XI. *On the Joint-Systems of Ireland and Cornwall, and their Mechanical Origin.*

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CONTENTS.

INTRODUCTION.

IN the Philosophical Transactions for 1858, I have given an account of the Joints of the Old Red Sandstone of the co. Waterford, and demonstrated in it the existence of the following Systems of Joints (page 348):—

First Conjugate System.

A . .	81 observations . .	7° 46′ N. of E. (Mag.) . .	32° 26′ N. of E. (True.)
C . .	49 „ . .	6° 57′ W. of N. „ . .	31° 37′ W. of N. „

Second Conjugate System.

A′ . .	135 observations . .	33° 31′ N. of E. (Mag.) . .	58° 11′ N. of E. (True.)
C′ . .	47 „ . .	35° 23′ W. of N. „ . .	60° 3′ W. of N. „

Third Conjugate System.

A″ . .	14 observations . .	30° 30′ S. of E. (Mag.) . .	5° 50′ S. of E. (True.)
C″ . .	12 „ . .	29° 10′ E. of N. „ . .	4° 30′ E. of N. „

Fourth Conjugate System.

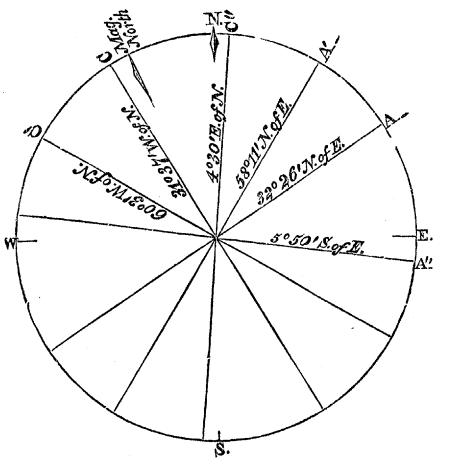
A‴ . .	1 observation . .	10° 0′ S. of E. (Mag.)
C‴ . .	6 observations . .	9° 30′ E. of N. „

Since the publication of the foregoing account, I have found the system (A, C) in Donegal, Mourne, Cornwall and elsewhere, and have reason to believe it to be the most important of all the joint-systems of Waterford. I shall therefore call it the Primary System of Conjugate Joints, and the systems (A′, C′) and (A″, C″) I shall call

correlated Secondary Systems of Conjugate Joints, as I believe that they can be shown to be simple mechanical consequences of the Primary System (A, C).

Neglecting for the present the system (A‴, C‴), the whole of the Joints of Waterford may be represented by the following diagram (fig. 1), to which I shall frequently have occasion to refer.

Fig. 1.



It will be observed that the Primary System (A) divides somewhat unequally the angle between (A′) and (A″).

Angle between A and A′ . .	25° 45′	} Mean = 27° 5′.
,, C and C′ . .	28 26	
Angle between A and A″ . .	38 16	} Mean = 37 11.
,, C and C′ . .	36 7	

PART I.—ON THE JOINT-SYSTEMS OF THE CO. DONEGAL.

The following Tables give the bearings of all the joints observed, arranged according to their azimuths, together with the locality, and a statement of the rock in which the joint was observed. In each locality several joints of the same bearing were measured but only one is recorded.

TABLE I.—East and West Joints in Donegal.

No.	Bearing.	Dip.	Locality.	Rock.
1	45° N. of E.	.....	Between Dunglow and Doocharry.	Granite.
2	45 ,,	.....	Culdaff.	Quartzite.
3	35 ,,	.....	The Mintiaghs.	,,
4	35 ,,	.....	Urrismenagh.	Granite.
5	30 ,,	90	Gweebarra, South.	,,
6	30 ,,	.....	The Mintiaghs.	Syenite.
7	30 ,,	.....	Gap of Mamore.	Quartzite.
8	20 ,,	.....	Barnesmore.	Granite.
9	20 ,,	.....	Barnesbeg.	,,
10	15 ,,	80 N.	Doocharry Bridge.	,,

TABLE I. (continued).

No.	Bearing.	Dip.	Locality.	Rock.
		°		
11	10° N. of E.	.....	Glenleheen.	Granite.
12	10 „	.....	Between Glenties and Gweebarra.	„
13	7 „	.....	Barnesbeg.	„
14	7 „	.....	Lackagh Bridge.	„
15	5 „	.....	Barnesbeg.	„
16	5 „	.....	Lackagh Bridge.	„
17	5 „	.....	Milford.	Quartzite.
18	0 E.W.	90	Annagary.	Granite.
19	0 „	.....	Fanad.	„
20	5 S. of E.	.....	McSwyne's Gun.	Syenite.
21	10 „	.....	Barnesmore.	Granite.
22	10 „	.....	Malin.	Quartzite.
23	10 „	.....	Moville.	Mica-slate.
24	10 „	.....	Shalwy.	Carb. Limestone.
25	10 „	90	Between Doocharry and Fintown.	Granite.
26	35 „	90	Shalwy.	Old Red Conglomerate.
27	35 „	.....	The Mintiaghs.	Quartzite.
28	40 „	.....	The Mintiaghs.	Syenite.
29	40 „	.....	Barnesbeg.	Granite.

TABLE II.—North and South Joints in Donegal.

