (1890) Mém. p. 28.

² W. Kilian, 'Notes sur l'Histoire et la Structure géologique des Chaînes alpines de la Maurienne, du Briançonnais et des Régions adjacentes,' Bull. Soc. géol. France, ser. 3, vol. xix. (1891) pp. 571–661; and 'Description géologique de la Montagne de Lure (Basses-Alpes),' 1888, Ann. des Sciences Géol. vol. xx. pp. 110–169.

³ E. Haug, 'Les Chaînes subalpines entre Gap et Digne; Contribution à l'Histoire géologique des Alpes françaises,' Bull. Serv. Carte géol. France, no. 21, vol. iii. (1891) pp. 169–191.

⁴ Diener, 'Gebirgsbau der Westalpen,' pp. 190–218.

With the exception of No. 5, these six divisions may be arranged into two groups; the first includes Nos. 2, 3, 4, and 6, the axes or directions of which have a general north or north-westerly to south or south-easterly range; the second includes the transverse fold of the Northern Cottians. The detailed work of Kilian and Haug¹ has shown that the dislocations of the Subalpine chains to the west may also be grouped into approximately meridional and transverse series.

It is tempting to try to correlate these with the dislocations of the Cottians, but this cannot be done, except in a very general way. Kilian points out that in the mountains of Lure the north-and-south series are pre-Miocene, and the east-and-west series post-Upper Miocene. Similarly in the Gap-Digne area the N.W.-and-S.E. folds are pre-Aquitania (Upper Oligocene) and possibly Lower Eocene, whereas the east-and-west set are mostly Helvetian (Middle Miocene), though some are pre-Aquitania. The same probably holds in the Cottians: the east-and-west fold of the Northern Cottians is apparently connected with the Paradiso intrusion, and is probably Miocene, certainly pre-Pliocene. The Pliocene beds of the Villafranchian stage on the eastern flank have been raised over 1500 feet by a movement which closed that period.² As, however, the Paradiso gneiss was exposed before this, a fact proved by the evidence of the Miocene conglomerates, this Pliocene movement must have followed along the old line. The crushing of the contact-rock between the gneiss and the schists may have been caused by such later movements.

The absence of fossiliferous Tertiary beds in the Cottians prevents any such definite determination of the succession of the movements as is possible in the Subalpine mountains of Dauphiné. Nevertheless a rough order may be safely established for the remaining five sets of dislocations. No. 5 is probably Upper Mesozoic,³ owing to the agreement of its rocks with those of the Mont Genève variolitic series; typical specimens of variolite derived from this mass occur in the bed of the Sangonetto above Palé. Nos. 3 and 4 are both later than the Cretaceous, some beds of which are included in the limestone series of Chaberton. No. 2 is still later, as it has cut through the overthrust limestones both at the Roc del Boucher and at Chaberton. These three sets, Nos. 2, 3, and 4, are probably more closely allied than the others; they are the result of enormous lateral compression and strain, and the secondary foliation so frequent in the schists of the district is probably due to them. The

¹ Haug, *op. supra cit.* pp. 184-187.

² Sacco, 'Il Cono di deiezione della Stura di Lanzo,' *Boll. Soc. geol. Ital.* vol. vii. (1888) p. 160; see also Gastaldi, *Mem. descriz. Carta geol. Italia*, vol. ii. (1874) pl. ii.

³ The latter basic series is accepted as Upper Mesozoic (probably Cenomanian) on the authority of Prof. Sacco's demonstration that the Ligurian beds containing the serpentines of Liguria are Cretaceous and not Eocene, 'L'Age des Formations ophiolitiques récentes,' *Bull. Soc. Belge Géol. Pal.* vol. v. (1892) *Mém.* pp. 60-95.

schists and the igneous rocks of the 'pietre-verdi' group have been foliated at right angles to the axis of compression. Though I am not aware of any evidence that gives positive proof of the exact age of these dislocations, it is highly probable that they are part of the great post-Helvetian pre-Tortonian movements in which the forces that raised the Western Alps attained their maximum intensity.

