A Study of Magnetic Sudden Impulses

by

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概　要

地磁気急変化は，SSC, S. I.，Bay，Pulsation 及び s. f. e に大別されるが， その中 S. I. 以外の諸現象については，現象論的にも，理論的にも，多くの研究が為され，かなりの程度迄明らかになって来た。又近時の惑星間空間に関する知識の増大に従い，発現機構も，推論の域を脱して，着実に実証されつゝある。一方，S. I. は，急始変化研究の初期には，SSC と区別されず，両者を意識的に分けて取り扱い初めたのは，比較的近年に属することであり，その後も研究者達の多くの努力は，SSC 研究に向けられ，その一部分を S. I. 研究にさいてきたに過ぎない。

他の地球物理学的現象の研究分野からの注意も SSC storm にのみ向けられてきた嫌いがないでもない。勿論この小規模の変化が急始磁気嵐程，顕著に他の現象との関連を示さない事が一因であることも否めない事実であろう。けれども，S. I. は今後に予想される人工的擾乱を識別する為にも，或いは，より深く急始磁気嵐を理解する上にも，明らかにされねばならない現象の一つであろう。本稿の第一部は，SSC と比較するという立場から，S. I. の現象論を記述し，第二部に於いては，その発現機構に就いての考察を記述した。第一部に於いては，最初に，中緯度地方の水平分力記録に基き，四種の基本的変化型に分類し，その表示記号を提出した。 それらの地理的分布，Dst に相当する擾乱及び赤道地方に於ける振巾の増大等を調査し，第一型の中の水平分力の増大する場合は，弱い急始磁気嵐と殆ど差がない事が明らかになった。一方この型に分類した変化の中で，水平分力の急減する現象は，かなり広範囲（低緯度地方でも） に起り， SSC の変化型の或る種の現象の水平分力の急減とは，異っている。水平分力の急減も，その急増と，ほゞ同程度の頻度で起り，急変化に伴なう脈動の様相は，両者で多少異なるように思はれる。第二型，第三型の尖塔状及び振動状の急変化は，擾乱中には数多く観測されるが，稀に静穏時に孤立して観測される。両者の成因が完全に同一か，否かは，明らかでないが，後者に属する変化が，擾乱中にも起っていることは，確かであろう。第四型は，第一型の水平分力の増大する場合と減少する場合が，二，三時間の間に起り、 両者相俟って， 独立した一現象と考えられるものである。 第二部に於ける S. I. の機構考察の基本的立場は，急始磁気嵐と殆ど同様の機構を考え，地球と微粒子流の相互位置関係の相違によって，一は SSC となり，他は S. I. となるとするものである。即ち一次的原因と考えられる微粒子流が，地球を包み込む過程を経ないで，或いはその縁辺を掠めて過ぎる場合或いは微粒子雲の一部分のみが地球磁場に影響する場合等には，急始磁気嵐のような擾乱を起さないであろうと思はれる。そのような接近の仕方をする微粒子流も地球磁場の急変化を起し得る事を近似的に検討した。

CONTENTS

Part I. Morphology of S. I.

Chpater I. Introduction

The magnetograms show ordinaliy many impulsive variations, evən at middle or equatoral latitudes and smooth traces are very rare. Some of those variations have been studied veryr well mnrphnlogically and theoretically. They are now notated as SSC, Bay, Pulsation and solar flare effect etc. Besldes them, there appear on the magnetogeams sudden displacements of the recorded traces, even in the rather quiet state of the geomagnetic field, which are somewhat fair. These have some regular characteristics, similar to SSc, except that iher are not followed by storminess.

Early workers of SSC did ihcludə them in their category of SSC, until V.C.A Ferraro described the classiffcation of SSC and examined mainly their occurrence frequency. [1] I. A. T. M. A. adopted the following definition in the″ Hints for the diagnosis of sudden commencements and solar flare-effects (s. f. e.) [2] ;

″a, sudden commencements……………………………………………………

b, sudden commencements of polar or pulsational disturbances……………………

c, sudden impulses (s. i)

Sometimes there appear in the magnetograms sudden displacements of the recorded traces, which cannot be interpreted as SSC or PSC. A few examples for the year bear before 1950 are ; 1950 May 31 d 13 h 58 m, 22 d 12 h 18 m, August 14 d 21 h 45 m.″

In accordance with the conception, some studies, together with the study of SSC, have been published.

While H. W. Newton published classification of SSC and remarked the similar impulsive variations in 1948. [3]

Besides, S. Imamiti [4], H. H. Howe [5], J. Bartels [6] and W. Jackson [7] remarked the special types of impulsive variations in the magnetograms and examined some of their features. Also Y. Yamaguchi described the impulsive variations of traces, and indicated the four fundamental shapes. mainly referring to the horizontal component. [8]

On the other hand, the impulsive variations in the disturbed state of the geomagnetic field, somewhat irregular, also have been examined by some authors.[9] Some of the impulsive variations in the disturbed state may be the same kind as those mentioned above, although it is not easy to grance the magtogram and point out them.

The Committee on Rapid Magnetic Variaion and Earth Currents of IAGA, IUGG notated them as S. I. and defined in the Resolution at the Meeting of the Committee at Copenhagen, April 9-11, 1957,as follows*;

i) If the observer sees an important sudden impulse during a storm but doubts that it represents the beginning of a new storm, he should report it as S.I.

ii) Occasionally if a magnetic storm apparently begins with two or more sudden movements, the observer should report each movement as SSC (or SSC*) unless he doubts that one or other is actually the beginning of a storm. In latter commencement should be reported as SSC (or SSC*), the other as S.I.

Generally speaking, the impulsive variations which cannot be regarded as onset of new storms may be a suitable definition of S. I., ignoring the background state of the geomagnetic field. Needless to say, Bay, s. f. e. are excluded.

In Part I of this paper, we will describe the morphology of S. I., comparing to SSC.

Chapter II Classification of S. I.

For the classification of the phenomena, we should employ the criteria, based on their essential characters. The essential characters, however, can be obtained practically by means of the examinations of the more or less classifiied examples.

Furthermore, it may be noted, the exmination without the stone wall between the variations in the quiet state and those in the disturbed state may make the essential features vague. The other to be noted is that the geomagnetic variations in the high latitude are rather complicated and thus it may be convenient to examine the magnetograms in the middle or low latitude and in the high latitude, separately.

§ 2.1 S. I. in the middle or low latitude

According to the conception of S. I., mentioned in the introduction, some typical cases on the quiet state and the disturbed state are given in Fig. 1. The traces of the variations at some observatories in the middle or latitude are very similar and then the magnetograms at Honolulu (Geomagnetic lat. 21.° 1 N, Geomagnetic lon. 266.°5 E) only are reproduced. Examination of IAGA Bulletins, Geomagnetic Indices K and C, shows that all of the observers do not always think them as S. I., But, the definition seems to include them and S. I. in this paper denotes such variations as examples.

A number of S. I. were observed during the I. G. Y., July 1957–Dec. 1958. They are listed in Table 1 with their some elements at Kakioka. [10]

The fourh column in the table shows K–index for E–time including an occurrence time of S. I. The fifth column descrides : "In which phase of a magnetic storm does S. I. occur ?." The notations used in the tables are as follows;

s(f) : during the first phase of a storm,

s(m) : durlng the main phase of a storm, s(l) : during the last phase of a storm,

s(-) : during a storm of which phases are odscure,

q : free from a magnetic storm,

The sixth column shows the morphological type of the variation, classified into four fundamental types In cases of S. I. (+i)'s the intervals in minutes are remarked. The seventh column give the directions of the horizontal vectors, reckoned from the geomagnetic meridian.

The selection of them among many other impulsive variations on the magnetograms is based on the following criteria.

a ; Selecting all the impulsive variation, acoording to the Resolution at the meeting of the Committee, at Copenaghen and or Provisional Atlas of Rapid Variations (I. A. G. A. Committee on Rapid Magnetic Variations and Earth-Current) once at least.

b ; Taking the ratio of S. I.'s amplitude to the range of disturbances during three hours including the S. I. (the latter are scaled in the same way as K-index, excluding the very impulsive variation concerned, S and L fields, etc). When the ratio is more than 2, between 2 and 1, and less than 1, the quality of the S. I. is assigned as A, B and C respectively, with some references to sharpness. The rate of the variations, assigned as B should be more than 3γ/min, and the limit of their magnitudes is of the order of 5 γ.

Thus, instead of the adoption of S. I. of slightly small amplitude in the quiet state, S. I. of distinct amplitde during the disturbance are only adopted.

Sever storms, for example, Sep. 3, 1957 have many impulses in the course of their disturbance and collectively in a certain period. This is one of those which make the temporal distribution of occurrence frequency rather insignificant, even if they are interesting from the other viewpoints.

From the mentioned data, at Kanoya Kakioka, and Memambetsu, the mean rate of the impulse changes are calculated, which are given in Table 2. (a,b,c)

Table 2. mean of Duration, Amplitude and Rate of S.I., I.G.Y.

The durations do not show significant differences between those in quiet state and in disturbed state, between SSC and S. I. and between stations, in this region The magnitude show somewhat differences. Therefore, rate of changes also do so.

§ 2.2 S. I. in the high latitude

As well known, the magnetograms in the high latitude show the rather irregular traces, even when the magnetograms in the middle and low are the smoothed

Table 1 SUDDEN IMPULSES S. I. during I. G. Y.

Observatory : KAKIOKA

Φ : 26.0° N

λ : 206.0°

Date	G. M. T. of beginning		Q	K-index	Storm phase	Type	H. V. D.	Remarks
1957 July	h	m						
1	18	13	A	5	s (−)	si (+ i)	11 NE	25 m
1	18	29	C	5	s (−)	si (+ i)	12 SW	10 m
1	19	04	B	5	s (−)	si (− c)	9 SW	
1	19	45	B	5	s (−)	si (+ c)	48 NE	
1	21	10	B	5	s (−)	si (− c)	45 SE	
4	23	51	C	3	q	si (+ c)	53 NW	
5	09	09	C	5	s (i)	si (+ c)	9 NE	
5	09	37	C	5	s (i)	si (+ i)	19 NE	11 m
11	09	44	A	2	q	si (+ c)	21 NE	
19	13	45	B	4	s (m)	si (+ p)	11 NE	
19	13	56	B	4	s (m)	si (+ p)	16 NE	
19	14	17	B	4	s (m)	si (+ i)	40 NE	10 m
19	14	56	B	4	s (m)	si (− c)	16 SW	
22	09	45	C	4	s (m)	si (− p)	23 SW	
23	03	40	B	5	q	si (+ i)	8 NE	79 m
23	04	18	C	5	q	i (+ i)	0 N	9 m
23	05	33	B	5	q	si (+ i)	3 NE	12 m
25	15	12	C	3	q	si (−+o)	14 NE	
27	23	31	C	3	s (−)	si (− p)	58 SW	
28	00	53	C	3	s (−)	si (+ i)	58 SW	35 m
29	06	40	C	2	q	si (− i)	15 SW	10 m
29	10	36	B	4	q	si (− c)	9 SE	
Aug.								
3	16	52	B	6	s (f)	si (− c)	18 SW	
4	06	58	C	3	s (i)	si (− c)	13 SW	
17	13	22	B	3	q	si (− c)	13 NE	
17	15	05	B	3	q	si (−+o)	17 NE	
18	10	15	A	4	q	si (− c)	28 SW	
25	15	05	B	2	q	si (− c)	27 SW	
30	16	29	B	4	s (i)	si (+ p)	23 NE	
31	19	05	C	4	s (f)	si (+ p)	30 NE	
Sep.								
2	11	45	C	5	s (i)	si (+ p)	23 SW	
3	03	48	C	5	s (i)	si (− p)	14 SW	
3	05	18	C	5	s (i)	si (+ p)	40 NE	
3	05	42	C	5	s (i)	si (− c)	19 NE	
3	06	18	A	6	s (i)	si (+ i)	4 NE	50 m
3	07	55	C	6	s (m)	si (+ p)	6 SE	
3	10	47	B	6	s (m)	si (+ c)	18 NE	
3	12	58	C	6	s (m)	si (+ p)	8 SW	
3	15	09	C	5	s (i)	si (+−o)	14 NW	
3	19	12	A	5	s (i)	si (+ p)	10 NE	
3	21	53	C	4	s (i)	si (−+o)	31 SW	
4	01	38	B	4	s (i)	si (− i)	33 SW	17 m
4	05	20	C	5	s (i)	si (− c)	0 S	
4	15	37	B	8	s (m)	si (+ p)	12 NW	
4	17	36	C	8	s (m)	si (− c)	8 SW	
5	13	51	C	4	s (i)	si (+ c)	10 NE	
5	20	39	B	4	s (i)	si (+ p)	42 NE	
6	01	17	C	4	s (i)	si (+ i)	43 NE	21 m
7	02	32	B	3	s (—)	si (− c)	25 SW	
7	03	55	C	4	s (—)	si (− c)	21 SW	
14	07	06	B	5	s (i)	si (− i)	9 SE	7 m
14	13	26	B	4	s (i)	si (+ p)	11 NE	
17	23	59	A	3	q	si (− c)	23 SE	
18	40	23	B	3	q	si (− c)	11 SW	

Table 1 SUDDEN IMPULSES S. I. (Continued)

Observatory : K A K I O K A

Φ : 26. 0° N

λ : 206. 0°

Date	G. M. T. of beginning	Q	K-index	Storm phase	Type	H. V. D.	Remarks
Sep.							
22	14 28	C	6	s (m)	si (+ c)	13 NE	
22	14 54	B	6	s (m)	si (− p)	17 SE	
22	15 17	B	5	s (m)	si (− c)	25 SW	
22	16 10	C	5	s (m)	si (− c)	17 SW	
23	04 42	B	7	s (m)	si (+ c)	14 SE	
23	07 55	C	5	s (i)	si (+ p)	45 NW	15 m
29	17 31	C	7	s (i)	si (+ i)	12 SE	
29	20 15	C	6	s (i)	si (+ c)	29 NE	
30	00 10	C	5	s (i)	si (− c)	41 SW	
30	02 43	C	5	s (i)	si (+ c)	42 NE	
30	07 45	C	4	s (i)	si (+ c)	15 NW	
Oct.							
14	13 20	B	5	s (i)	si (+ c)	25 NE	
14	16 08	B	5	s (i)	si (+ p)	31 NE	
18	03 27	B	1	q	si (− c)	21 SE	
21	23 08	C	6	s (f)	si (− p)	11 NE	
23	21 00	C	3	q	si (+ c)	23 NW	
Nov.							
6	23 21	B	6	s (m)	si (+ p)	32 SW	
14	02 00	C	3	q	si (− c)	51 SE	
18	22 04	C	3	q	si (− c)	41 SW	
26	14 54	C	4	s (m)	si (− c)	17 SW	
27	11 30	C	5	s (m)	si (− p)	34 SW	
29	02 25	B	3	q′	si (+ i)	43 NE	15 m
Dec.							
1	06 44	B	5	s (f)	si (+ i)	25 NE	16 m
26	02 46	B	2	q	si (− c)	14 SW	
31	02 20	B	4	s (i)	si (− c)	6 SW	
31	03 20	B	4	s (i)	si (− c)	7 SW	
1958 Jan.							
1	04 10	C	4	s (i)	si (+ p)	51 NW	
5	00 52	C	3	q	si (− c)	14 SW	
10	02 36	C	3	q	si (+ c)	31 NW	
10	19 03	C	2	q	si (− c)	0 S	
10	19 25	C	2	q	si (− c)	0 S	
16	17 07	C	3	q	si (− c)	24 SW	
20	21 43	B	3	q	si (+ p)	0 N	
30	07 43	B	3	q	si (− c)	16 SW	
30	04 43	C	2	q	si (− c)	14 SW	
30	09 50	B	3	q	si (− c)	17 SW	
30	12 07	C	3	q	si (− c)	14 SW	
Feb.							
4	16 53	C	4	s (—)	si (− c)	——	
4	17 44	C	4	s (—)	si (+ p)	23 NE	
4	18 52	C	4	s (—)	si (− c)	17 SE	
7	01 20	C	3	s (—)	si (+ p)	76 NW	
11	10 46	B	7	s (m)	si (− p)	45 SE	
11	12 37	B	7	s (i)	si (+ p)	56 NW	
12	00 29	C	5	s (i)	si (+ c)	33 NW	4 m
12	02 00	C	5	s (i)	si (+ i)	24 NE	4 m
12	05 55	B	5	s (i)	si (+ i)	26 NE	
12	07 23	B	6	s (i)	si (− c)	19 SW	
12	09 06	B	5	s (i)	si (+ p)	27 SW	
17	01 12	C	5	s (f)	si (− c)	27 SW	
17	01 34	C	5	s (f)	si (− p)	23 SW	
19	00 46	B	3	s (—)	si (+ p)	77 NW	