No.	Bearing.	Dip.	Locality.	Rock.
		°		
1	40° E. of N.	.....	Culdaff.	Quartzite.
2	30 „	90	Shalwy.	Old Red Conglomerate.
3	15 „	.....	Meen Banad.	Granite.
4	10 „	.....	Shalwy.	Carb. Limestone
5	10 „	80 E.	Sheskina Roan.	Granite.
6	7 „	90	Annagary Hill.	„
7	5 „	.....	McSwyne's Gun.	Syenite.
8	5 „	.....	Glen (North).	Granite.
9	5 „	.....	Fanad.	„
10	5 „	.....	The Mintiaghs.	Syenite.
11	0 N.S.	.....	Barnesbeg.	Granite.
12	0 „	.....	Glen (North).	„
13	0 „	.....	Sheskina Roan.	„
14	5 W. of N.	.....	Barnesbeg.	„
15	5 „	.....	Milford.	Syenite.
16	5 „	.....	Glenleheen.	Granite.
17	5 „	90	Lough Anure.	„
18	7 „	.....	Lackagh Bridge.	„
19	10 „	.....	Between Glenties and Gweebarra.	„
20	10 „	.....	Gweebarra (South).	„
21	10 „	80 E.	Doocharry Bridge.	„
22	10 „	90	Annagary Hill.	„
23	10 „	.....	Between Dunglow and Doocharry.	„
24	10 „	90	Between Doocharry and Fintown.	„
25	10 „	.....	Glen (North).	„
26	10 „	.....	Lackagh Bridge.	„
27	10 „	.....	Ards.	Quartzite.
28	15 „	.....	Fintown Gap.	Gneiss.
29	20 „	.....	Urrismenagh.	Granite.
30	20 „	.....	Glen (North).	„
31	22 „	.....	Urrismenagh.	„
32	25 „	.....	Fanad.	„
33	25 „	.....	Barnesbeg.	„
34	40 „	.....	Gap of Mamore.	Quartzite.
35	42 „	.....	Barnesbeg.	Granite.

If we arrange the 64 observations recorded in the preceding Tables according to their azimuths and the number of observations corresponding to each, we shall obtain the following:—

TABLE III.—Joints of Donegal, arranged according to azimuths and number of observations.

Azimuth.	No. of observations.
42° W. of N.	1
40 „	1
25 „	2
22 „	1
20 „	2
15 „	1
10 „	9
7 „	1
5 „	4
0 N.S.	3
5 E. of N.	4
7 „	1
10 „	2
15 „	1
30 „	1
40 „	1
45 N. of E.	2
35 „	2
30 „	3
20 „	2
15 „	1
10 „	2
7 „	2
5 „	3
0 E.W.	2
5 S. of E.	1
10 „	5
35 „	2
40 „	2
Total	64

An inspection of this Table shows that, of the 64 observations, 24 are included in the angle between 10° E. of N. and 10° W. of N., and that 15 are included in the angle between 10° N. of E. and 10° S. of E.,—making a total of 39 in 64, or 61 per cent. of the whole number of observations contained between these two limits. Dividing the N.S. observations equally between those that lie to the E. and W. of North, we find the following mean azimuths:—

I. 7° 33′ W. of N. from 15½ observations =24 per cent.
II. 5° 32′ E. of N. from 8½ observations =13 per cent.

In like manner, dividing the E.W. observations equally between those that lie to the N. and S. of East, we find the following mean azimuths:—

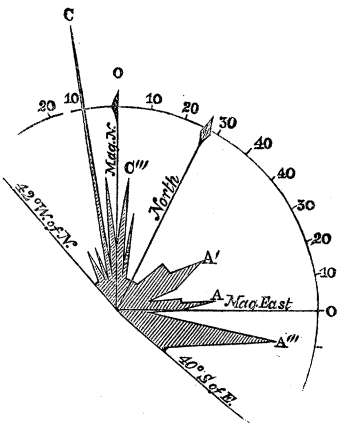
III. 6° 7′ N. of E. from 8 observations =12½ per cent.
IV. 7° 51′ S. of E. from 7 observations =11 per cent.

From Table III. it also appears that between 30° and 35° North of East, there are five observations, whose mean is

V. 32° 0′ N. of E. from 5 observations =8 per cent.

The accompanying diagram (fig. 2) is a graphical representation of Table III., and shows sufficiently well the five systems of joints that have been deduced from that Table.

Fig. 2.



Of the joints themselves, I. and III., II. and IV. are evidently conjugates, being nearly at right angles respectively, while V. belongs to a system different from the others.

Adopting the notation used by me already* in my paper on the Joints of the co. Waterford, and comparing the results there obtained with those here found, we may construct the following Table:—

TABLE IV.—Comparison of the Joints of Donegal and Waterford.