The Waldensian gneisses have not been affected by any of the previous movements. The differences in this respect between the gneisses and the neighbouring schists is one of the most striking features in the Cottians. In the gneisses the minerals are all fresh, and the original fluxion-foliation undisturbed. In the schists the minerals are altered, often till no trace of the original constituents remains; instead of the felspars being water-clear, the original fragments are saussuritized or represented only by grains of zoisite, while the pyroxenes have been uralitized, and the resulting pseudomorphs, as well as the original amphiboles, have been converted into smaragdite. The changes in the structures and field relations of the rocks have been still more striking; the schists have been intensely crumpled and contorted, folds have been inverted, and the materials of the concave limb crushed into mylonites; gnarled schists have been a second time crumpled, foliation has been impressed on foliation, and fault has broken the continuity of fault. It seems almost impossible to believe that the gneisses can have remained fresh and undisturbed through the dislocations that have produced such changes in the rocks with which they are in contact; this affords another proof not only that the Waldensian gneisses are younger than the schists, but that they are later than the great earth-movements at the close of the Middle Miocene. It is quite possible that the gneiss of the enormous massif of the Paradiso was intruded somewhat earlier than that of the Eastern Cottians, and this would account for the pebbles in the Miocene. The low banks of gneiss which even now have only a very restricted outcrop, sometimes merely on the floors of the Waldensian valleys, are most unlikely to have been exposed during Miocene times.

In the Alps of Dauphiné the Pliocene movements are very feeble, but this does not forbid their powerful influence in the centre of the Cottian group, for feeble also are the movements in the Miocene there—compared with those which elevated the main chain of the Western Cottians. The elevation of the Villafranchian beds has been shown by Sacco to demonstrate an elevation of over 1500 feet, and the gneiss-intrusion may well have been contemporary with this. Paradoxical though it may appear, the evidence renders it most probable that the Waldensian gneiss, instead of being of Laurentian age, is really Pliocene, and, with the exception of the Saharian and recent alluvium and the glacial moraines, is the newest rock in the Cottians.

VIII. SUMMARY OF CONCLUSIONS.

1. The Cottian Sequence consists of:—

- (a) A series of coarse-grained gneisses occurring along the line of the Eastern Cottians; for convenience of reference these are called 'the Waldensian gneisses.'
- (b) A thick succession of schists which are gneissoid near the junctions with the gneisses, are mica-schists at the base, and pass upward into calc-schists.
- (c) An extensive group of epidiorites, serpentines, etc. (the 'pietre verdi' of Gastaldi), which traverse the lower part of *b*.
- (d) A series of fossiliferous beds ranging from the Carboniferous upward.

2. The Waldensian Gneisses. A description of their field-relations and microscopic structure is given, and it is contended:—

- (a) That they occur as independent, isolated masses, and not as a continuous band having a fixed geological horizon at the base of the whole series.
- (b) That instead of being basal Laurentian rocks, overlain by or faulted against the schists, they are a series of igneous intrusive rocks; this is demonstrated by
 - i. The contact-metamorphism around them, both exomorphic and endomorphic;
 - ii. The occurrence of apophyses of gneiss and aplite from the gneiss into the schist;
 - iii. The gneiss often containing large altered blocks of the schists, and being sometimes saturated with chloritic and amphibolic material absorbed during intrusion;
 - iv. The transgressive nature of the junction between the two series;
 - v. The failure of any of the igneous rocks, intrusive into the schists, to cut the gneiss;
 - vi. The fact that the gneiss has not been affected by the earth-movements which have crushed and contorted the schists.

3. The Paradiso Gneiss. The relations of this on one margin are also described, and it is shown that it agrees in all respects with the Waldensian gneisses, except for

- (a) Its greater mass.
- (b) The possibility that it was in part intruded at an earlier date.

The evidence in this case is less complete.

4. The Gneissic Structure.

This is shown not to be due to dynamo-metamorphism, but to be an original fluxion-structure formed owing to the intrusion of the rock in a viscid condition. It is, therefore, not to be expected that these fluxion-gneisses will produce such extensive contact-metamorphism as rocks intruded at a higher temperature. Other gneisses in the Cottians were formed by the dynamo-metamorphism of igneous rocks and mechanical sediments. The example of those writers who use the term 'gneiss' only in a structural sense is, therefore, followed; and the three groups met with in the Cottians are referred to as clastic gneisses, metapyrigen-gneisses, and fluxion-gneisses.