Table 1 SUDDEN IMPULSES S. I. (Continued)

Observatory : KAKIOKA

Φ : 26.0° N

λ : 206.0°

Date	G. M. T. of beginning		Q	Kindex	Storm phase	Type	H. V. D.		Remarks	
Feb.										
22	18	06	C	3	q	si (− c)	0	N		
Mar.										
3	15	30	B	3	s (f)	si (+ p)	32	SW		
13	14	28	C	5	s (i)	si (+ c)	21	NE		
14	14	53	C	5	s (f)	si (− c)	11	SW		
15	02	50	C	4	s (i)	si (+ i)	14	NE	30	m
15	04	21	C	5	s (—)	si (− i)	25	SW	28	m
15	06	43	B	4	s (i)	si (− c)	11	SW		
15	09	59	C	4	s (i)	si (+ p)	25	SW		
21	08	21	B	3	q	si (− c)	——			
25	17	50	B	6	s (f)	si (− c)	13	SW		
25	22	53	B	3	s (f)	si (− c)	47	SW		
30	13	44	B	5	q	si (+ i)	6	SW		
30	15	22	C	5	q	si (− c)	16	SW		
Apr.										
2	06	48	C	4	s (i)	si (− i)	15	SW	9	m
2	14	26	B	4	s (i)	si (− c)	11	SW		
2	17	32	B	3	s (i)	si (+ p)	21	NE		
11	09	00	C	3	q	si (− c)	32	SW		
14	12	45	C	4	q	si (− c)	11	SW		
16	14	05	C	4	q	si (− p)	6	SE		
24	02	34	C	3	q	si (+ p)	34	SW		
24	02	50	C	3	q	si (+ p)	21	NE		
26	19	07	B	4	s (—)	si (+ p)	28	NE		
May										
9	06	49	B	4	q	si (+ i)	0	N	54	m
9	11	09	C	3	q	si (+ p)	41	NE		
9	11	36	C	3	q	si (+ c)	17	SE		
9	12	06	B	3	q	si (− p)	33	NE		
12	15	21	C	3	q	si (− c)	21	SW		
12	17	00	C	3	q	si (+ i)	13	NE	86	m
21	04	03	C	3	q	si (−+ o)	——			
26	07	21	C	3	s (—)	si (− c)	4	SE		
26	22	27	C	3	s (—)	si (+− o)	3	NW		
29	10	34	B	5	s (i)	si (− p)	12	SW		
29	23	29	C	3	q	si (− p)	48	SW		
June										
1	02	56	C	5	s (i)	si (− c)	32	SW		
1	05	36	C	5	s (i)	si (+ i)	14	NE	13	m
8	17	28	B	3	q	si (+ i)	13	NE	16	m
8	19	25	B	3	q	si (+ i)	31	NE	19	m
8	22	42	B	3	q	si (− c)	17	SW		
9	11	40	C	3	q	si (− c)	13	SE		
9	17	45	C	3	q	si (+ c)	17	NE		
14	18	46	B	4	s (f)	si (− c)	21	SW		
19	16	00	A	3	q	si (+ i)	15	NE	26	m
21	06	44	B	4	s (—)	si (+ c)	17	NW		
22	01	26	C	3	s (—)	si (+ c)	17	NW		
30	04	00	B	3(1)	q	si (− c)	66	SW		
July										
8	13	35	C	6	s (m)	si (+ i)	21	NE	35	m
8	21	56	B	7	s (m)	si (+ i)	66	NW	39	m
12	01	11	B	3	q	si (− i)	45	SW		
12	03	47	C	4	q	si (+ p)	0	S		
12	06	25	C	4	q	si (+ i)	0	N		
13	07	08	B	3	q	si (+ c)	45	NE		

Table 1 SUDDEN IMPULSES S. I. (Continued)

Observatory : KAKIOKA

Φ : 26.0° N

λ : 206.0°

Date	G. M. T. of beginning	Q	K-index	Storm phase	Type	H. V. D.	Remarks
July.							
17	09 30	A	4	q	si (− c)	23 SW	
18	02 18	B	3	q	si (+ c)	6 NE	
21	19 26	B	5	s (m)	si (+ i)	14 NE	31 m
22	22 07	C	5	s (—)	si (+ i)	17 NE	69 m
27	21 01	B	5	s	si (− c)	22 SW	
27	21 23	B	5	s	si (+ p)	27 NE	
Aug.							
10	08 18	C	3	q	si (− c)	0 S	
10	15 38	C	3	q	si (+ i)	21 NW	27 m
11	03 12	C	3	q	si (+ c)	7 NW	
11	18 46	B	3	q	si (+ c)	11 NE	
13	10 12	C	3	q	si (−+ o)	23 SW	
13	15 02	C	2	q	si (+ c)	21 NE	
17	15 30	C	5	s (m)	si (+ c)	11 NE	
18	06 56	C	5	q	si (+ p)	8 NW	
24	11 22	C	5	s (m)	si (+− o)	29 NE	
24	12 03	C	5	s (m)	si (+ p)	23 NE	
24	18 39	C	3	s (i)	si (− c)	12 SW	
25	02 23	B	3	s (i)	si (− c)	21 SW	
25	07 46	C	3	s (i)	si (− c)	11 SE	
25	12 53	B	4	s (i)	si (+ c)	16 NE	
27	05 42	C	6	s (m)	si (− p)	6 SW	
27	06 14	C	6	s (m)	si (+− o)	7 NW	
Sep.							
3	11 00	B	6	s (m)	si (+ i)	18 NE	78 m
3	14 52	C	5	s (m)	si (+ i)	14 NE	60 m
3	20 50	C	5	s (m)	si (+ p)	73 NE	
3	21 10	C	5	s (m)	si (− p)	63 SW	
3	21 29	C	5	s (m)	si (+ p)	69 SW	
4	22 16	B	6	s (m)	si (+ c)	84 SE	
4	22 53	B	6	s (m)	si (+ c)	69 NW	
5	07 48	C	4	s (i)	si (+ p)	33 NE	
Oct.							
1	04 11	B	4	q	si (− c)	21 SW	
26	03 26	C	3	q	si (+ p)	12 NE	
28	07 53	B	5	s (f)	si (− c)	10 SW	
31	16 12	B	4	q	si (− c)	13 SW	
Nov							
1	14 51	C	3	q	si (+ c)	17 NE	
16	02 20	C	3	q	si (+ i)	21 NE	73 m
Dec.							
4	22 22	C	5	s (m)	si (+ p)	28 NW	
5	02 31	C	4	s (i)	si (+ c)	32 NE	
5	11 56	C	3	s (i)	si (− c)	13 SW	
13	11 49	C	3	s (m)	si (− p)	17 SW	
13	12 26	B	6	s (m)	si (− p)	19 NW	
13	12 58	B	6	s (m)	si (− p)	18 SW	
14	04 54	B	4	s (i)	si (− c)	11 SW	
14	13 08	B	4	s (i)	si (− c)	28 SW	
14	23 35	C	3	s (i)	si (+ i)	54 NE	11 m
17	21 53	C	5	s (m)	si (− c)	——	
18	02 52	C	4	s (i)	si (− c)	——	
18	03 38	C	4	s (i)	si (− c)	17 SW	
18	13 07	B	3	s (i)	si (− c)	16 SW	
25	23 30	B	4	q	si (+ i)	11 NE	93 m
30	15 41	C	3	q	si (+ p)	17 NE	

Table 2 Means of Amplitudes, Durations and Rates of Changes of S. I. during I. G. Y.

(a) Kanoya (Gm. lat. 20°.5 Gm. lon. 198°.1)

		quiet state	disturbed state				total or mean
			S(f)	S(m)	S(l)	S(−)	
number		56	8	21	30	12	127
Mean duration (in minutes)	H	4.2	3.8	5.0	4.5	5.0	4.7
	D	4.1	3.7	4.2	4.2	4.0	4.0
	Z	4.4	4.0	4.8	4.7	4.9	4.8
Mean amplitude (in γ)	H	16.8	20.3	32.6	20.3	25.7	18.1
	D	10.2	11.0	15.0	12.2	15.6	9.1
	Z	8.0	9.3	16.1	10.2	13.2	9.0
Mean rate (in γ/min.)	H	4.3	6.5	6.0	4.0	4.0	4.0
	D	2.3	2.9	2.5	3.0	3.9	2.3
	Z	1.9	2.9	3.9	2.3	3.3	1.3

(b) Kakioka (Gm. lat. 26°.0, Gm. lon, 206°.0)

		quiet stae	Disturbed state				total or mean
			S(f)	S(m)	S(l)	S(−)	
number		77	12	39	54	21	203
Mean duration (in minutes)	H	4.3	3.9	5.1	4.6	4.1	4.8
	D	4.2	4.1	4.3	4.3	4.1	4.2
	Z	4.5	4.1	4.9	4.8	4.3	4.8
Mean amplitude (in γ)	H	16.9	20.4	32.7	20.4	25.8	19.4
	D	10.3	11.1	15.1	12.3	15.7	8.5
	Z	8.1	9.4	16.2	10.3	13.3	11.3
Mean rate (in γ/min.)	H	4.0	5.6	6.1	4.1	4.1	4.0
	D	2.4	3.0	2.6	3.1	4.0	2.0
	Z	2.0	3.0	4.0	2.4	3.4	2.4

(c) Memambetsu (Gm. lat. 34.°0, Gm. lon. 208.°4)

		quiet state	disturbed state				total or mean
			S(f)	S(m)	S(l)	S(−)	
numder		77	12	39	54	21	203
Mean duration (in minutes)	H	4.4	4.0	4.7	4.7	4.2	4.1
	D	4.3	4.2	4.4	4.4	4.2	2.6
	Z	4.6	4.2	4.4	4.9	4.4	2.6
Mean amplitude (in γ)	H	17.0	20.5	32.8	20.5	25.9	22.1
	D	10.4	11.2	15.2	12.4	15.8	11.2
	Z	8.2	9.5	16.3	10.4	13.4	3.9
Mean rate (in γ/min)	H	4.5	6.7	6.2	4.2	4.2	5.4
	D	2.5	3.1	2.7	3.2	4.1	4.3
	Z	2.1	3.1	4.1	2.5	3.4	1.5

Table 3 Mean of Amplitudes, Duration and Rate of changes of SSC. I. G. Y.

(a) Kanoya

	Mean duration (in minutes)	Mean amplitude (in γ)	Mean rate (in γ/min)
H	3.5	26.4	7.5
D	2.9	8.5	2.9
Z	3.6	11.9	2.3

(b) Kakioka

	Mean duration (in minutes)	Mean amplitude (in γ)	Mean rate (in γ/min)
H	3.3	25.8	7.8
D	2.6	11.4	4.4
Z	3.3	14.1	4.4

(c) Memambetsu

	Mean duration (in minutes)	Mean amplitude (in γ)	Mean rate (in γ/min)
H	2.9	27.0	9.3
D	2.2	14.4	6.5
Z	2.2	4.8	2.2

ones. And many impulsive changes appear. If we are much particular to the definition, most of them may happen to be included in S. I. But, in this paper S. I. are limited to the variations which are evident also in the middle or low latitude. Frankly speaking, the variations in the high latitude at the moment of S. I. 's occurrence in the middle or low latitude are regarded as S. I., Needless to say, if the variations occur in the quiet state in the high latitude, they can be clearly distinguished from the other variations. An example is given in Fig. 2.

Generally speaking, the shapes of the traces in the onset and ending parts of the impulses are to some extent deformed from those in low latitudes. And also, the varitions of declination are rather violent and their amplitudes are of the same order as those of horizontal component. While, in the low latitude the variations of declination are unnoticeable. These are directly shown in some examples of the horizontal diagrams in Fig. 4, made by read the traces on the rapid-run magnetograms at the principal times at which either of the horizonntal component or declination change their attitudes. The changes of the horizontal vector direction in a few minutes may be an noticeable phenomena. The circumstannces are very alike to SSC, of which knowledges also are not abundant.

The sense of rotation of the end point of the horizontal vector might shew an appearance of local time dependency, as Bay do, but we could not find it conclusively.

§ 2.3 Classification of S. I.

In the previous description, we indicated the four fundamental types of S. I., based on the shape of the traces of the horizontal component.[8]The "fundamental" means "without deformation", thence "in the low latitude". Thus the variations similar to the preliminary reversed impulse of SSC* are ignored, which are frequent

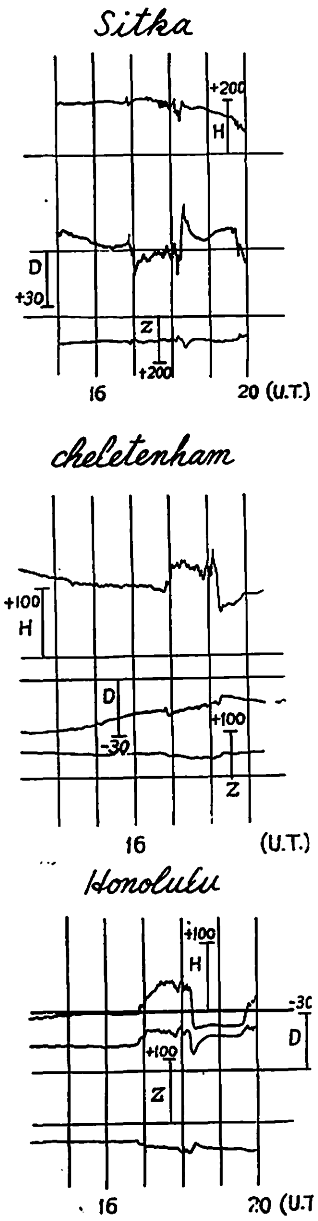


Fig. 2 S. I. on 6th Apr. 1948. Showing the correspondence of the variaions in the high latitude and in the low latitude region.