(C). West of North (Magnetic).		(A). North of East (Magnetic).		(C). West of North (true bearings†).		(A). North of East (true bearings).	
Donegal.	Waterford.	Donegal.	Waterford.	Donegal.	Waterford.	Donegal.	Waterford.
7° 33′	6° 57′	6° 7′	7° 46′	34° 13′	31° 37′	32° 47′	32° 26′
Angle of Axes = { 91° 26′ Donegal / 89° 11′ Waterford } from East to North.							
(C‴). East of North (Magnetic).		(A‴). South of East (Magnetic).		(C‴). West of North (true bearings).		(A‴). North of East (true bearings).	
Donegal.	Waterford.	Donegal.	Waterford.	Donegal.	Waterford.	Donegal.	Waterford.
5° 32′	9° 30′	7° 51′	10° 0′	21° 8′	15° 10′	18° 49′	14° 40′
Angle of Axes = { 92° 19′ Donegal / 90° 30′ Waterford } from East to North.							
(A′). North of East (Magnetic).				(A′). East of North (true bearings).			
Donegal.		Waterford.		Donegal.		Waterford.	
32° 0′		33° 31′		31° 20′		31 49′	

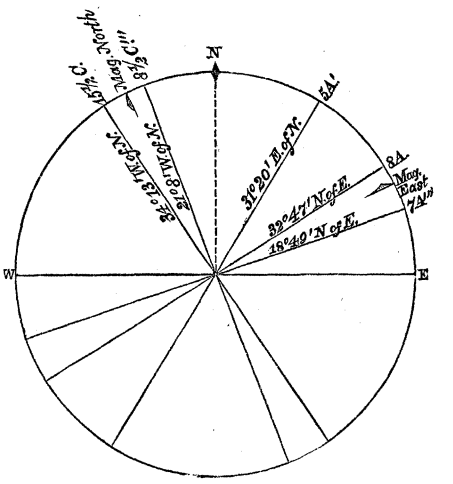
The agreement between the respective systems A, C and A′ is very remarkable; that between A‴ and C‴, in the two localities, is perhaps as good as can be expected from the

* Philosophical Transactions, 1858, p. 333.

† The magnetic variation in Donegal was 26° 40′ W. and in Waterford 24° 40′ W.

limited number of observed planes, which was $15\frac{1}{2}$ in Donegal, and only 7 in Waterford, where this conjugate system is very subordinate in importance.

Fig. 3.



The annexed diagram (fig. 3) shows the Donegal joints divided into two conjugate systems, (A, C) and (A‴, C‴), together with one plane (A′) of a third system; all of which are represented in the co. Waterford.

Of the whole 64 joints recorded, 44, or 69 per cent., are involved in these five planes; and the number of observations belonging to each is placed beside its designation in the diagram.

If we combine together the systems (A, A‴) and (C, C‴), we obtain the following as the most simple combination of joints observable in Donegal.

	No. of observations.	Magnetic bearing.	True bearing.
I. Primary System (A—A‴) . .	15 . .	0° 24′ S. of E.	26° 16′ N. of E.
II. Conjugate Primary (C—C‴) .	24 . .	2° 55′ W. of N.	29° 35′ W. of N.
III. Secondary System (A′) . . .	5 . .	32° 0′ N. of E.	58° 48′ N. of E.

The angle between the Primary System and its Conjugate (A, C) is therefore found to be 93° 19′.

And the angle between the Primary and Secondary Systems (A, A′) is 32° 24′.

The angle between (A, C) and (A′, C′) in the co. Waterford has been already stated to be 27° 5′.

Part II.—On the Joint-Systems of the Mourne and Newry Mountains.

The following Tables contain the observed joint-planes of the Mourne and Newry mountain district.

Table V.—North and South Joints of the Mourne and Newry Mountains.

No.	Bearing.	Dip.	Locality.	Rock.
1	45° W. of N.	.....	Railway cutting *.	Granite.
2	45 „	70 N.	„	„
3	45 „	90	Back of Eagle Mountain.	„
4	45 „	65 N.	Campbell's Quarry, Newry.	„
5	45 „	90	„ „	„
6	30 „	90	Summit of Eagle Mountain.	„
7	30 „	55 E.	Killowen.	Slate.
8	30 „	60 E.	„	„

* The railway cuttings are from the Main Line Station of the Dublin and Belfast Junction Railway to the open plain under Slieve Gullion.

TABLE V. (continued).

No.	Bearing.	Dip.	Locality.	Rock.
9	25° W. of N.	.....	Railway cutting.	Granite.
10	25 „	90	Killowen.	Slate.
11	20 „	80 E.	Eagle Mountain (summit).	Granite.
12	15 „	.....	Railway cutting.	„
13	15 „	75 E.	„	„
14	15 „	80 E.	„	„
15	15 „	.....	„	„
16	15 „	90 to 65 E.	Wellington Inn *.	„
17	15 „	90 to 65 E.	„	„
18	15 „	.....	Rostrevor.	Slate.
19	15 „	.....	Eagle Mountain (summit).	Granite.
20	15 „	90	Slieve Bingian.	„
21	10 „	70 E.	Railway cutting.	„
22	10 „	90	Rostrevor.	Slate.
23	5 „	90	Back of Eagle Mountain.	Granite.
24	5 „	90	Campbell's Quarry, Newry.	„
25	5 „	80 E.	„ „	„
26	0 N.S.	90	Eagle Mountain.	„
27	0 „	90	„	„
28	0 „	90	„	„
29	5 E. of N.	80 E.	Campbell's Quarry, Newry.	„
30	10 „	.....	Railway cutting.	„
31	15 „	90	Rostrevor.	Slate.
32	15 „	90	Killowen.	„
33	15 „	90	Eagle Mountain.	Granite.
34	15 „	90	Campbell's Quarry, Newry.	„
35	15 „	90	„ „	„
36	15 „	80 E.	„ „	„
37	20 „	90	„ „	„
38	20 „	.....	Railway cutting.	„
39	20 „	65 E.	Rostrevor.	Slate.
40	20 „	70 W.	„	„
41	22 „	.....	Slieve Bingian.	Granite.
42	25 „	90	Railway cutting.	„
43	30 „	90	„	„
44	30 „	.....	„	„
45	30 „	90	„	„
46	30 „	90	„	„
47	40 „	90	Campbell's Quarry, Newry.	„
48	40 „	.....	Railway cutting.	„
49	45 „	.....	„	„
50	45 „	80 E.	„	„
51	45 „	.....	„	„
52	45 „	90	Summit of Eagle Mountain †.	„
53	45 „	90	„ „	„
54	45 „	90	„ „	„
55	45 „	80 W.	Campbell's Quarry, Newry.	„