5. The Age of the Waldensian Gneisses.

- (a) They are later than the schists, and the uppermost member of this series belongs in all probability to the Palæozoic; this conclusion is based on :
 - i. The stratigraphical evidence relied upon by Lory and Kilian ;
 - ii. The evidence of the radiolarian fauna in the calc-schists ;
 - iii. The schists, however, are unquestionably pre-Triassic.
- (b) The gneisses have not been affected by the great Miocene (post-Aquitanian, pre-Langhian, post-Helvetian, and pre-Tortonian) earth-movements which have crushed and contorted the schists.
- (c) The elevation of the marine Pliocenes to the height of 1500 feet shows that powerful earth-movements occurred in late Pliocene times ; the intrusion of the Waldensian gneiss was probably contemporary, and perhaps the cause of these.

EXPLANATION OF PLATE XV.

Fig. 1. Typical Waldensian Gneiss. From quarries at Bussoleno. $\times \frac{42}{2\frac{1}{2}}$

The minerals shown are large, eroded, dusty crystals of orthoclase (o), water-clear quartz-orthoclase mosaic (x), numerous crystals of muscovite (m), and granules of kyanite (k).

Fig. 2. (a) Gneiss from the margin of the Paradiso massif, consisting of a fine-grained, quartz-orthoclase mosaic (x), muscovite (m), included granules of epidote (e) and aggregates of zoisite (z) and chloritic material (c).

(b) An included fragment from the adjoining 'pietre-verdi' series, showing the indefinite groundmass, quartz, and glaucophane (gl).

From the Vonzo Valley, near Chialamberto. $\times \frac{42}{2\frac{1}{2}}$

Fig. 3. Junction of the aplite-dykes with the rocks of the 'pietre-verdi' series; from the Rocce Roccaglie, Angrogna Valley; see fig. 9, p. 257.
 $\times \frac{26}{2}$

Fig. 4. Part of the thickest aplite-dyke from the same locality. It consists, in the main, of quartz-orthoclase mosaic and bands of muscovite; it contains included grains of the surrounding rocks, like that seen in fig. 3.

Figs. 5 & 6. The Contact-series at Ostana, near Crissolo, Po Valley. $\times \frac{42}{2\frac{1}{2}}$.

Fig. 5. The contact-rock; all the minerals are authigenous or due to injection from the gneiss; the rock consists of orthoclase (*o*), quartz-orthoclase mosaic, biotite (*b*), and zoisite aggregates (*z*).

Fig. 6 (a). The lead-coloured mica-schists, 100 yards from the contact.

Fig. 6 (b). The gneissose mica-schist near the contact; the principal secondary minerals produced are garnets (*gr*), often traversed by veins of chlorite, muscovite (*m*), and rutile (*n*).

All the figures are drawn under ordinary transmitted light.

DISCUSSION.

The PRESIDENT felt sure that all would join in offering a welcome to Dr. Gregory on his first appearance at the Society, as an Author, since his adventurous African journey; and he further expressed a hope that, ere long, the Society would hear something of the geological features of Mount Kenya.

The paper contained some startling conclusions in respect to the lowest rocks not necessarily being the oldest; but for these we had been more or less prepared by the work of Lawson in America and of Barrow in Scotland. Hence there was no *à priori* improbability. The question was whether the evidence and arguments in this case favoured the notion of a gneiss having been intruded into schists. He (the President) thought it was so, though without further proofs as to age it might be merely an instance of an Archæan gneiss intruded into Archæan schists. Thus it became important to determine, if possible, the age of the schists. He commented on the fact that no fauna lower than the Carboniferous had been discovered in the Western Alps, and expressed curiosity to know what had become of the older Palæozoics: the discovery of radiolaria may possibly lead to results of importance in this direction.

But by far the most astonishing part of Dr. Gregory's paper is the last, where he speculates on the age of the gneiss itself, and concludes that, owing to its freedom from the effects of earth-movements, it is actually amongst the youngest rocks in the Alps. On this point, more especially, he expected an animated discussion.

Prof. Judd said that all his prepossessions were in favour of accepting the views of Dr. Gregory concerning the hypogene origin of these gneisses and their late geological age. He felt, however, that, in a district which has undergone such great movements, the evidence brought forward must be scrutinized with the most extreme care. He was not satisfied that the evidence of contact-metamorphism, of included fragments, and of apophyses of aplite proceeding from the gneiss into the schists had been established beyond every possibility of doubt.