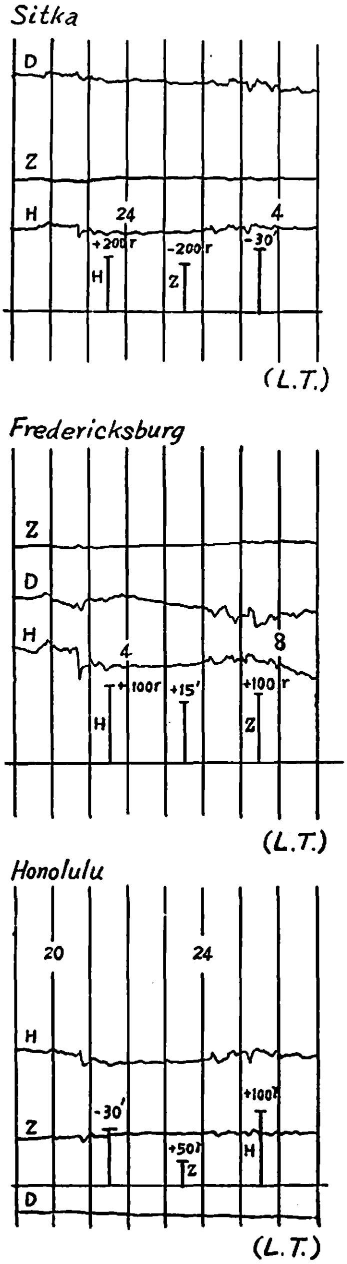


Fig. 3 S. I. on 20 th May 1950, showing the correspondence of the variations in the high latitude and in the low latitude region.

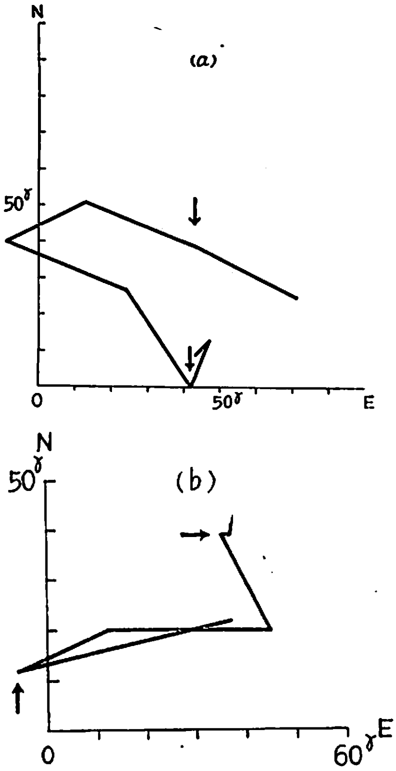


Fig. 4 Examples of the horizontal vector diagrams at Sitka(Gm. lat. 60.°0 N ; Gm. lon. 275.°4) The arrows denote the beginning and ending of S. I. at Kakioka (Gm. lat. 26.0°0 ; Gm. lon. 206.°0)
a : Dec. 31 d 03 h 20 m, 1957. (U. T.)
b : Oct. 31 d 16 h12 m, 1958. (U. T.)
In both, H at Kakioka decreased suddenly

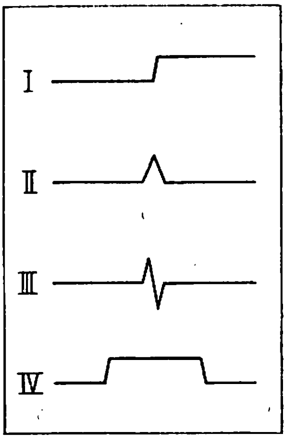


Fig. 5 Idealized model of the four fundamental classes of the S. I.

in the high latitude.

This author also emphasized the suddenly decreasing of the horizontal component, as shown in some reproductions of the magneto grams in Fig. 1 Concerning sudden commence ment, the reversed type, that is, the decreasing of horizontal component, are-sometimes observed. Some authors published hat those were the phenomena in the high latitude region, depending on local time and had been seldom observed in the low latitude. [1] At Kakioka, May 30d 15h 02m 1930 and May. 18d 07h 00m 1944 were only two, observed for the years from Jan. 1924 to Dec. 1951. Contrary to the circumstances, the "decreasing S. I." were obsrved as frequently as the "increasing S. I." This is said from the materials in the Report of the Geomagnetic Observations, I. G. Y., 1957-1958, Kakioka Magnetic Observatory. [10] In the Report, we took into consideration of the back ground distubance in picking up S. I. on the magnetograms and thus rather small S. I. in the quiet state are adopted, while most of them in the disturbed state are omitted.

The perfect sellection of S. I. is very difficult, but, at least it may be said the "decreasing S. I." is more frequent in the low latitude than the "decreasing SSC".

And also they occure as frequently as " the increasing S.I."

S. Chapman and S. I. Akasofu proposed the notation easy to see the increase or decrease of the horizontal component for the four fundamental types shown in Fig. 5. but to be exhaustive and acceptable, the preliminary reverse impulses may be desirable to be notated by something, for example, by the asterisk. [11]

Table 4 Proposal for Notations

Fundamental type	Notations
I	S. I. (+C), S. I(−C), S. I*(+C), S. I. *(−C)
II	S. I. (+P), S. I. (−P), S. I. *(+P), S. I. *(−P)
III	S. I. (+−O), S. I. (−+O), S. I. *(+−O), S. I. *(−+O)
IV	S. I. (+i). S. I. (−i), S. I. *(+i), S. I. *(−i)

In this paper, the notations in Table 4 will be emploged.

We indicated the four fundamental types, but, in the disturbed state, the variations at the same time are sometimes observed in different types at some observatories from those observatories. The cases are apt to occur, especially, in S. I. (+−*O*) and S. I. (+*P*). The S. I. during the I. G. Y. at Kakioka are classified and listed in Table 1.

Chapter III S. I. (+C) and S. I. (−C)

§ 3.1 Introductory surveys.

S. I. in this class has been examined by some authors and the similarity to SSC is nearly exhaustive. Only one distinction between them, hitherto published, seems to be one related to the diurnal variation of the occurrence frequency by V. C. A. Ferraro et al. [1]

After them, the occurrence frequency of S. I. is expressed by the following formula experimentally:

$$4.17+0.33\cos(\Theta+43^\circ)+0.71\cos 2\ (\Theta-34^\circ),$$

Taking into account the uniformity over the whole day of the number recorded at any one U. T. hour of the day,

$$0.993+0.020\cos(\Theta-88^\circ)+0.095\cos 2\ (\Theta-26^\circ).$$

On the other hand, the occurrence frequency of SSC could be expressed by the following;

$$0.17-0.30\cos(\Theta-63^\circ)+0.10\cos(\Theta-7.5^\circ)$$

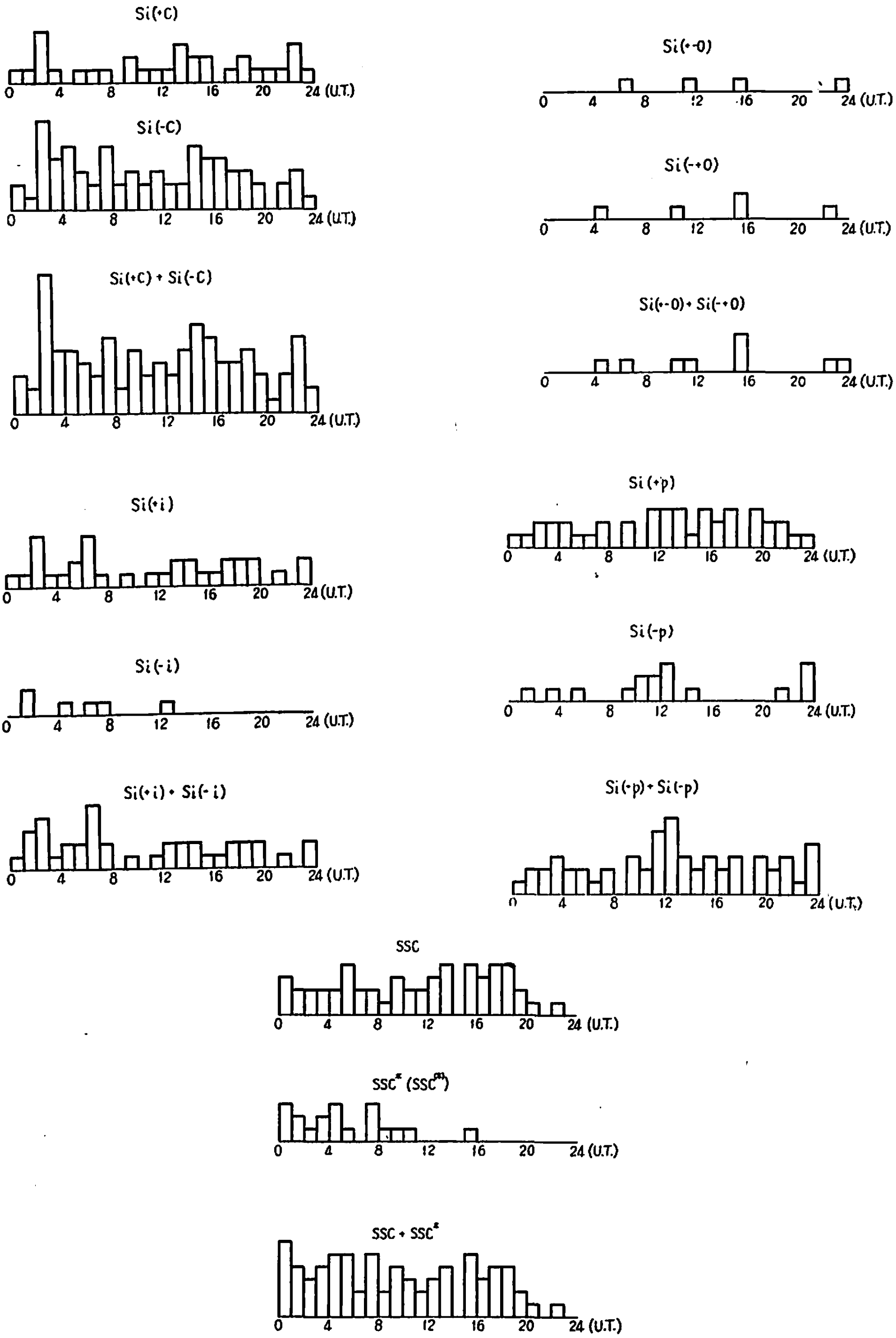


Fig. 6 The daily distribution of S. I. and SSC during the I. G. Y. at Kakioka

and $0.752-0.30 \cos(\Theta-9.5^\circ)-0.029 \cos 2(\Theta+14^\circ)$.

The relation of the magitude of the amplitudes of the first term and second term of S. I. is contrary to that of SSC. Thus, it was suggested that there was an essential difference between SSC and S. I., in spite of their simirarity of their appearance on the magnetograms. This examination was made by means of the data of the observatories Cheltenham, Tucson, San Juan, Honolulu, Huncayo and Watheroo. The data at Kakioka Magnetic Observatory are treated by Yokouchi [12] and the same conclusion is deduced.

But, we have some queries on the results, because

(a) Picking up S. I. on the magnetograms is very difficult to obtain a perfect occurrence frequency pattern, compared to SSC

(b) both the amplitudes of the diurnal and semi-diurnal terms are small, compared to the first constant and the difference of them is also so.

(c) The diurnal behavior of the occurrence frequency is said to be dependent on the magnitude of the hrizontal component [13].

Thus, the expressions seem, to our regret, unsatisfactory, and further examination will be necessary, to establish the events. The major efforts in this chaper is the comparison of S. I. with SSC.

A mordhological study of the disturbance field is tobe considered with the determination and repesentation of the magnetic field vector over the globe as a furnction of bothtime and position. The general morphology of magnetic storms has been studied by N. A. F Moos [14] in 1910 first and then it was fllowed by S. Chapman and his colleagues [15].

The sutdy of the average propeties of the D field during recent years by M. Sugiura and S. Chapman will be the most comprehensive one. [16]

The disturbance field can be thought to be separated, for convenience, into three partial fields, namely the diurnal part of the D field, the zonal component from spherical harmonic analysis and the irregular varition.

The first is a function of storm time-reckoned from the sudden commencement of the storm —, of geomagnetic latitude and of geomagnetic local time and denoted by DS. The second is symmetical around the geomagnetic axis and is a function of storm time and geomagnetic latitude. It is called as the storm variation of the geomagnetic storm, with a notation of Dst. Di denotes the irregular part of the D field. Thus

$$D=DS+Dst+Di$$

The partial fields DS and Dst have been determined statistically by averaging of a number of storm fields. Averaging of a number of the disturbance fields, the irregular variation Di will be averaged out or becomes small.

A typical magneti storm begins with SSC and then after some honr the horizontal component begins to decrease and gradual recovery follows after minimum in the middle or low latitudes. The increase of the horizontal component for few hour, the deminution of it and the recvery stage are named as the initial phase, the main phase and the last phase of the geomagnetic storm, respectively.

Some workers noticed a distinct development of the DS field even in the earier stages of a magnetic storm and the sudden changes such as SSC and S. I. conld be separated into two partial fields, Dst and DS^C. [17] [18] [19] [20]. Also the important results as regard to the amplitude of SSC have been obtained. [21].

From the physical stand point of views, the separation of D fineld into partial fields in other way will be useful. One is the following;

$$D=D_W+D_t$$

where D_W means the worldwide varation of the disturbance field due to the extraterrestrial origins, such as the solar corpuscular streams or clouds and the ring current, while D_t includes the variation flields caused by the terrestrial origins.

Terrstrial origin part Dt will be subdivided into equatorial origin part D_E and polar origin part D_P, according to the locations of the origins. D_P includes DS(DS^C) polar part of Dst and irregular variations, which may be produced by the entry of particles into the ionosphere in the high latitudes. The entry of the particles into the auroral zone atmosphere generates the electrojet cureent along the auroral zone and the current circuits are completed over the polar cap and/or in the extra-terrestrial regions. A part of the leakage current enters in the middle latitude and constitutes a part of Ds current. A zonal current near the auroral zone, shown in the Dst current system by S. Cha man will be classified in D_P.

D_E may include a part of the irregular variation, but neglecting the irregular variations, the terrestrial origin part D_t of D field is originated mostly in the polar region (including the auroral zone) and equalized to D_P. Thus D field will be expressed foromally as follows;

$$D=D_W+D_P,\quad D_{st}=D_w+D_P,\quad D_S=D_P$$

Recently, some workers discuss the problem hydromagnetically.