* These joints are beautifully curved.

† These joints form the faces of the splendid granite columns, 150 feet in height, for which this mountain is celebrated.

TABLE VI.—East and West Joints of the Mourne and Newry Mountains.

No.	Bearing.	Dip.	Locality.	Rock.
1	40° N. of E.	90°	Columns at summit of Eagle Mountain.	Granite.
2	40 „	90	„ „ „	„
3	35 „	.....	Railway cutting.	„
4	30 „	90	Summit of Eagle Mountain.	„
5	30 „	65 N.	Rostrevor.	Slate.
6	30 „	90	Railway cutting.	Granite.
7	20 „	65 N.	„	„
8	20 „	45 S.	Rostrevor.	Slate.
9	15 „	.....	Railway cutting.	Granite.
10	15 „	.....	„	„
11	15 „	.....	„	„
12	15 „	90	Campbell's Quarry.	„
13	10 „	.....	„	„
14	10 „	90	Rostrevor.	Slate.
15	10 „	60 N.	„	„
16	10 „	90	Eagle Mountain.	Granite.
17	5 „	25 N.	Rostrevor.	Slate.
18	0 E.W.	80 S.	Railway cutting.	Granite.
19	0 „	.....	„	„
20	0 „	90	„	„
21	0 „	60 N.	Eagle Mountain.	„
22	0 „	90	„	„
23	5 S. of E.	90	„	„
24	5 „	80 N.	Campbell's Quarry.	„
25	5 „	85 N.	Slieve Bingian.	„
26	20 „	.....	„	„
27	22 „	.....	„	„
28	25 „	.....	„	„
29	25 „	70 N.	Campbell's Quarry.	„
30	25 „	.....	Railway cutting.	„
31	30 „	90	Eagle Mountain.	„
32	30 „	70 N.	Railway cutting.	„
33	40 „	90	„	„
34	40 „	70 N.	Campbell's Quarry.	„

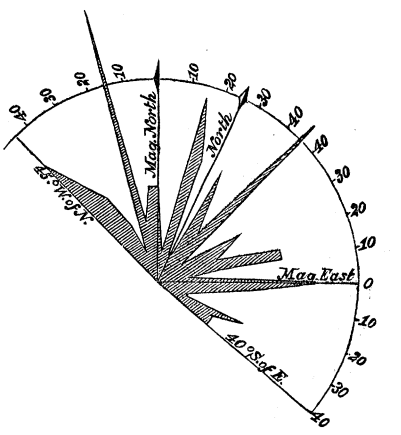
Collecting together into one Table the 89 observations, and arranging them by azimuths and the number of observations belonging to each, we find the following:—

TABLE VII.—Joints of the Mourne and Newry Mountains, arranged according to azimuths and number of observations.

Azimuth.	Number of observations.
45° W. of N.	5
30 „	3
25 „	2
20 „	1
15 „	9
10 „	2
5 „	3
0 N.S.	3
5 E. of N.	1
10 „	1
15 „	6
20 „	4
22 „	1
25 „	1
30 „	4
40 „	2
45 „	7
40 N. of E.	2
35 „	1
30 „	3
20 „	2
15 „	4
10 „	4
5 „	1
0 E.W.	5
5 S. of E.	3
20 „	1
22 „	1
25 „	3
30 „	2
40 „	2
Total	89

The accompanying diagram (fig. 4) represents graphically the preceding Table.

Fig. 4.



From an examination of Table VII., it appears that 71 per cent. of the total observations may be included in six systems of joints, each contained within limits of 10°.

1. Between 5° and 15° W. of N. . . . 14 observations.
2. „ 15 and 25 E. of N. . . . 12 „
3. „ 40 and 50 E. of N. . . . 7 „
4. „ 10 and 20 N. of E. . . . 10 „
5. „ 5 N. of E. and 5° S. of E. 9 „
6. „ 45 and 20 W. of N. . . . 11 „

63 or 71 per cent. of 89 observations.

The precise bearings of these systems are—

1.	12° 8′ W. of N.	(C).	
2.	18 5 E. of N.		(C″).
3.	45 0 E. of N.	(A′).	
4.	14 0 N. of E.	(A).	
5.	1 6 S. of E.		(A″).
6.	46 26 W. of N.	(C′).	

Of these systems of joints, 1 and 4, 3 and 6 are evidently conjugates, and neither system closely corresponds with those of Waterford and Donegal, although that named (A, C) comes within a few degrees of (A, C) of those localities.