Mr. BARROW observed that the paper before the Society might be divided into four parts. The first dealt with the evidence of the intrusive nature of the coarse gneiss; and the Author was to be congratulated on the careful manner in which he had gone over the ground, and the clearness with which he had summarized his evidence. The second referred to the contact-effects of the intrusion. But here the evidence was too vague to enable us to form any opinion as to the accuracy of the Author's views. Did he suppose that the crystalline character of the surrounding schists and gneisses was essentially due to this intrusion or merely modified by it? Thirdly, the evidence of age would require most searching examination. The movements on the margins of mountains have frequently associated fossil-bearing rocks with older crystalline schists in such a manner as to have deceived some of our most acute observers, and led to the conclusion that they were all of one age. Lastly, the fact that the great earth-movements do not appear to have effected any crushing in the coarsely crystalline rocks was not a satisfactory line of argument as to the age of the rocks. Powerful earth-movements frequently fail to crush more than the outer margins of crystalline areas; these harder rocks escaping at the expense of the softer and often unaltered sediments by which they are flanked. The latter, indeed, are frequently themselves altered to finely schistose rocks giving every appearance of a passage from one series to the other.

Prof. BONNEY said that he had only examined these Cottian gneisses in one locality, and had found it extremely difficult to make out what their origin might be. If fluxion-gneisses, which was very possible, they were rather peculiar. He quite agreed that a group of granitic rocks existed in the Alps later than any of the crystalline schists, but that did not prove that they were Tertiary, Secondary, or Palæozoic. The discovery of radiolaria in the 'schistes lustrés' did not show that these were Palæozoic, because, if the rocks were *schists*, there would be no radiolaria remaining; and nothing was commoner in the Alps than to find wedges of Jurassic, or Triassic, or older but comparatively unaltered sediments in the crystalline masses. Also the Carboniferous rock was very apt to have its base full of material from the older underlying rock. As to the age of the gneiss, he agreed with Mr. Barrow that no great value attached to the fact of these rocks being uncrushed. He gave instances, and said he felt incredulous as to a Pliocene age, because there was no evidence, so far as he knew, of outbreaks of igneous rock of Tertiary age, except the basalts in the S.E. The Permian or some part of the Trias seemed the latest possible.

Mr. A. M. DAVIES said that he had accompanied Dr. Gregory on his last visit to the Cottians, and had seen the greater part of the evidence on which his conclusions were based. Some of the junctions (such as that at the Roc del Pelvo) showed striking evidences of intrusion, but there was room for much more detailed study; and the mountainous nature of the district would add greatly to the

difficulties of mapping. There was some evidence of Tertiary (or Upper Mesozoic) volcanic activity farther west, though faulted junctions prevented clear demonstration in the most desirable case. There, in the Mont Genève and Chaberton region, the presence of Mesozoic sedimentaries enabled one to immediately recognize folds, faults, and thrusts, the importance of which might easily be underestimated in the area of crystalline schists and gneisses.

Mr. VAUGHAN JENNINGS and Dr. G. J. HINDE also spoke.

The AUTHOR, in reply, admitted the need for caution and careful mapping. He did not think the inclusions could be segregations, owing to their difference in composition from any of the minerals of the gneiss and their resemblance to those of the altered 'pietre verdi'; segregations do occur, and are easily distinguished. No aplite-dykes occur in the gneiss, and the aplite is mineralogically almost identical with the selvages of the gneiss masses; the evidence of the Crissolo section seems conclusive that the aplite-dykes are offshoots from the gneiss. As regards the argument from the unaltered nature of the gneiss, it was admitted that rocks in mass could readily escape; but this could hardly be the case with dykes ranging from 100 feet to 1 foot in width. The absence of pebbles in the conglomerate tells also very strongly in favour of the recent age of the gneiss. The interlamination of thin beds of the radiolarian phthanites with the calc-schists renders it very difficult to explain their occurrence by any system of infolds. He had no doubt of the occurrence of igneous rocks of post-Palæozoic age in the Cottians.

F.H. Michael del. et lith.

Mitern Bros. imp.

GNEISSES, APLITES & CONTACT-ROCKS.