§ 3.2 Geographical Distribution of the variation vector

An average equivalent current current systems of the Dst, DS and the resultant for the main phase and those for SSC are given in Fig. 7. The Dst part of the equivalent current for SSC flows eastward, opposite to that for the main phase in which the horizontal component is below normal. DS current for SSC over the polar cap flow nearly parallel, with eastward and westward return flow. The DS

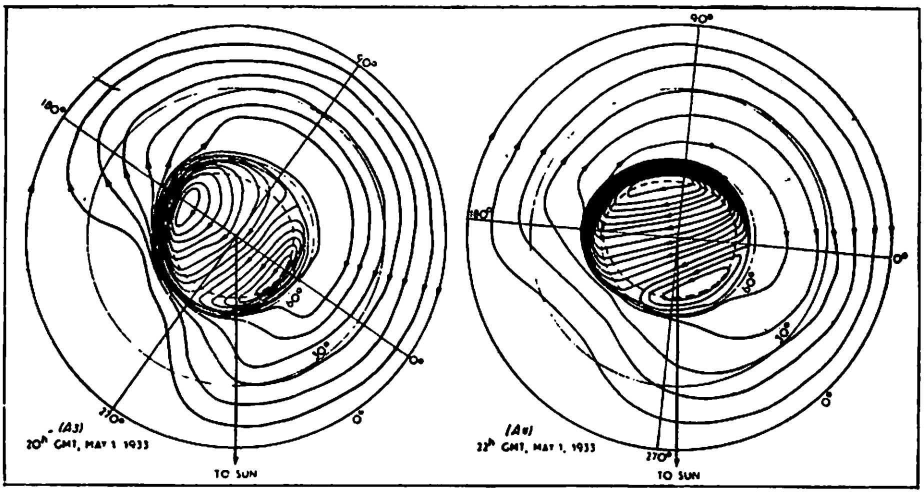


Fig. 7a Current diagrams for the main phase of four magnetic storms, Current flow between adjacent lines : 100,000 A. (after Vestine)

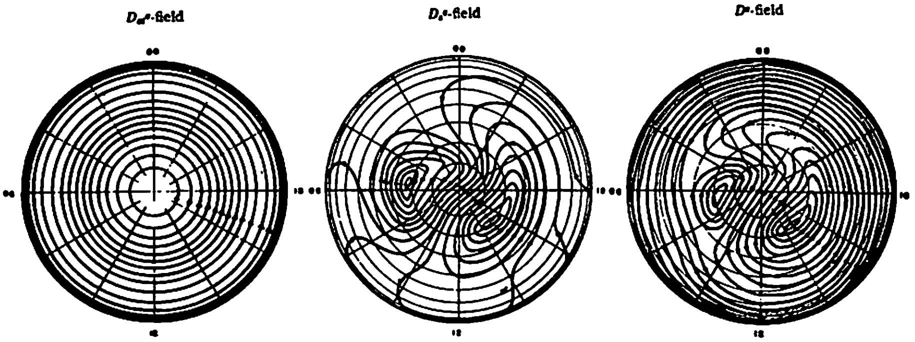


Fig. 7b Electric current-systems of D_{st}^c, D_s^c and D^c–fields for sudden commencements of magntic storms. (viewed from above the pole ; 10,000 amp. flow between successive stream lines. after Obayashi)

current system, however, different from those for the main phase and/or the polar magnetic storm in which they show the auroral electrojet — marked concentration of eatward and westward current along the auroral zone. Nor the DS current system for SSC show the current loops outside the auroral zone, while those for the main phase and the polar magnetic storm give a small part of the zonal currents over the middle latitude zone, which complete the return flow of the electrojets.

The distribution of the variation vector of S. I. (+C) over the globe

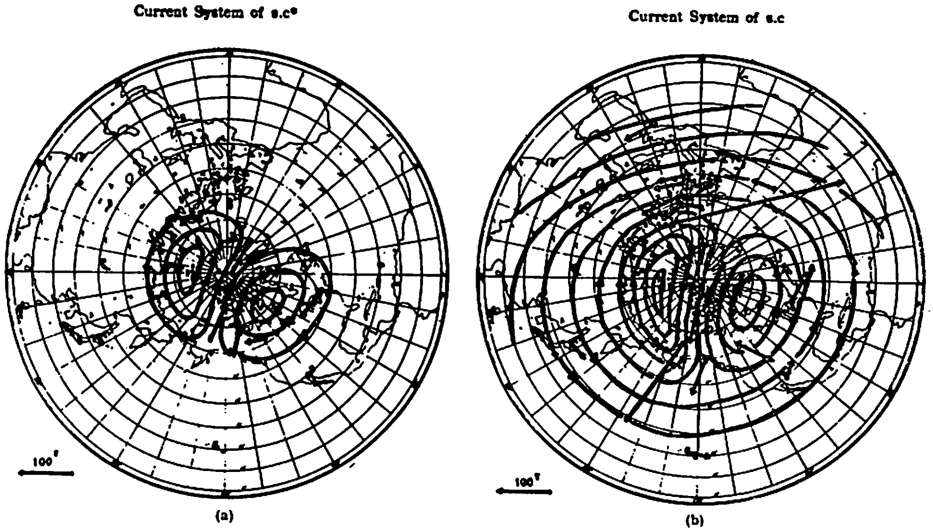


Fig. 7c Current-systems of sudden commencement at 20 h 12 m on Oct. 13, 1949. (after Obayashi)

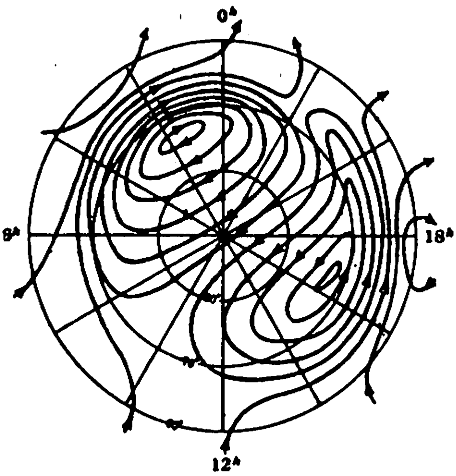


Fig. 7 d The mean equivalent current system for polar magnetic storms during the Second Polar Year. (Electic current between successive stream lines is 2.9×10^4 amp.) (after T. Nagata)

can be compared to those of the preliminary reverse impulse of SSC, SSC, the main phase of the magnetic storm and bay(or the polar magnetic storm). We may be able to say the similarity of it to that of SSC, taking into consideration that an average equivalent current system deviates somewhat from those of the individual ones.

The distribution of the variation vector of S. I. $(-C)$, shown in Fig.8 is very interesting. The pattern of the current system resembles to that of SSC, but the direction of the current flow is nearly opposite to that of SSC and coinsident with those of the preliminary reverse impulse and/or of the main phase of magnetic storms, except that the current system of the preliminary reverse impulse has a tendency to be limitted in more or

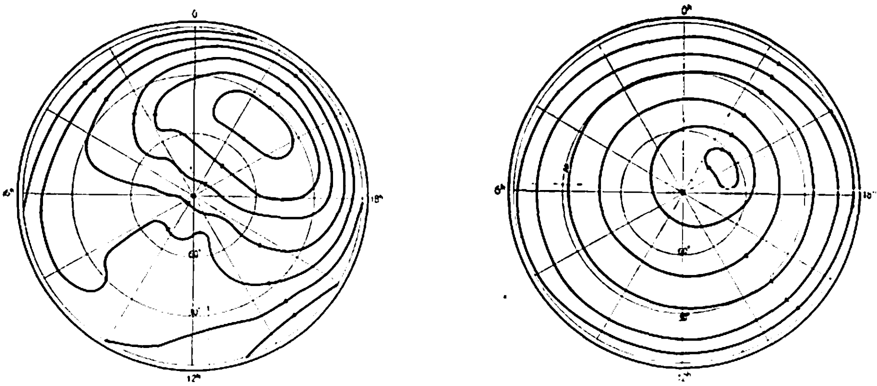


Fig. 8 The Average Equivalent Current System for four S. I. (-c) 's : July 23 04^h59^m, Aug. 18 10^h15^m, Aug. 25 15^h05^m, 1957; July 17 09^h30m, 1958
a : Current System for the first half Duration
b : Current System for the Whole Duration
(Electric Current between successive Stream Lines is 2.5×10^4 amp.)

less high latitude regions and not to come in the low latitude regions.

Since Newton, the shape of the traces at SSC has been examined by many writers. Ferraro et al showed the four typical SC_S' which are reproduced in Fig. 9, and some authors concluded that the various manifestation of SSC depends on the local time and the geomagnetic latitude of the observatories. The average equivalent current system of SSC shows the circumstances straight forwardly. That is, the reversed SSC in the high latitude manifest itself mostly as normal SSC in the low latitude, in case of which the horizontal component increases.

For convenience, SSC field is separated into two partial field, Dst and Ds. Dst field for SSC is observed as the increase of the horizontal component at the earth's surface, while the horizontal component in the DS field increases and decreases, according to the position of the observatories. Thus, DS field strengthens the increase of the horizontal component in the Dst field in a region and weakens it (sometimes cancels over) in the other. Moeover, DS field is predominant in the high latitude regions and only a small part of it remains in the middle or low latitude. This may be able to explain the formation of the inverted SSC, although not physically. Thus, the inverted SSC has been seldom observed in the low latitude regions. At Kakioka Magnetic Observatory, only two were observed during the period from 1924 to 1951. V. C. A Ferraro who analysed the data at San Juan, Tucson, Huncayo, Cheltenham, Watheroo and Honolulu, for the period from 1926 to 1946, found very few number, eight being recorded at Watheroo, two at Honolulu and one at the remaining stations, excepting San Juan, where none were recorded, making a total of 13. W. Jackson examined the records at Abinger, saying "they were

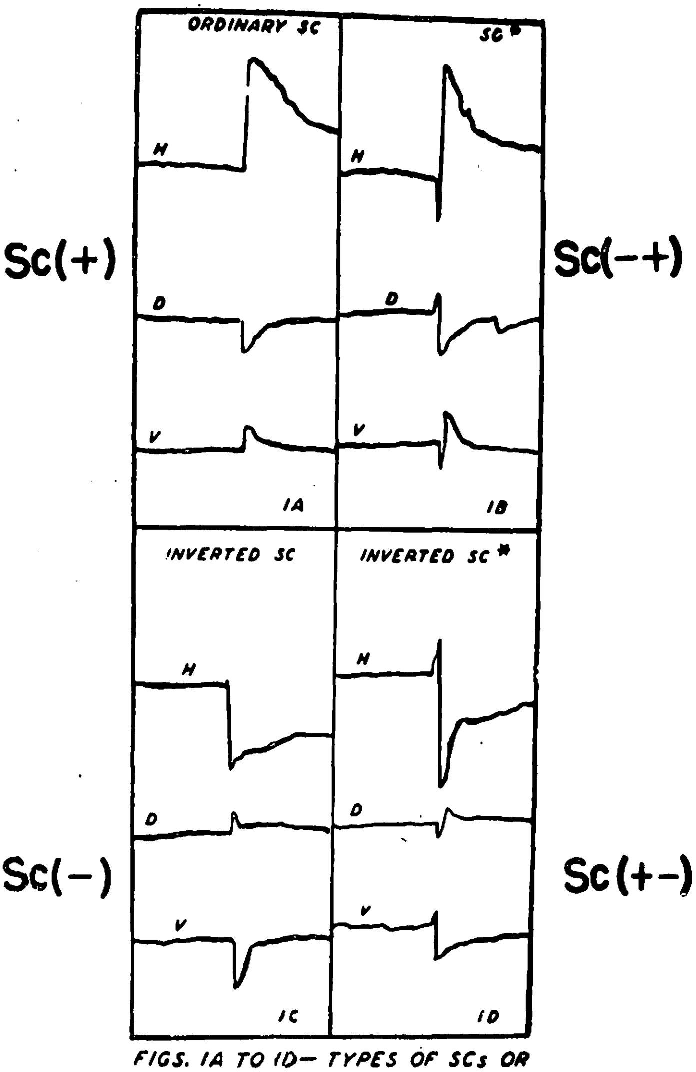


Fig. 9 Notations in the margin Proposed by S. I. Akasofu and S. Chapman.

seldom, if ever, directly related to the commencement of a storm, and they were sometimes recognised as the terminal movement of a group of S. C-type. The picture suggested is that the H changes in S. C. s is always positive, unless midified at the anomalous local times; other reversed S. C. movments are asseciated with S. C. -type movements rather than S. C. s." The notations he used as S. C. s and S. C. -type denote respectively the variations SSC and S. I. by the current notations.

On the other hand Ferraro et al who studied the daily variation of the frequency of SSC* and S. I.*, found that both occurr more frequently during the local afternoon hours.

After T. Nagata, the origins of the preliminary reversed impulse of SSC* are in the high latitude region. Thus the composition of the horizontal component in the various types of SSC and S. I., can be tabulated. In the table, some notations are employed temporarily.

Table. 5 The composition of the Horizontal Component

		SSC	SSC*		Inverted SSC		Inverted SSC*	
			p. r i.	m. i.	W.	R.	P. r. i	m.
Dw		$\Delta H>O$	$\Delta H\approx O$	$\Delta H>O$	$\underline{\Delta H<O}$	$\Delta H>O$	?	?
Dp	morning	$\Delta H<O$	$\Delta H>O$	$\Delta H<O$	$\Delta H\approx O$	$\Delta H<O$ $(Dw<Dp)$	?	?
	afternoon	$\Delta H>O$	$\Delta H<O$	$\Delta H>O$	$\Delta H<O$	$\Delta H>O$	?	?
		S. I. (+C)	P. r. i.	m. i	W	R		
			S. I. *(+C)		S. I. (−C)		S. I. *(−C)	

W : World wide
R : Regional
—— : Valid only S. I.

§ 3. 3 Following storminess

In individual cases of magnetic storms, the phenomena are very complicated. In some cases two or more SSC and/or the main phases can be found in the course of the disturbances. This may correspond to sudden enhancements of a continuous stream, or to the onset of a new storm after the first or earlier streams had ceased to flow on to the earth. In other cases, the main phases and /or the last phases are not always well defined, however great the storminess are. While, S. I.'s are distinguished from SSC by saying that they are not followed by storminess or not thought as onsets of new storms morphologically. But, we are in trouble on account of the variety of magnetic storm, when we make a distinction between S. I. and weak SSC storm, especially in case of S. I. (+C). And only a small difference of estimation of the storminess after the impulsive variations makes sometimes the employment of the different notations, as though the phenomena are caused by the entirely different mechanism.

Qualitatively speaking, the storminess after S. I. is not appreciable on the magnetogram with usual sensitivity. But whether we are concerned in only the magnitude of storminess, or we are faced to treat the special mode of storminess, may be an important problem.

The disturbance field are usually divided into DS and Dst fields. And in the low latitude, Dst field is generlly more excellent than DS field and the horizontal component of Dst is most distinguished. So, it will be most easy to be obtained. The results in Fig 10 are based on the horizontal component at Kakioka, in which 188 S. I.'s during 1924~1951 are examined. The method of the calculation is the same for SSC storm by S. Chapman, but Sq to be subtracted is replaced by S during the previous 24 hours after confirming that any irregular variaon is not appreciate for the period.

Arranging hourly values at occurrence times in the same colum, the following hourly values are set in the same line. And the corresponding values at the same columns are averaged all over the phenomena. And then the mean values for the occurrence times and for 24 hours after it are minused by the mean value for 24 hours before the occurrence time. In the same way, the value 23 hours before it, is subtracted from the values an hour after and 25 hours after the occurrence times.

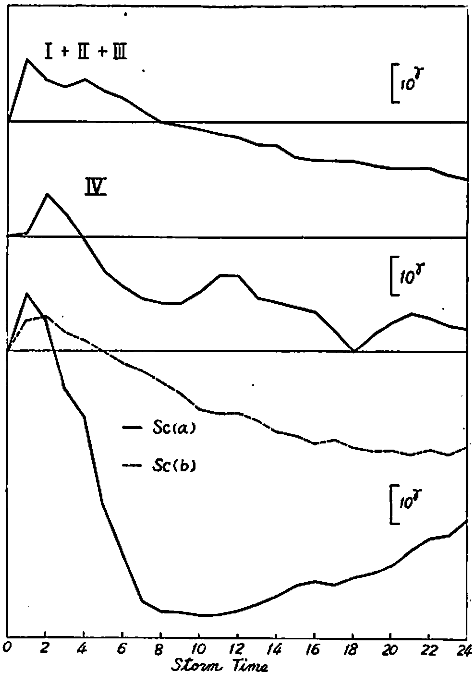


Fig. 10 The average storm time variation of S C (after Y. Yokouchi) and S. I. SC (a) : Ordinary typical storm, S. C (b) : Sudden Commencements followed by irregular variations of fairy long period.

Although the range is only one-tenth of that of Dst for SSC storm, the aspects is very much similar to the case of the weak storm.

From the recent data during the I. G. Y., the same conclusions are obtained. The cases are adopted the maximum K-indices during the period from 24 hours before the occurrence times to 48 hours after them are less than 4 [10].