The Conjugate Joint-Systems of the Mourne and Newry Mountains are therefore as follows:—

TABLE VIII.—Conjugate Joints of the Mourne and Newry Mountains.

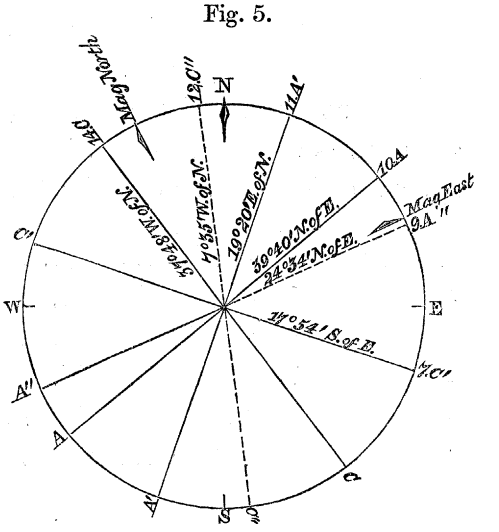
Designation.	Magnetic bearing.	True bearing*.	Angle from East to North.
A	14° 0′ N. of E.	39° 40′ N. of E.	88° 8′
C	12 8 W. of N.	37 48 W. of N.	
A′	45 0 E. of N.	19 20 E. of N.	88 34
C′	46 26 W. of N.	17 54 S. of E.	

In addition to the foregoing systems, which are evidently conjugate, we have the other systems, 2 and 5.

	Magnetic bearing.	True bearing.
System No. 2 (C″).	18° 5′ E. of N.	7° 35′ W. of N.
System No. 5 (A″).	1 6 S. of E.	24 34 N. of E.

The accompanying diagram (fig. 5) exhibits the six systems of joints just described, with the number of observations on which each is founded.

Fig. 5.



A very remarkable system of trap dykes penetrating the granite is exhibited in the railway cuttings from the Goragh Wood station to Slieve Gullion, in the Newry Mountains.

They are twenty-five in number, and are given in the following Table, numbered in order from Goragh Wood to Slieve Gullion. It appears evident from the Table that they are all reducible to four systems, two of which have directions closely corresponding with the joint-systems (C) and (C′) already found.

* The magnetic variation of the Mourne district was 25° 40′ W.

TABLE IX.—Trap Dykes in Granite between Goragh Wood and Slieve Gullion.

System (A″)?

No.	Bearing.	Dip.	
15	10° S. of E.	60° S.	Dolerite.
17	20 „	50 S.	Dolerite.

System C.

No.	Bearing.	Dip.	
1	10° W. of N.	°	
5	15 „	— E.	
7	5 „	90	
9	15 „	90	
13	15 „	70 E.	
16	15 „	70 E.	Basalt.
18	15 „	45 E.	
19	20 „	70 E.	
20	15 „	90	
21	15 „	70 E.	
22	15 „	65 E.	
23	15 „	70 E.	
24	10 „	90	
25	10 „	70 E.	
Mean	13° 34′ W. of N.		

System A′.

No.	Bearing.	Dip.
10	30° E. of N.	65° W.
12	55 „	90

System C′.

No.	Bearing.	Dip.
2	45° W. of N.	°
3	45 „	70 N.
4	35 „	70 N.
6	45 „	90
8	50 „	65 S.
11	50 „	75 N.
14	35 „	45 S.
Mean	43° 34′ W. of N.	

The trap dykes, with which other and distant parts of the Mourne district are intersected, correspond in general direction with the joint-systems already found, as is shown by the following, among other examples:—

Trap Dykes of Systems A and A″.

Bearing.	Dip.	Rock.	Locality.
5° N. of E.	50° S.	Felstone dyke in slate.	Rostrevor.
E.W.	90	Greenstone dyke (19 feet wide) in slate.	Rostrevor.
5 N. of E.	90	Greenstone dyke (12 feet wide) in slate.	Killowen.
10 N. of E.	.....	Greenstone in slate.	Clogh More.
15 N. of E.	.....	Dolerite in slate.	Slieve Bawn.
5 S. of E.	85 N.	Felstone porphyry in granite.	Slieve Bingian (little).
10 S. of E.	90	Felstone in slate.	Armer's Hole.
20 S. of E.	90	Elvan in granite.	Slieve Bingian.

Trap Dykes of System C.

Bearing.	Dip.	Rock.	Locality.
° N.S.	90°	Basalt dyke in granite.	Ballymacilreiny.
10 W. of N.	80 W.	Greenstone dyke in slate.	Carlingford Mountain.
5 W. of N.	30 W.	Syenite in slate.	Carlingford Pier.

We have therefore evidence of the existence of the following systems of Joints and Dykes in the Mourne and Newry Mountains:—

I. Primary System:—

(A). Joints . . . 14° 0′ N. of E. (Mag.)=39° 40′ N. of E.

II. Conjugate of Primary:—

(C). Joints . . . 12° 8′ W. of N. (Mag.)=37° 48′ W. of N.
Dykes . . . 13° 34′ „ „ =39° 14′ W. of N.

III. First Secondary System:—

(A′). Joints . . . 45° 0′ E. of N. (Mag.)=19° 20′ E. of N.