Both the above stated results are said about the data including all the types of S. I.. The following are those of S. I. ($+C$) and S. I. ($-C$). It is possible that the

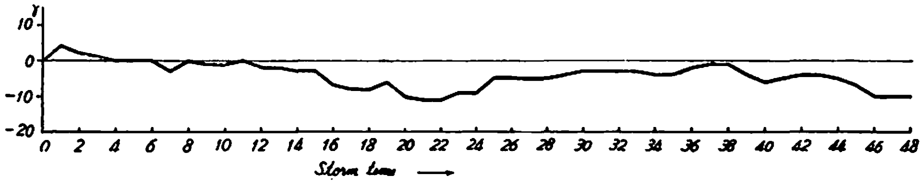


Fig. 11 After effect of S. I. during I. G. Y. (all type)

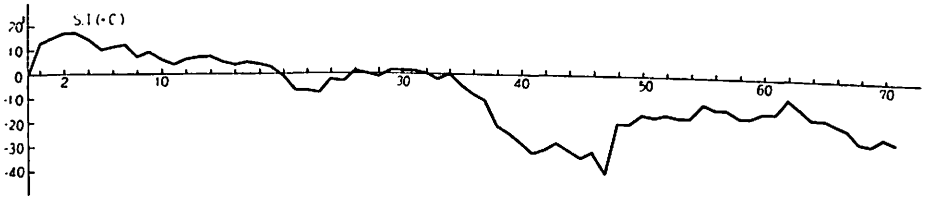


Fig. 12 a. After effect of S. I. (+C)

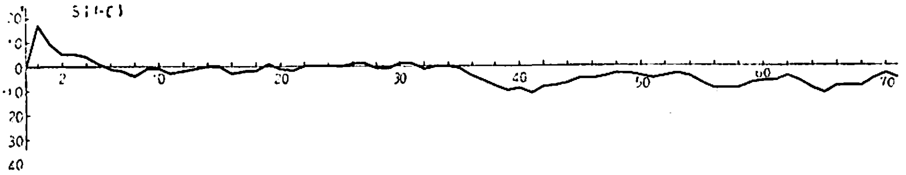


Fig. 12 b. After effect of S. I. (−C)

Table 6. The selected S. I. and Maximum Kp during 72 hours

S. I. (+C)		S. I. (−C)	
Date	Main characters	Date	Main characters
1957. July 11 0944	3_0	1957 July 23 0459	3−
〃 23 0340	3−	Aug. 18 1015	3−
Aug. 17 1322	3_0	〃 25 1505	3_0
1958 July 13 2208	3+	Nov. 18 2200	3+
Aug. 11 1846	3_0	1958 June 30 0400	4_0
Dec. 25 2330	3−	July 12 0347	3+
		〃 17 0930	4_0

average of D field at some observatories, with nearly same geomagnetic latitude will give approximately Dst field at the latitude circle. The observatories of which data are used are Honolulu, San Juan, Kakioka and Tamanrasset(or *M'* Bour)and the selected S. I'.s are listed in Table 6.

Although the accuracies of the results, depending mainly on the selected date are not sufficiently discussed, all three results are in consistent and the main features of the life of the effects arevery similar to those of the weak storms.

Table 7 Main characters of Dst of SSC storm and after effect of S. I.

	S. I (+C)	S. I. (−C)	Weak storm	Moderare storm	Great storm
Max. in initial phase	15γ	15γ	11γ	10γ	12γ
Duration of initial phase	19. 6h	5. 0h	4. 0h	2. 0h	1. 5h
Min. in main phase	8γ	3γ	19γ	39γ	88γ
Duration of main phase	? γ	2. 0h	8. 3h	7. 2h	5. 1h

In Table 7, the duration of first phase means the hour during which H-component are above zero and that of main phase, uo to the minimum value of Horizontal component.

Although the DS field is not discussed, owing to the difficulty of the elimination of the irregular variations, it may be suggested that the disturbance fields after S. I. (+*C*) and S. I. (−*C*) might be similar to that after SSC, only with the difference of their activity.

On the other hand, a note must be added to the beginning of magnetic storms. Although magnetic storm begins usually with an abrupt increase of the horizontal component, in some cases they are commenced gradually which have not any fine onsets. Not only the perfectly smooth traces of the increasing horizontal component, but rather irregular ruggedness creep previous to the distinct storminess. It is preferable to say that clear abrupt changes such as SSC are not previously occurred.

The gradually commencing storms have been shown by Thelliers [22] and Newton and Milson [23] to be those that most clearly manifest the 27 day recurrence tendency. This implies that they are mainly caused by long continuing solar streams, from the emitted regions named M regions by Bartels. The suddenly commencing storms may be ascribed to the onset of the limited solar clouds, such as we suppose to be ejected during solar flares : or to continuing M streams that happen to have rather sharp boundaries. The particles of M streams may well travel more slowly than those in the clouds that produce SSC storms. This would allow longer time for thermal motions, and perhaps also turbulence, to make the lateral boundaries of the stream diffuse. As the solar rotation brings first the leading edge of the stream, and then the body of the stream, in line with the earth, this diffuseness could make the storm beginning gradual. The outlying part would be halted by the gemagnetic field at a distance of very many earth-radii. As the body of the stream came to impinge on the field, the surface of the hollow would shirink inwards, and the field could grow gradually. For similar reasons the entry of the particles into auroral zones, and the onset of the Dp part of the field, would be more gradual.

On the other hand, in a cloud of gas the particles that had been ejected with the greatest outward speed would travel on beyond their more tardy companions, This would tend to make the sudden commencement rather more sharp, although the number density would decrease for the particles with the most extreme speeds.

Table 8 Classification of Magnetic Storm.

	Abrupt changes	Eollowing stormimess
SSC storm	distinct	distinct
Gradually commenced storm	obscure	distinct
S. I. (+C), S. I. (−C)	distinct	obscure

Table 8. suggests qualitatively a causal agency for S. I..

§ 3.4 The augmentation of the amplitude near the equatorial zone

The amplitude of SSC shows a distinct daily variation, which is reminiscent of

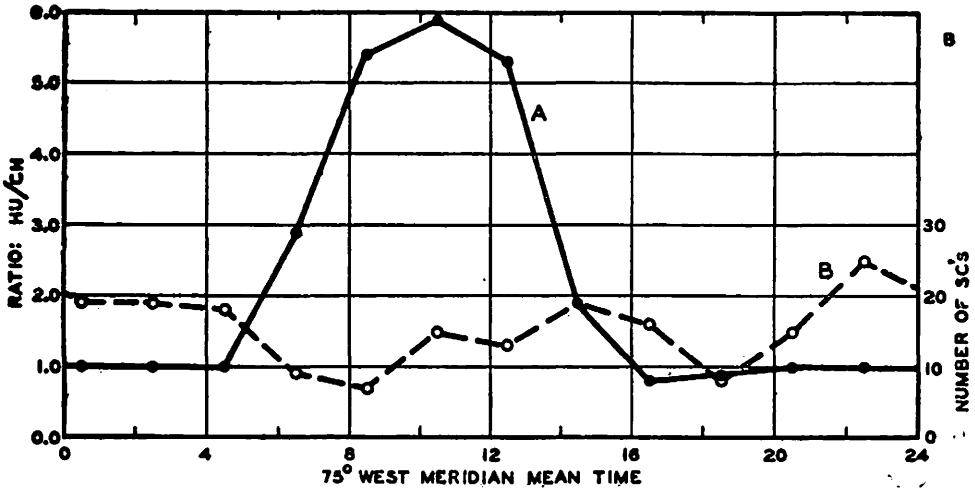


Fig. 13 a The diudlurnal variation of the ratio of amplitudes of SC’$_s$ (ΔH) at Huancayo to those at Cheltenham, 183 SC’$_s$, 1922–46

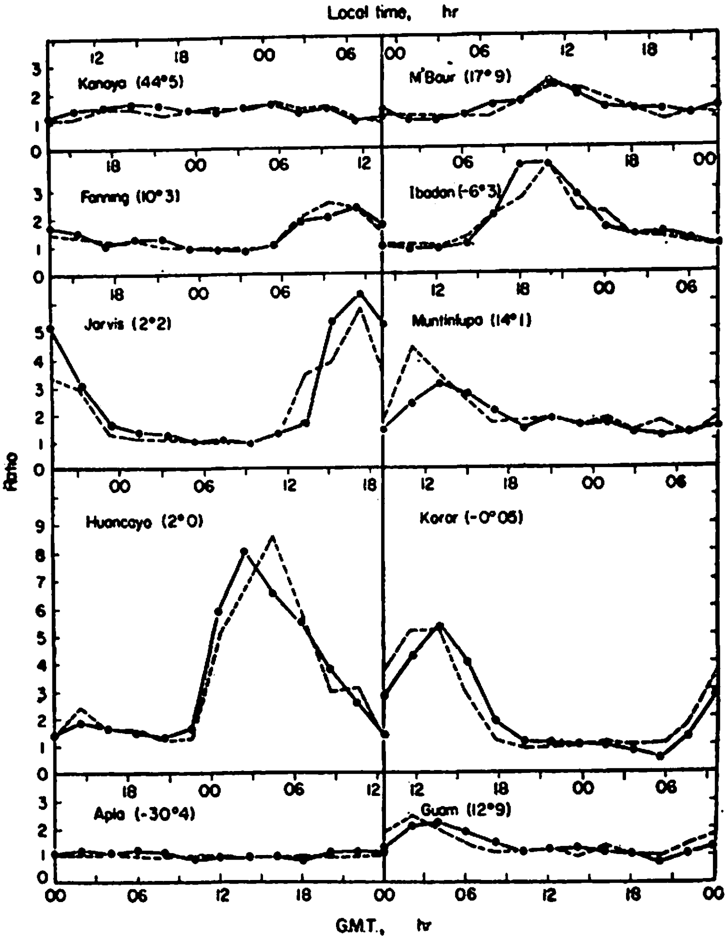


Fig. 13b Daily variation of the ratio of amplitudes of S. I.'s (ΔH) (full lines) and S. C.'s. (ΔH) (dotted lines) at Kanoya, M'Bour, Fanning Ibadan, Jarvis, Muntinlups, Huancayo, Koror, Guam and Apia to those at Honolulu, during the IGY.

the anormalous enhancement of Sq and L. [1] at Huncayo (Gm. lat. 0.6 S, Gm. lon. 353.8). The initial phase (not only SSC) is enhanced at the same observatory, though DS and the main phase of Dst are not. H. Maeda and Y. Yamamoto examined the subjects on S. I., including all the types and found the similar results to SSC. [24]

The present author examined S. I. (+*C*) and S. I. (−*C*) separately. Typical data are adopted and the results of both are same.

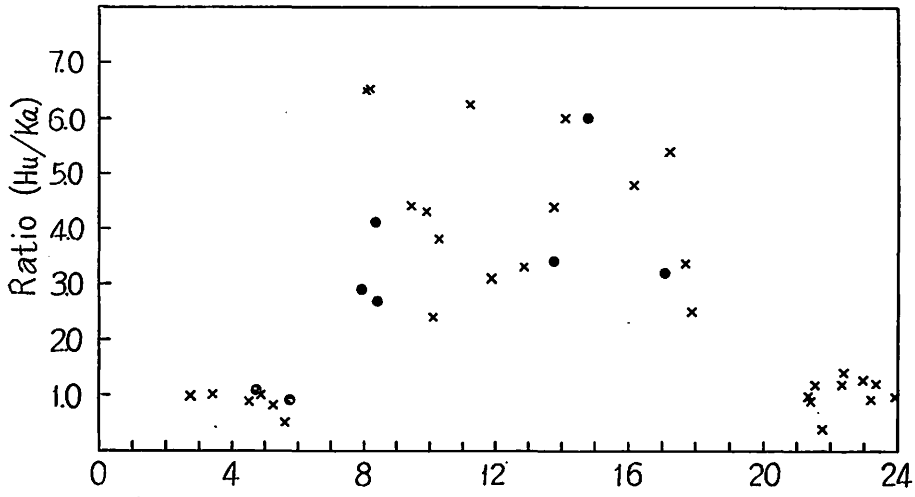


Fig. 13c. The Diurnal Variation of the Ratio of Amplituclos of S. I. (+C) and S. I. (−C) at Huncayo to those at kakioka •……S. I. (+), ×……S. I. (−C)

§ 3.5 The simultaneity of occurrence

Long ago, Adams Ellis showed that SSC may be simultaneous over the earth to within a few ninutes [25]. Bauer also concluded that SSC has a time of a propagation round the earth of the order of 3 or 4 minutes. Otherwise, Chree, Angenheister and Chapman critically discussed his results and indicated the relative inaccuracy of the records. Chapman suggested a possible minmum range of the time of SSC at difflerent places of the order of 30 sece. After then, S. Imamiti studied the problem on SSC (which included abrupt changes, harply followed by stominess) with every possible precautions. Recently, V. L. Williams V. B. Gerard published the statical referred to the storm theory by Singer. [26] [27]

The results on SSC, by Williams and Geraard are summarized as follows ;

1. The sudden commencements were registered in the high andmiddle latitudes first.
2. The sudden commencements verr registered at Little America first or second about 85 per cent of the time.

These are inconsistent with Imamiti's conclusions. That is, latter conclued that SSC occurred earlier in the low latitude regions than in the high latitude regions.

Previously, we mentioned the simultaneousoccurrence of S. I. over the wold, within one minute. Recently Y. Yamamoto and H. Maeda examined the subject on S. I. and compared them with the results on SSC by Gerad and Willams. Yamamoto and Maeda examined the 4 sudden impulses on Oct. 14 d 13 m, 1957, Feb. 12 d 05 h

55 m, 1958, luly 21 d 19 h 25 m, 1958, Nov, 11 d 01 h 29 m 1958 and conclu edad follows : [28]

(1) Time difference of sudden impulses around the earth were within one minute ;

(2) The sudden impulses always occurred first in high latitudes ;

(3) The average propagation velocity of sudden impulses between Honolulu and Kororwas 1300 km/sec.

For the examination, as accentuatedby some workers, the instruments and methods of observation of the magnetic field must be selected with greatest care. Moreover, the rapid run magnetograms as employed in the above mentioned examina tions, are inquired to be sufficiently high sensitive in order to indicate the very beinning of SSC or S. I..

Evev if the above mentined conditions are fullfiled, the various shapes of the traces at the moment of the changes, depending on the locations of the observatory, make it difficult to detrmine orderly the first manifestation of SSC and/or S. I.

Chapter IV Other types

§ 4.1 S.I. (+P) S.I. (−P) S.I. (+−O) and S.I. (−+O)

Most of so-called irregular varitions in the course of magnetic disturbance appear in these shapes of traces……peak and oscillation. These might be due to the irregularities in solar stream or the irregularities or the magnetic field in the outer atmosphere and usually occur in succession. Excluding such variations, we sometimes observe some isolated peaks or oscillations, even in the comparatively puiet state of the magnetic field. This is a reason why we produced as one of the four fundamental types.

Typical examples are given in Figs. 1 and these are too beatiful to be treated as irregularities. Although such distinct phenomena as shown in figuresare not so frequently observed, small amplitude ones in the quiet state are very familiar. Some workers pointed out this fact by comparing the magnetograms at distant observatories. As statedbefore by this writer, some deformed S. I. (+*C*) or S. I. (−*C*) have a danger to be misconceived, owing to the supeposition of any other variations during the disturbed state. But, the frequentoccurrence of these types during a disturbance may be also true.