IV. Conjugate of First Secondary:—

(C′). Joints . . . 46° 26′ W. of N. (Mag.)=17° 54′ S. of E.
Dykes . . . 43° 34′ „ „ =20° 46′ S. of E.

V. Second Secondary System:—

(C″). Joints . . 18° 5′ E. of N. (Mag.)=7° 35′ W. of N.

The angles between the Primary and Secondary Systems are

Between Primary and First Secondary Systems—

A—A′ . . . . . 31° 0′
C—C′ (Joints) . . . . . 34° 18′
C—C′ (Dykes) . . . . . 30° 0′
} =31° 46′.

Between Conjugate to Primary and Second Secondary—

C—C″ (Joints) . . . . . 30° 13′
C—C″ (Dykes and Joints) . . . 31° 39′
} =30° 56′.

Part III.—On the Joint-Systems of Cornwall.

The following notice of the Joint-Systems is founded on my own observations, with the exception of the two sets of observations made by Sir H. De la Beche and Mr. N. Whitley, which I was permitted to copy by tracing from the diagram deposited in the Museum of the Geological Society of Cornwall, in Penzance.

Sir H. De la Beche and other observers have noticed the relation between the directions of the lodes and of the joints in Cornwall. This relation is even more intimate than they supposed, and extends to the Secondary Joints, which are well represented in the mines by the Caunter Lodes, while the Conjugate Joints are represented by the Cross Courses.

Joint-Planes observed in Cornwall.

System A.

No.	Bearing.	Dip.	Locality.	Rock.
1	10° N. of E.	90°	Land's End.	Granite.
2	E.W.	90	Carn Bosavern.	,,
3	E.W.	90	Carn Marth.	,,
	From the MS. observations of Sir H. De la Beche and Mr. N. Whitley, in the Geological Society of Penzance.			
4	24 N. of E.	.....	Land's End.	Granite.
5	21 ,,	.....	,,	,,
6	3 ,,	.....	,,	,,
7	6 ,,	.....	Gunnis Lake.	,,
8	8 S. of E.	.....	,,	,,
9	8 N. of E.	.....	,,	,,
10	14 ,,	.....	,,	,,
11	6 ,,	.....	,,	,,
12	9 ,,	.....	,,	,,
13	10 S. of E.	.....	Trincomlee Hill.	,,
Mean	6° 23′ N. of E.	.....		

System C.

No.	Bearing.	Dip.	Locality.	Rock.
1	10° W. of N.	90°	Land's End.	Granite.
2	N.S.	90	Carn Bosavern, St. Just.	,,
3	N.S.	90	Carn Brea.	,,
4	N.S.	90	Carn Marth.	,,
5	N.S.	90	Portreath.	Slate.
	From the MS. observations of Sir H. De la Beche and Mr. N. Whitley, in the Geological Society of Penzance.			
6	10 W. of N.	.....	Pedn maen du.	Granite.
7	10 ,,	.....	Carn Clog.	,,
8	15 ,,	.....	Carn Creis.	,,
9	21 ,,	.....	Mill Bay.	,,
10	17 ,,	.....	Carn Barra.	,,
11	7 ,,	.....	Carn Mellyn.	,,
12	17 ,,	.....	Tol pedn penwith.	,,
13	7 ,,	.....	Porth Chaple.	,,
14	13 ,,	.....	Pedn maen an mear.	,,
Mean	9° 4′ W. of N.			

Other systems of Joint-Planes occur in the granite of Cornwall. Mr. WHITLEY has observed at Gunnis Lake the following joint-planes:—

21° E. of N. (Mag.)
16° „ „ „
22° „ „ „
} 19° 40′ E. of N.

and at Trincomlee Hill, 13° E. of N.

And I observed at Carn Brea well-marked joints, which seem to be conjugate to the foregoing, viz. 20° S. of E.

These joint-planes may possibly indicate the System (A″—C″) observed in the co. Waterford.

At Carn Marth I found joints bearing 40° W. of N., as in the Mourne Mountains.

The relation between the directions of the lodes and joints in Cornwall has been long known. I was desirous of testing it in the Carn Brea district, and therefore asked permission of the officers of Carn Brea, Dolcoath, and North Roskear Mines to make use of their maps for the purpose; the permission was readily granted, and I have here tabulated the results of my investigation.

Direction of Main Lodes (Mag.), 1840.

System A.

No.	Bearing.	Name of lode.	Mine.
1	15° N. of E.	Highbarrow.	Carn Brea.
2	9 „ „	Druid's.	„
3	5 „ „	Teague's.	„
4	16 „ „	Western part.	Dolcoath.
5	5 „ „	Eastern part.	„
6	11 „ „	South lode.	„
7	16 „ „	Entral, western.	„
8	5 „ „	Entral, eastern.	„
9	10 „ „	Main lode.	North Roskear.
10	E.W.	„ „	„
11	5 N. of E.	„ „	„
Mean	8° 45′ N. of E.		

Direction of Cross Courses conjugate to Main Lodes.

System C.

No.	Bearing.	Name of lode.
1	N.S.	Carn Brea.
2	14° W. of N.	„ „
3	6 „ „	Great Cross Course, dividing Dolcoath from Cooks Kitchen.
Mean	6° 40′ W. of N.	

Direction of Caunter Lodes (A″?).

No.	Bearing.	Lode.	Mine.
1	16° S. of E.	Barncoose.	Carn Brea.
2	22 „ „	Vigors' Caunter.	„ „
3	39 „ „	Caunter.	Dolcoath.
4	40 „ „	Caunter.	N. Roskear.

Cross Course, conjugate to the Caunters.

(C″) 20° E. of N. in Carn Brea.

The following Systems may be regarded as fully established in Cornwall:—

I. *Primary System.*

(A) Joints . . 6° 23′ N. of E. (Mag.)* =30° 20′ N. of E.
Lodes . . 8° 45′ „ „ =34° 45′ „

II. *Conjugate of Primary.*

(C) Joints . . 9° 4′ W. of N. (Mag.) =33° 4′ W. of N.
Cross Courses 6° 40′ „ „ =32° 40′ „

The following System exists also, but is not so prominent.

III. *Secondary System.*

(A″) Joints and Cross Courses 20° 0′ S. of E. (Mag.) =4° N. of E.

IV. *Conjugate of Secondary.*

(C″) Joints . . . 18° 0′ E. of N. (Mag.) 6° W. of N.
Caunter Lodes 19° 0′ „ „ 7° „

The angles between the Primary and Secondary Systems are as follows:—
Between Primary and Conjugate of Secondary,

(A—A″) . . { Joints . . . . 26° 23′ / Lodes . . . . 30° 45′ } Mean . . 27° 28′

(C—C″) . . { Joints . . . . 27° 4′ / Cross Courses . . 25° 40′ }

* I have assumed the mean variation in Cornwall to be 24° W. in 1860, and to have been 26° W. in the year 1840.

Part IV.—On the Joint-Systems of the Co. Fermanagh.

I have made the following observations on the Joints of the Carboniferous limestone of the co. Fermanagh.

System A.

No.	Bearing.	Dip.	Locality.
1	5° N. of E.	90°	Belmore Mountain.
2	E.W.	90	„ „
3	15 S. of E.	90	Dunbar Quarry.
4	8 S. of E.	90	„ „
Mean	4° 30′ S. of E.		

System C.

No.	Bearing.	Dip.	Locality.
1	5° E. of N.	90°	Dunbar Quarry.
2	N.S.	86 E.	„ „
3	5 W. of N.	80 W.	„ „
4	7 E. of N.	90	„ „
5	15 E. of N.	90	„ „
6	10 W. of N.	90	Belmore Mountain.
7	N.S.	90	„ „
8	10 W. of N.	90	„ „
9	N.S.	90	„ „
10	N.S.	80 E.	„ „
Mean	0° 12′ E. of N.		

System A′.

No.	Bearing.	Dip.	Locality.
1	20° N. of E.	90°	Carrickreagh Quarry.
2	35 „ „	90	„ „
3	27 „ „	90	Belmore Mountain.
4	30 „ „	90	„ „
Mean	28° 0′ N. of E.		

System C′.

No.	Bearing.	Dip.	Locality.
1	26° W. of N.	84° E.	Carrickreagh.
2	30 „ „	78 W.	„
3	32 „ „	80 W.	„
Mean	29° 20′ W. of N.		

System (X).

No.	Bearing.	Dip.	Locality.
1	45° N. of E.	90	Carrickreagh.
2	45 „	90	„
3	45 „	90	„
4	45 „	76 S.E.	Dunbar.
5	45 „	90	Belmore.
Mean	45° N. of E.		

In these observations there is distinct evidence of a Primary and Secondary Conjugate System, and of a third series of planes (X), which is well represented in the Mourne Mountains.

I. Primary System	4° 30′ S. of E. (Mag.)	=	21° 30′ N. of. E.
II. Conjugate to Primary . .	0° 12′ E. of N. „	=	25° 48′ W. of N.
III. Secondary System . . .	28° 0′ N. of E. „	=	54° 0′ N. of E.
IV. Conjugate to Secondary .	29° 20′ W. of N. „	=	55° 20′ W. of N.
V. (X) . .	45° N. of E. . „	=	19° 0′ E. of N.

The angle between the Primary and Secondary Systems is thus found:

$$\left.\begin{array}{ll} A—A' & 32^\circ\ 30' \\ C—C' & 29^\circ\ 32' \end{array}\right\} = 31^\circ\ 1'.$$

PART V.—GENERAL CONCLUSIONS FROM THE FOREGOING OBSERVATIONS.

Collecting together into one Table the results of the preceding observations, we find the following:—

TABLE X.—Primary and Secondary Joints (True Bearings).

	Waterford.	Donegal.	Mourne.	Cornwall.	Fermanagh.
Primary System (A)	N. of E. 32° 26′	N. of E. 26° 16′	N. of E. 39° 40′	N. of E. 32° 34′	N. of E. 21° 30′
Conjugate to Primary (C) ...	W. of N. 31° 37′	W. of N. 29° 35′	W. of N. 38° 31′	W. of N. 32° 55′	W. of N. 25° 48′
First Secondary (A′)	N. of E. 58° 11′	N. of E. 58° 40′	N. of E. 70° 40′	....	N. of E. 54° 0′ [and 71° 0′]?
Conjugate to First Secondary (C′)	W. of N. 60° 3′	....	W. of N. 70° 40′	....	W. of N. 55° 20′
Second Secondary (A″)	S. of E. 5° 50′	....	....	N. of E. 4° 0′	....
Conjugate to Second Secondary (C″)	E. of N. 4° 30′	....	W. of N. 7° 35′	W. of N. 6° 30′	....