§ 4.2 S.I. (+i) and S. I. (−i)

The main featurs as follows,

i) The amplitudes of the first and second impulses are nearly same.

ii) The most frequent duration between the first and second impulses are

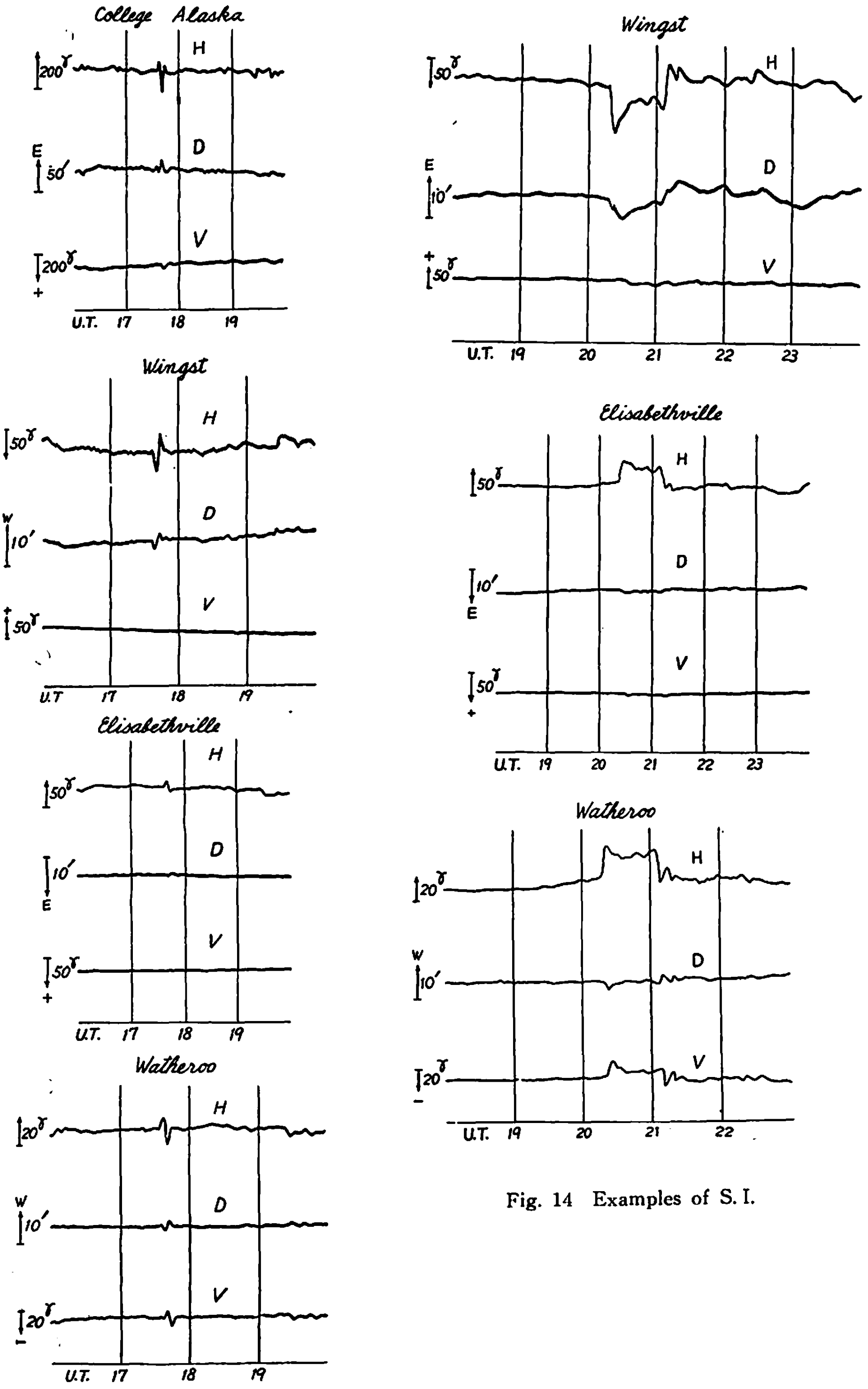


Fig. 14 Examples of S. I.

about 35 minutes.

iii) Sometimes SSC may be the first impulses and the second impulsses call for the main phases or the ending of the storm. In these cases, the durations of both impulses are naturally long.

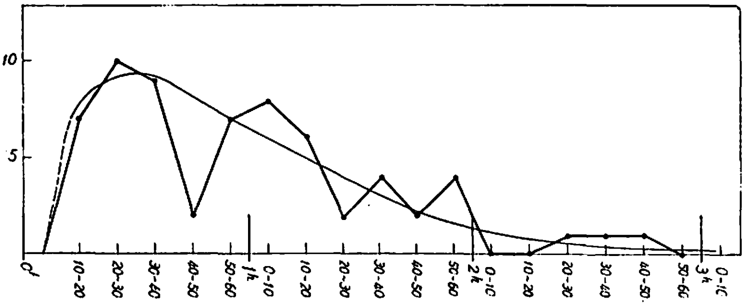


Fig. 15 The frequency distribution of the duration of S. I (+−i)

Example on iii) is given in Fig. 16. In this case, a distinct SSC occurred at 23h 13 m, 2 nd April and then disturbance in which the main and/or last phases are not well defined continued, until the suddenly decreasing of horizontal component occurred at 08 h 04m, 5th. Some S. I.'s were observed during the disturbance, but, the abrupt case of the violent disturbance after S. I. were found on only the last. And then it may be natural to be thought that the suddenly decreasing of the horizontal component is the second impulse of S. I. (+−*i*), of which first impulse may be the mentioned SSC.

In practical procedure of selection of S. I., these facts may be desirable to be bore in mind.

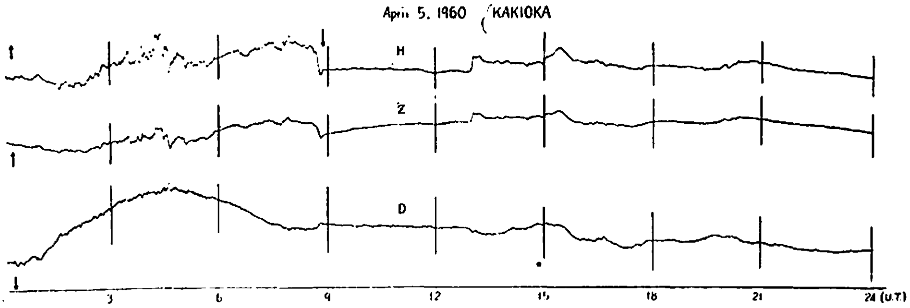


Fig. 16 Example of S. I.

Chapter V S. I. and Pulsations

Y. Kato et al described about the pulsations together with SSC and S. I., and remarked that they are distinct in the day time, and unnoticeble during the night time. The period of them has the fine dependency on the local time. K. Yanagihara described the pulsaions at the time of SSC in day time as pc-like pulsations in a narrow sense, of which period is larger than 10 sec. and those in night time as spt, according to his notation.

On the other hand, the relation between the pulsation and the magnetic activity are examined Furthermore, J. Veldkamp reported the giant pulsation and S. I at nearly sametime 09 h 30 m,on 17 th July 1958.

The pulsation are classified into three types in the resolution are resolution at the Meeting of the Committee on Rapid Magnetic Variation and Earth Currents of IAGA, IUGG, held at Copendagen during April 9–11, 1957, and the notations pt, pc and pg are given.

§ 5.1 Pulsation together with S. I.

During the I. G. Y., large number of S. I. were observed, but, some of them occurred in the course of pulsation……usually, pc……, and so it is difficult to confirm whether the S. I. is a primary phenomena or not.

The cases from the pulsation……at most, usually reported, ignoring the indistinct vestiges……during one hour before the occurrence of the S. I'́s, are selected.

The phenomena, dated on the following give good exmples of the S. I. accompanied by the pulsation.

'57 Nov. 29, 02 h 25 m (U. T.)

'58 June 19, 16 h 00 m (U. T.)

Both of the S. I. are S. I. $(+i)$ and followed by the sudden decreasing of the horizontal component at 02 h 40 m, 29, Nov. '57 and 17 h 16 m, 19 d, June,

Table 9 Characters of S. I. and pulsation in both cases. (Upper : Ka; Lower : Mm)

Date	time	Quality	$\triangle$H
'57 Nov. 29	02h 25m	B	$+13\gamma$
'57 Nov. 29	02 40	B	-10γ
'58 June 19	16 00	A	$+11\gamma$
'58 June 19	17 16	B	-10γ

Date	Amplitude	Period	Duration
'57 Nov. 29	0.144 γ/sec.	15 sec.	2 min.
'57 Nov. 29	—	—	7
'58 June 19	—	—	
'58 June 19	—	—	

On the induction magnetograms used, the short descriptiptions are given in "Report of the Geomagnetic and Geoelectric Observations I. G. Y. 1957–58, Kakioka Mag. Obs.

As stated above the pulsations at time of SSC are predominant in the day time and very small in the night time. There seems to be the tendency in this cases. However, the distinction between the cases of the first impulse ($\Delta H > 0$) and the second ($\Delta H < 0$) must be especially emphasized. The case on 29 Nov. 1957 is the phenomenon in the day time and the pulsation ot the first impulse is distnct, while at the second impulse, the pulsation can be hardly recognized.

Speaking of the case on June 19, 1958, pt pulsations are observed at 16 h 00m, 26 h 24 m, 16 h 28 m, and 16 h 48 m. From 17 h 10 m, the pulstions continue.

On the other hand, the event on 1 July 1957 may be notewortly. On the ordinary magnetogram, we observed SSC at 17 h 13 m, S. I. ($+C$) at 18 h 13 m, S. I. ($-C$) at 18h 25m, S. I. ($-C$) at 1904, S. I. ($+C$) at 1945, S. I. ($-C$) at 21 h 10 m.

On the induction magnetogram, a series of small pulsations continue from about 9 h 30 m and merge into lnto larger amplitude pulsation at about 17 h 50 m. The rather larger pulsation continue till 21 h 20 m, with a temporary suspension from 19 h 06 m to 19h 36 m. During the period, small pulsation such as those before 17 h 50 m survive, and characters of series of pulsations before and after the suspension seems to be rather different. After 21 h 20 m, a series of faint indications are only noticeable.

Rather distinguished increase of amplitude can be observed at 18h 12 m or 13m and 18 h 18 m 40 sec, though any change of the period is difficult to be measured.

Thus, that the pulsations with SSC more clear than those with S. I. seems to be appendixed with the exception. But, these descriptions are based on the magnetograms at only one station and the authorization of SSC or S. I. should be re-examined on other observation and/or at other observatories.

Part II. Tentaive Theory of S. I.

Chapter I. Introduction

Morphlogical examination of magnetic impulses shows that the phenomena are very similar to SSC and this also suggests the mechamism of both phenomena may be perhaps kindred. The mechanism of SSC have been rather clear by many research worker's efforts, but they have hardly referred to S. I.. The main morphological distinctions of S. I. from SSC is the following two ;

I. S. I.'s are not followed by distinct storminess.

II. There are S. I. $(-C)$ and S. I. $(+-i)$, namely suddenly decreasing of the horizontal component, even in equatorial region.

And they occur as frequently as S. I. (+C).

Among them, the first means the geomagnetic field after S. I. include a partial field alike to Dst of magnetic storm, with small intensity and the second may be more important distinction. Although cassification of SSC shows the existence of the inverted SSC (or inverted SSC*), S. I. $(-C)$ should be distinguished from them. Because S. I. $(-C)$ are the world wide phenomena, while the inverted SSC's are the regional ones.

And the decreasing of the horizontal component in the latter might be attributed to DS^{C} (DS part of SSC). That is, D^{C}st (Dst part of SSC) is always the increasing of the horizontal component and more intense DS^{C} than D^{C}st decrease regionally the horizontal component. Thus, all the storm theories have treated the sudden increase of the horizontal component at the time of SSC, excluding the preliminary reverse impulse of SSC*. Thence, each theory of SSC seems to be unsuitable for the explnatin of S. I. $(-C)$ in its original form.

The theories of geomagnetic storm, which were initiated by Birkeland and Stormer, have been developep by Chapman, Ferraro, Martyn and others. In most of them, the solar corpuscular streams or clouds are postulated as the basic agency. The gas is streaming away from the sun with velocities of about 100 km/sec. Its density is usually of the order of $10^2/\mathrm{cm}^3$ at the orbit of the earth, but $10^5/\mathrm{cm}^3$ during brief periods of extraordinary solar activity.

The corpuscular clouds can penetrate into the geomagnetic field up to the distance where the hydrodynamic pressure of the cloud equals to the magnetic pressure of the earth and flow round the surface of a cavity surrounding the earth. The size of the cavity depends on the kinetic energy density of the corpuscular clouds and is estimated that it may be apart from the earth's center about 5~6 earth radii, at the equatorial plane. The shape of the surface is not perfectly understood.

The conditions for growing up the cavity may be all the time satisfied by the orbital motion and others, because the orbital motion of the earth through the surrounding ionized gas is equivalent to the motion of a stream of gas past the earth. Since the earth's velocity is 30 km/sec, the cavity will be formed at the distance of 10 earth radii. Thus, the geomgnetic field is confined within 10 earth radii.

The inrush of the solar corpuscular streams or clouds compress the cavity and increase the geomagetic field. This may be thought as the onset of magnetic storms, namely SSC. S. Chapman et al had shown the circumstances in an idealized form. And the variation of the geomagnetic field by the impact of solar streams or clouds can be represented by the image dipole, which is the case of the field variation by the electromagnetic induction in the infinite, perfectly conducting sheet with at oward-moving dipole. Naturally, the mean free path of a hydrogen ion in the solar streams or clouds is of the order of 10 km and 10 times the dimensions of the geomagnetic field. The stream or clouds pass the " small " earth. Thence strictly speaking, the details of the interaction between the solar streams or clouds can not be discussed.

But, now we will not interest in all over the branches of the various aspects of magnetic storm, and Chapman-Ferrero model seems to be highly important and also the direct expression within a limmitted problem.

Meanwhile, the mechanism of the main phases has been discussed by some workers. Roughly speaking, the formation of the equatorial current ring is the key of the problem, though the details of the procedure of forming the ring or its stability are not always consistent.

Well the discussed problems are related to the solar streams or clouds with the frontal surface perpendicular to the direction of their motion. This is a limitted case and in practical cases, the solar streams or clouds being able to be in various places relative to the earth. Not only oblique incidence, but also the passage above and/or below the earth of the streams or cloud-smay happen, even if the physical state of the space through which the streams or clouds move, restrict to some extent their free behaviours. The latter gives also an impotant problem to be answered, but, in the first place, we will put it aside.

Among the various configurations, which may be perhaps attributed to the position of the sun relative to the earth (season), the birth place of the streams or clouds on the sun etc., might be included some cases in which the corpuscular streams or clouds don't swallow the earth but their edges pass by the earth at some distances from it. In such cases, the caving may fail to glow up completely. And then the main or last phases will be insignificant. These configurations seemto be the cases of S. I. (not followed by storminess)

And also rather small clouds, even if they impact to the earth in its eqnatorial zone, may grow up only the weak ring current and then cause the insignificant main and/or last phases. These cases seem also to be the S. I. phenomena.

Chapter II Image dipole model

§ 2.1 Induced currents in thin conductive sheets

We idealize the stream front as plane of in finite extent and calculate the induction currents in the surface of the highe lectrical conductive medium. Let $\Omega^{(e)}$ denote the potential of the external inducing field and $\Omega^{(i)}$ the potential of the field of the induced currents, then the potential Ω of the total field is given by

$$\Omega=\Omega^{(e)}+\Omega^{(i)}$$

Both $\Omega^{(e)}$ and$\Omega^{(i)}$ satisfy Laplace 's equation; im general, $\Omega^{(i)}\rightarrow O$ at infinity.

The boundary condition is

$$\frac{\partial^2\Omega^{(i)}}{\partial Z^2}=-2\pi\sigma\frac{\partial^2}{\partial t\partial z}(\Omega^{(e)}+\Omega^{(i)}) \qquad (Z=0) \qquad (1)$$

To solve the problem, define $\overline{\Omega}^{(e)}$ at a field point $P(x.y,z)$ in the region $Z>0$ by

$$\overline{\Omega}^{(e)}=\Omega^{(e)}\ (x,y,-z,t)$$

so that $\overline{\Omega}^{(e)}$ is the value of $\Omega^{(e)}$ at the image of P in the sheet.

Consider the function

$$\phi=\frac{\partial^2\Omega_{-}^{(i)}}{\partial z^2}+2\pi\sigma\frac{\partial^2}{\partial t\partial z}\ (\Omega^{(i)}+\overline{\Omega}^{(e)})$$

Then in the region $Z>0, \phi$ satisfies Laplace' s equation, possesses no singularities and vanishes at infinity and for $Z=0$, since $\Omega^{(e)}=\overline{\Omega}^{(e)}$ over the sheet $Z=0$

Hence, $\phi=0$ everywhere in this region and

$$\frac{\partial^2\Omega_{-}^{(i)}}{\partial Z^2}=-2\pi\sigma\frac{\partial^2}{\partial t\partial Z}(\Omega^{(i)}+\overline{\Omega}^{(e)})$$

Integrating with respect to t from $Z=0$ to $Z=\infty$, we have

$$\frac{\partial\Omega_{-}^{(i)}}{\partial Z}=-2\pi\sigma\frac{\partial}{\partial t}(\Omega^{(i)}+\overline{\Omega}^{(e)})$$

To examine the decay of a system of current induced in the sheet, we put $\Omega^{(e)}=0$, so that$\overline{\Omega}^{(e)}=0$ in (3). we then have

$$\frac{\partial\Omega_{-}^{(i)}}{\partial Z}=-2\pi\sigma\frac{\partial\Omega_{-}^{(i)}}{\partial t}$$

the solution of wich is

$$\Omega_{-}^{(i)}=F(x,y,z-Rt)$$

where $R=(2\pi\sigma)^{-1}$ and has the dimensions of a velocity. Thus the decay of currents may be obtained by taking the initial induced distribution and moving it parallel to itself with a velocity R along the positive direction of the Z axis. The decay is slower the greater the conductivity.

Let $\overline{\Omega}^{(e)}\tau$ denote the function derived from $\overline{\Omega}^{(e)}$ by replacing Z by $z+R\tau$ and t by $t+\tau$ and suppose that $\Omega^{(e)}$ vanishes for $t=-\infty$. Then the solution of (3) is given by

$$\Omega_-^{(i)}=-\int_0^\infty \frac{\partial\Omega_-^{(e)}\tau}{\partial t}d\tau$$

If the dipole of moment μ, at (a, b, c,) are on the plane parallel to XZ plane and have the angle α with Z axis, the magntic potentic potential at $(x, y, z,)$ are,

$$\Omega^{(e)}=\mu\{(x-a)sin\alpha+(z-C)cos\alpha\}/\{(x-a)^2+(y-b)^2+(z-C)^2\}^{3/2}$$

When a=ut, b=vt, c=wt$-$c$_0$ (c$_0$ > 0)

$$\overline{\Omega}^{(e)}=\mu\{(x-a)\,sin\alpha-(z-C_0+wt)cos\alpha\}/\{(x-a)^2+(y-b)^2+(z-C_0+wt)^2\}^{3/2}$$

Placing R= $(2\pi\sigma)-1$

$$\overline{\Omega}^{(e)}\tau=\mu\,\frac{(x-ut-u\tau)sin\alpha-(z+R\tau+wt+w\tau-C_0)sin\alpha}{\{\sqrt{x-ut-u\tau})^2+(y-vt+v\tau)^2+(z+R\tau-C_0+wt+w\tau)^2\}^3}$$

If the above is put into (4) and the calculations are performed,

$$\Omega^{(i)}=-\mu\,\left[\frac{e_1e_2(2\,r_0V-S)}{r^3{}_0(r_0V-S)^2}+\frac{e_1f_2+e_2f_1}{r_0(r_0V-S)^2}+\frac{f_1f_2}{V(r_0V-S)^2}-\frac{\Gamma}{r_0(r_0V-S)}\right]$$

where

$$e_1=(x-ut)ein\alpha-(z-c_0+wt)cos\alpha$$
$$e_2=u(x-ut)+v(y-vt)-w(z-c_0+wt)$$
$$f_1=-\{usin\alpha+(w+R)cos\alpha\}$$
$$f_2=-\{u^2+v^2+w(w+R)\}$$
$$r^2{}_0=(x-ut)^2+(y-vt)^2+(z-c_0+wt)^2$$
$$S=u(x-ut)+v(y-vt)-(w+R)(z-c_0+wt)$$
$$V^2=u^2+v^2+(w+R)^2$$
$$\Gamma=u\ sin\alpha+w\ cos\alpha$$

The solution can be arranged as follows;

$$\Omega_-^{(i)}=-\mu\left\{\frac{(e_1V+f_1r_0)\ (e_2V+f_2r_0)}{r^2{}_0V(r_0V-S)^2}+\frac{e_1e_2-r_0\Gamma}{r^3{}_0(r_0V-S)}\right\}$$

Thus, the three components of the induced field intensity on the negative side are

$$X=-\frac{\partial\Omega_-^{(i)}}{\partial x}\qquad Y=-\frac{\partial\Omega_-^{(i)}}{\partial y}\qquad Z=-\frac{\partial\Omega_-^{(i)}}{\partial z}$$

§ 2.2 The solar corpuscular streams or clouds approach to the earth with their faces parallel to the magnetic axis of the earth

Case I. $\alpha=\frac{\pi}{2}$, $u=0$, $v\neq 0$, $w\neq 0$

The clouds or streams may happen to be in advance or behind on the orbit of the earth 's revolution. In this case, the first of (13) gives the following at the observatory on the equator nearest to the streams or clouds.

$$X=\mu\left\{-\frac{2w}{r^3_0(V+w+R)}-\frac{v^2}{r^3_0(V+w+R)^2}\right\}$$

where $r_0=2c-a$, c : the distance between the center of the earth and the face of the streams, a : the radius of the earth.

The minus sign of X means the same sign with the inducing dipole field(gemagnetic field) at the surface of the earth. The X component of the induced field corresponds to the horizontal component of the geomagntic field and (6) shows the sudden increase of the horizontal component.

Case II. $\alpha=\frac{\alpha}{2}$, $u=0$, $v=0$, $w\neq 0$

The case was applied to the sudden increase of the horizontal component at the moment of SSC by S. chapman.

§ 2.3 The earth moves with its magnetic axis normal to the face of the solar corpuscular streams or clouds

In the cases, the X (Y) axis is artificial and on the equator, the horizontal component of the geomagnetic field corresponds to the Z component in this calculation.

At the center of the inducing dipole(earth)

$$Z=-\frac{2}{(2c)^3}\mu\frac{(u^2+v^2)(V+2w)+2w(w+R)(V+w+R)}{V(V+w+R)^2}$$

Case III. $\alpha=0$, $u=0$, $v\neq 0$, $w=0$,

From the above equation, $Z=-\frac{2\mu}{(2c)^3}-\frac{v^2}{(V+R)^2}$

If the medium is perfectly conductivc, $Z=-\frac{2}{(2c)^3}\mu$

Case IV. $\alpha=0$, $u=0$, $v=0$, $w\neq 0$.

$$Z=-\frac{2}{(2c)^3}\mu\frac{w}{w+R}$$

If the medium is perfectly conductive, $Z=-\frac{2}{(2c)^3}\mu$ In both cases, the field of the induced currents are identical with the mirror image dipoles and the horizontal compnent of the geomagnetic field at the surface of the earth is increased by the added field of the mirror image dipoles.

§ 2.4 Finite Current sheets

Next we consider the case of finite model, instead of infinite plane model. The theory of the currents induced in a finite thin sheet was worked out by J. H. Jeans (Proc. Lond. Math. Soc., Vol. xxxI pp. 151-169, 189) After him, the followings are descrided.

We start with a current function defined as that by Maxwell and a knowledge of at every point will give us a complete knowledge of the currents in the sheet. We next introduce Maxwell 's function P, defined for all points in space by the equation

$$P=\iint \frac{\Phi}{r} dx'dy'$$

where (dx′ dy′) is an element of the current sheet at which the current function is Φ and r is the distance from this element to the point at which we are evaluating P. P is the gravitational potential due to a distribution of density over the surface of the sheet, and therefore the magnetic potential $\Omega^{(i)}$ due to the currents in the sheet is given by $\Omega^{(i)}=-\frac{dP}{dz}$

Also, since the value the value of P is symmetrical as regards the two surfaces of the sheet, we have at the positive surface

$$\Omega_+{}^{(i)}=-\frac{dP}{dz}=2\pi\Phi$$

and at the negative surface

$$\Omega_-{}^{(i)}=-\frac{dP}{dz}=-2\pi\Phi$$

Let P' a quantity analogous to P, defined by

$$\Omega^{(e)}=-\frac{dP'}{dz}$$

where $\Omega^{(e)}$ is the scalar potential of the inducing field. P is, so for, defined except for an arbitrary function of x and y and this can be so chosen that P′ shall be the potential of the matter none of which is indefinitely near to the current sheet. For a value of P′ which satisfied the above mentioned equation is the potential of thin cylinders of matter starting from each pole of the extenal field, and going to infinite in the direction of the positive axis of Z, the line density of any cylinder being equal to the strength of the pole from which it started. Take as the additional arbitrary function of x and y the potential due to a series of cylinders coincing with such of the above cylinders as pass through the current - sheet, and of equal but opposite strength. Then P′ will satisfy the condition mentioned above.

We consider the currents induced by a sudden change in the external field, following the method adopted by Maxwell. Writing $R=(2\pi\sigma)^{-1}1$ we can obtained that at the positive surace of the sheet

$$\frac{d}{dt}\left[\frac{d^2}{dz}(P+P')\right]=R\frac{d^3P}{dz^3}$$

and at the negative surface

$$\frac{d}{dt}\left[\frac{d^2}{dz^2}(P+P')\right]=-R\frac{d^3p}{dz^3}$$

Integrating either equation with respect to the time throughout the indefinitely short period during which the change is supposed to occur.

$$\left(\frac{d^2}{dz^2}(P+P')\right)=\pm R\int_0^\tau\frac{d^3P}{dz^3}d\tau=0$$

If τ is supposed to vanish in the limit, since $\frac{d^3P}{dz^3}$ is finite.

Now $\left[\frac{d}{dz}(P+P')\right]$ or $-$ $[\Omega^{(i)}+\Omega^{(e)}]$ is the potential due to an unknown distribution on the current sheet and a known distribution in external space. Denoting this potential by W the electrical equations express that $\frac{dw}{dz}$ vanishes at both surfaces of the current sheet.

Also the poles of w are known in the space external to the current sheet, being identical with those of $[\Omega^{(e)}]$, and w vanishes at infinity. Hence sufficient is known about w to uniquely determine its value for all space. If the current sheet is perfectly conducting, the solution thus found will represent the currents at any time.

In dealing with a semi-infinite plane, let us take cylindrical coordinates ξ, r, ϑ Let the axis of ξ coincide with the free edge of the current sheet, the positive side of its surface coinciding with the sectorial plane $\vartheta=0$, and the negative side of it with $\vartheta=2\pi$. To find the value of the potential w we shall use the method of multiform potential introduced by Sommerfeld. ("Uber verzweigte potentiale im Raum", Proc. Lond. Math. Soc., Vol. XXVIII, p. 395) Let us construct a Riemann ' s space of two windings, such that the branch-line coincides with the edge of our current sheet, and let the position of a point in this space be determined by the cylindrical coordinates. Moreover, let that sheet of the space in which varies from 0 to 2 be identical with our original space. Then, the uniquness of the solution be verified and u, which satisfies the following special conditons, will at all points withtin this region be equal to the potential

(i) Its infinities must be the same as those of $[\Omega^{(e)}]$

(ii) It must satisfy $\Delta^2 u=0$ except at these infities.

(iii) It must vanish at infinity and $\frac{dw}{dz}$ must vanish over the boundaries $\vartheta=0$ and $\vartheta=2\pi$

It is seen that a value of ϑ which satisfies the specified conditions may be obtained as follows.

In the section of the Riemann ' s space in which ϑ varies from -2π to 0 (from 2π to 4π) place a magnetic system which shall be a positive image with respect to the plane of $\vartheta=0$ of the system whose potential is $[\Omega^{(e)}]$, and calculate the potential due to the combined systems in the manner appropriate to a Riemann ' s space.

The result will be rather useful to be expressed by the Cartesian coordinates. Let x, y, z, be the coordinates of any point in ordinary space, the axis of reference being so chosen that the current sheet is that part of the plane of xy for which x is positive. This is identical with the first region of the Riemann's space in which ϑ varies from 0 to 2π. When the point is supposed to lie in the second region, for which $2\pi<\vartheta<4\pi$, its coordinates will be denoted by x'; y'; z';

Here $x=x'$, $y=y'$, $z=z'$, if the sign(=)is regard as rigard as simply asserting the algebraical equality of the nagnitudes which it separates.

Any system of poles in ordinasy space can be denoted by f (x, y, z) and any system in the second region of the Riemann's space by f (x', y', z')

In dealing with our Riemann's space of two windings the positive image of $f\ (x, y, z)$ in the current sheet $(\vartheta=0)$ will be $f\ (x', y', -z')$.

The Newtonian potential of the system $f\ (x, y, z)$ will be denoted by $\Pi\ \{f(x, y, z)\}$ and the Riemann's potential by $P\ \{f\ (x, y, z)\}$. Then, the following equation holds for any system, viz,

$$\Pi\ \{f\ (x, y, z)\}=P\ \{f(x, y, z)\}+P\{f\ (x', y', z')\}$$

Identifying $f\ (x, y, z)$ with the magnetic systcm whose potential $[\Omega^{(e)}]$, we have

$$(\text{i})\quad -[\Omega^{(e)}]=\Pi\{f\ (x, y, z)\}=P\{f\ (x', y', z')\}+P\{f(x', y', z')\}$$

$$(\text{ii})\quad -[\Omega^{(e)}+\Omega^{(i)}]=\{f\ (x, y, z)\}+P\{f(x', y', -z')\}$$

$$(\text{iii})\quad -[\Omega^{(i)}]=P\{f\ (x', y', -z')\}-P\{f\ (x', y', z')\}$$

$$(\text{iv})\quad \Phi=1/2\pi[P\{f\ (x', y', z')\}-P\{f\ (x', y', -z')\}]$$

The last equation having reference only to points for which $\vartheta=0$. we have thus obtained the currents induced by a sudden change in the external field. After Sommerfeld, if there is a pole of strength m at ξ', r$'$, ϑ', the potentential at ξ, r, ϑ is

$$\Omega^{(i)}=\frac{1}{\pi\sqrt{rr'}}\ \{\frac{1}{\sqrt{\sigma^2-\tau^{12}}}\tan^{-1}\sqrt{\frac{\sigma+\tau'}{\sigma-\tau'}}-\frac{1}{\sqrt{\sigma^2-\tau^2}}\tan^{-1}\sqrt{\frac{\sigma-\tau}{\sigma+\tau}}\}$$

The total potential can be obtained by summation over all poles. Where

$$\tau=\cos\frac{\vartheta-\vartheta'}{2} \qquad \tau'=\cos\frac{\vartheta+\vartheta'}{2}$$

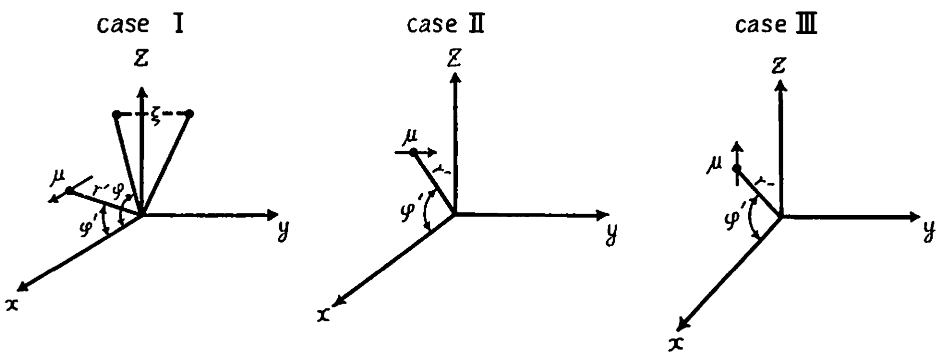
$$\sigma=\cos\frac{i\alpha}{2} \qquad \cos i\alpha=\frac{(\xi-\xi')^2+r^2+r'^2}{2rr'}$$

and $\tan^{-1}$ is to denote that particular value which lies between 0 and 2π, the radical being always taken positively.