The only remarkable agreement as to direction of Joints disclosed by the preceding

Table, is that between Waterford and Cornwall. If we compare together the primary and secondary joints in each locality, we find the following Table:—

TABLE XI.—Angle between Primary and Secondary Joints.

	Waterford.	Donegal.	Mourne.	Cornwall.	Fermanagh.
Primary (A, C) and First Secondary (A′, C′)	+ 27° 5′	+ 32° 24′	+ 31° 46′	+	+ 31° 1′
Primary (A, C) and Second Secondary (A″, C″)	− 37° 11′	−	− 30° 56′	− 27° 28′	− .....

This Table discloses a very interesting and unexpected result, viz. that, in Waterford, Donegal, Mourne, and Fermanagh, the angle between the Primary and First Secondary Joint-Systems ranges between the narrow limits of 27° 5′ and 32° 24′, and that in Waterford, Mourne, and Cornwall the angle between the Primary and Second Secondary Joint-Systems ranges from 27° 28′ to 37° 11′.

I hope to be able to show that this important result of observation is an easy consequence of the mechanical theory of Joints; but before doing so, I shall prove by the following Table, that the theory of Conjugate Joints used in my paper on the co. Waterford applies equally well to the other districts examined by me.

TABLE XII.—Angles between Conjugate Joints, measured from East to North.

Systems.	Waterford.	Donegal.	Mourne.	Cornwall.	Fermanagh.
Primary (A, C)	89° 11′	93° 19′	88° 51′	90° 21′	94° 18′
Secondary (A′, C′)	91° 52′	.....	90° 0′	.....	91° 20′
Secondary (A″, C″)	91° 20′	.....	.....	92° 30′	.....

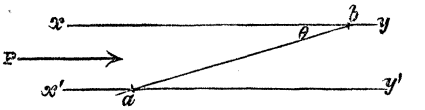
The tendency of Conjugate Joints to place themselves at right angles is plainly shown by the foregoing Table.

PART VI.—MECHANICAL THEORY OF ROCK JOINTS.

Rock masses are always arranged in sheets, whose dimensions in two rectangular directions are much greater than in the third direction at right angles to the first two. Hence, when a system of forces acts upon such a mass, its first effect will be to produce a system of fissures at right angles to the plane of the resultant force. When other forces are subsequently applied to the rock mass, already divided into bands by the parallel fissures, their effect upon these rock bands will be different according as they have a large vertical or large horizontal component. In the first case the bands of rock will simply bend and break across along new fissures at right angles to the original fissures. This cause produces the phenomena of conjugate joints, which have been described and accounted for by several writers, and have been fully discussed by myself in the paper, "On the Physical Structure of the Old Red Sandstone of Waterford," so often referred to by me.

I shall therefore direct my attention at present to the phenomena of Secondary Joints, which have been shown to take place along directions inclined at about 30°, on each side of the primary direction of the original joints. Let xy, $x'y'$ be the directions of two primary parallel joints, and let a force P, acting horizontally, tend to produce a fracture in some unknown direction, ab, making an angle θ with the directions xy, $x'y'$; if the band of rock were capable of bending, this direction would be at right angles to the direction xy; but if, from the pressure of superincumbent rock masses, or other cause, it be prevented from bending, it will fracture along the line ab, which is the plane of easiest fracture, and whose direction θ is thus found.

Fig. 6.



Let K denote the coefficient of cohesion of the rock, l the length of ab, and h the perpendicular distance between xy and $x'y'$, and let $\mu = \tan\lambda$ denote the coefficient of friction of the rock.

The mechanical condition of equilibrium is evidently as follows:—

$$P\cos\theta = Kl + \mu P\sin\theta,$$

or

$$P\cos\theta = \frac{Kh}{\sin\theta} + \mu P\sin\theta. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Differentiating this equation, regarding P as a minimum and therefore $dP=0$, we find

$$-P\sin\theta = -\frac{Kh\cos\theta}{\sin^2\theta} + \mu P\cos\theta. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Equating the values of P deduced from (1) and (2), we find

$$\sin\theta(\sin\theta + \mu\cos\theta) = \cos\theta(\cos\theta - \mu\sin\theta);$$

from which follows

$$\cos 2\theta = \mu\sin 2\theta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

or

$$\cot 2\theta = \tan\lambda;$$

and, finally,

$$2\theta + \lambda = 90°. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The values of λ, determined for various kinds of rock, limestone, sandstone, and slate, vary from 30° to 38°, thus giving for θ corresponding values from 30° to 26°. These values agree very well with the angles between the systems of Primary and Secondary joints determined by the preceding observations in different localities; and I believe that the mechanical cause I have assigned is the true cause of these joints.

From this it follows that a single hypothesis as to the direction of a system of forces is sufficient to account for the existence of three conjugate systems of joints, involving six directions; and it also explains the rudely hexagonal jointing of many rocks, if the coefficient of friction be such as to render the angle θ nearly 30°.

Many other consequences flow from the preceding investigations, into which I have not time to enter, but which may be readily found and turned to practical use by the field geologist who prefers one hypothesis to many.