§ 2.5 The dpiole of monent μ is the external field

Three cases that the dipole is parallel to the X, Y, and Z axes, respectively, are sufficient to be considered.

Case I : The dipole axis is parallel to X axis
Case II : 〃 Y axis
Case III : 〃 Z axis



In each case, the component along the axis of the inducing dipole at the center of it is expressed as follows;

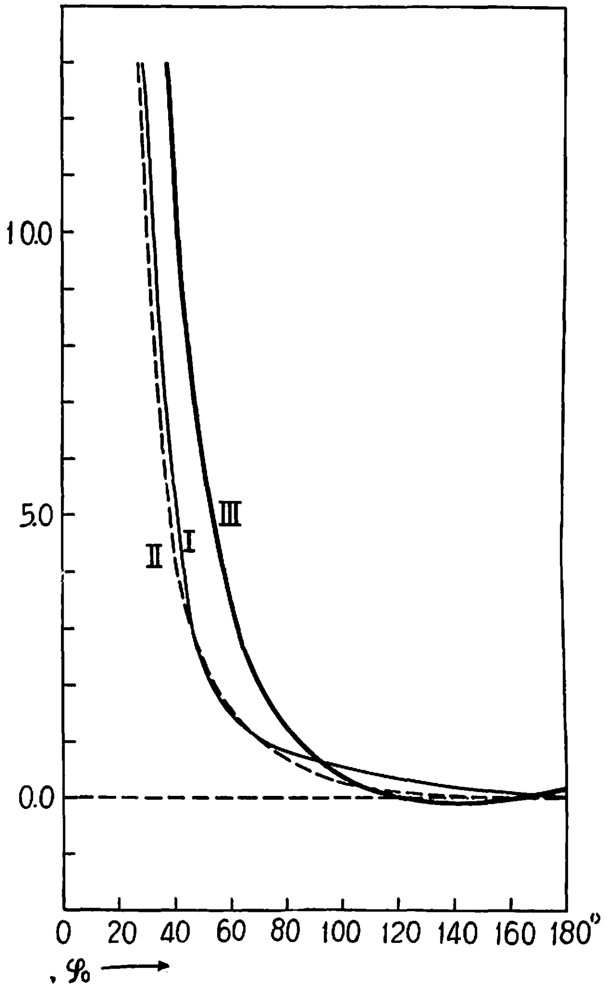
Case I $$-\frac{\partial\Omega^{(i)}}{\partial x}=-\frac{\mu}{4\pi r^3_0}\{(\frac{1}{2}\cos\vartheta_0\cot\vartheta_0-\frac{3}{4}\cos^2\vartheta_0-\frac{1}{8})+\frac{\pi-\vartheta_0}{2\sin^3\vartheta_0}\}$$

Case II $$-\frac{\partial\Omega^{(i)}}{\partial y}=-\frac{\mu}{4\pi r^3_0}\{\frac{1}{2}\frac{\cot\vartheta_0}{\cos\vartheta_0}-\frac{3}{8}+\frac{\pi-\vartheta_0}{2\sin^3\vartheta_0}\}$$

Case III $$-\frac{\partial\Omega^{(i)}}{\partial z}=-\frac{\mu}{4\pi r^3_0}\{\frac{3}{2}\cos\vartheta_0+\frac{3}{4}\cos^2\vartheta_0+\cos\vartheta_0.\cos^2\vartheta-\frac{1}{8}+\frac{\pi-\mu}{\sin^3\vartheta_0}\}$$

where the coordinates pf the dipole o, r_0, ϑ_0

Fig. 4. The induced field components along the dipole axis at the dipole center, $\times\ (-\frac{\mu}{4\pi r^3_0})$



Chapter III Intrusion of Small Clouds into the Outer Atmosphere

§ 3.1 Solar Wind Pressure

Assume that, the small solar clouds intrude into the outer atmosphehere at $R=R_1$, $\theta=\theta_1$, The gas, excluding the geomagnetic lines of force, is diamagneticw ith a dipole moment μ essentially equal to its volume multiplied by the mean field in itsvicinity. Thus

$$\mu=B_0\ (b/R_1)^3\ [1+3\cos^2\theta_1]^{\frac{1}{2}}$$

From the geometry of the geomagnetic dipole it is readily shown that μ makes an angle α with R, where

$$\tan\alpha=\frac{1}{2}\tan\theta_1$$

It then follows from elementary geometrical considerations that at earththe field of μ is essentially uniform and makes an angle β with thegeomagnetic axis where

$$\beta=\theta_1-\arccos\ [4\cos\theta_1/(1+15\cos^2\theta_1)^{\frac{1}{2}}$$

The maximum vualue of β is about 37°, which occurs for $\theta_1=63°$

Thus we have a disturbance field which is always nearly parallel to the geomangetic axis no matter where the intrusive gas body is located; the nonuniformity over earth is only $[1+0(b/R_1)]$

What is particularly interesting about these results is that no matter where, or how unevenly, the solar wind may distort the outer geomagnetic field, we will observe on the earth a geomagnetic change which is nearly uniform in magnitude around the plaent and which is nearly parallel to the geomagnetic axis.

In this way the simultaneous worldwide increase of the horizontal component of the geomagnetic field follows automatically.

§ 3.2 Solar Wind Tension

It is obvious that the solar wind tends to carry away the lines of force of the outer geomagnetic field, just as a high wind blows smoke away from a chimney. In this connection the wind may contribute a geomagnetic effect which is opposite in sign to the wind pressure on the sunward side.

Not only may the solar wind blow the outer field away, but it may also introduce enough gas into the geomagnetic field that the centrifugal force of the rotation of earth will pull away the outer field. For beyond $R=R_2$, where

$$W^2{}_E R_2=GM/R^2{}_Z$$

the centrifugal force in the equatorial plane dominates over the terrestrial gravitational attraction. The angular velocity of the earth is $W_E=0.727\times10^{-4}$/second its mass is $M=6\times10^{27}$g. Hence $R_2=4.2\times{}^{-}10^4$km$=6.6$b.

Any gas into the geomagnetic field beyond $R=R_2$ will tend to spring the field outward ; the field beneath R_2 is thereby allowed to expand outward, and a decrease of the horizontal componet of the geomagnetic field will be observed at the surface of the earth.

If the outward pulling stretches the geomagnetic lines of force so that they point nearly radially outward at $R=R_2$ over a region of about 30° on either side of the equator, then the geomagnetic field may be represented in an approximate way be the simple potential

$$\psi\ (R_1\theta)=B_0b^3\cos\theta\ [1/R^2-R/R^3{}_2]$$

in $R<R_2$. It follows immediately that the geomagnetic field on the equator at the surface of the earth is reduced from its usual value B_0 to $B_0[1-(b/R_2{}^3)]$; with $B_0=0.35$ gauss.

If the field is drawn outward at $R=R_2$ over only a small azimuthal sector Φ_0

rather than all the way around, then the field in $R<R_2$ is basically of the form $\Phi(R,\theta,\Phi,)=B_0(b^3/R^3)\cos\theta\,\{1-\frac{\Phi^3{}_0R^3}{[R^2+R^2{}_2(1+\Phi_0)^2-2R_2R(1+\Phi_0)\sin\theta\sin\Phi]}$ the geomagnetic dipole plus the field of an image dipole of momeni-Φ_0B_0 b^3 outsideR_2 at $R_2\times(1+\Phi_9)$, Since $R_2\gg b_1$, we have that the geomagnetic field is altered by the essentially uniform field $-B_0$ $(b/R^3{}_2)$ $[\Phi_0/(1+\Phi_0)^3]$; the horizontal intensity at the equator of the earth is decreased uniformly around the earth.

Table 10 The Primary Agency for SSC and S. I.

			Onset	Main andlast phases
Typical SSC storm			impact of Solar stream or clouds	Ring curreut
S. I.	S. I. (+C)		small clouds intrusion intothe $R=R_1$ region	weak ring current
			solar streams or clouds by the side of the earth	weak ring current
	S. I. (−C)		small clouds intrusion in the $R=R_2$ region	weak ring current
	S. I. (+P), S. I. (−P) S. I. (+−O), S. I. (−O)		....	....
	S. I. (+−i)	together withSSC. near the main phase.	impact of solar streams or clouds	Ring current
		eud of Sono disturban ces	solar streams or clouds by the side of the tarth	Pluching up the geomagnatie field by solar streams or clouds
	S. I. (−+i)	uncertain		

If the solar wind blows away, or othrwise pulls out, the geomagnetic lines of force beyond $R=R_3$, we have a decrease of the horizontal intensity at the surface of the earth

$$\Delta B\simeq {}^2/_3\ B_0\ (b/R_1)^3\ [\cot^2\theta_3-2+\log\ (2R_3/R_1\ \sin\ \theta)]^{-1}.$$

Chapter IV Conclusions

We examinined the morphology of S.I. in Part I, but some types of them occur too rare to be examined exauhstively. Then, the discussion of the mechanism of them will be insignificant. The discussions in the previous chapters may be briefly tabulated, comparing to SSC. The types of S. I.. excluded in the discussions, are as follows ; S. I. (+*P*), S. I.(=*P*), S.I. (+−0), S. I.(−+0)' and S. I.(−+i).

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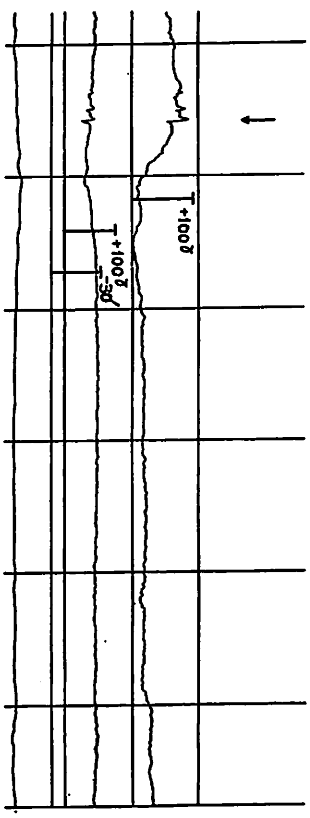

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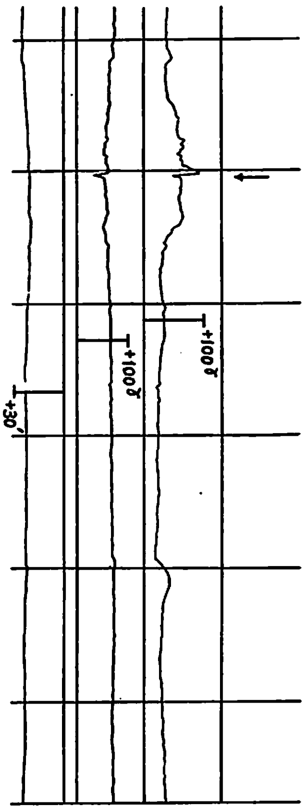

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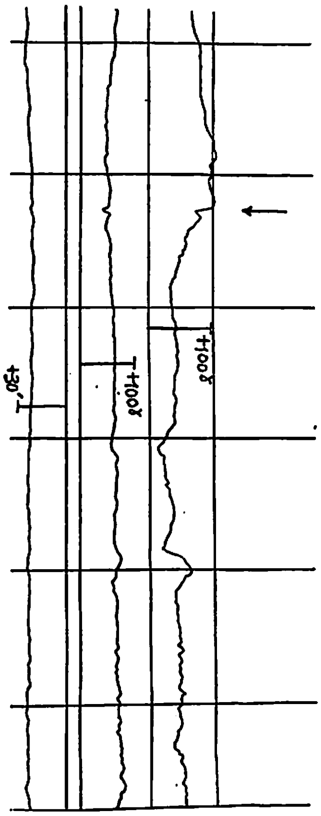

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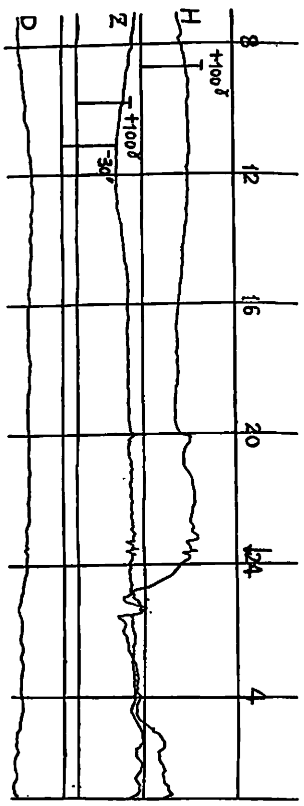

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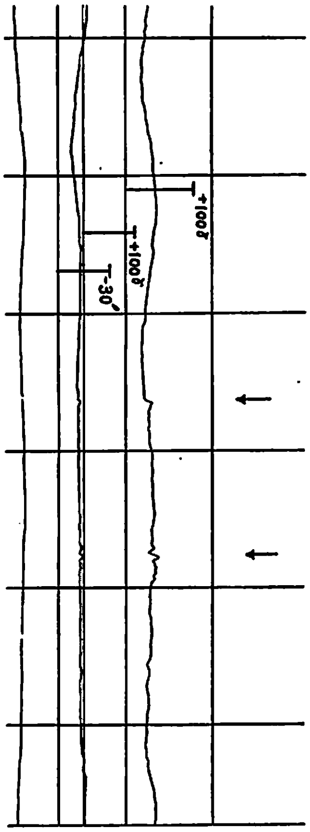

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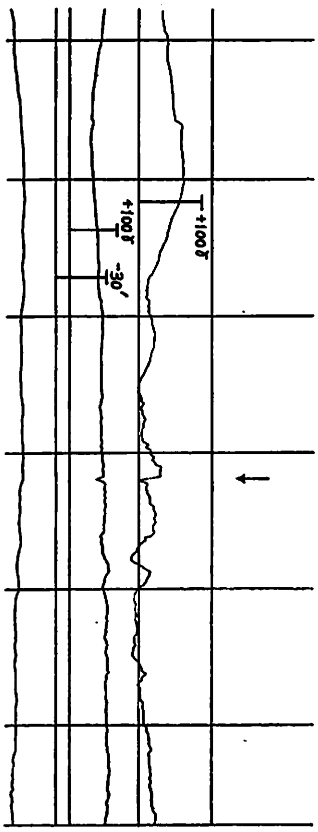

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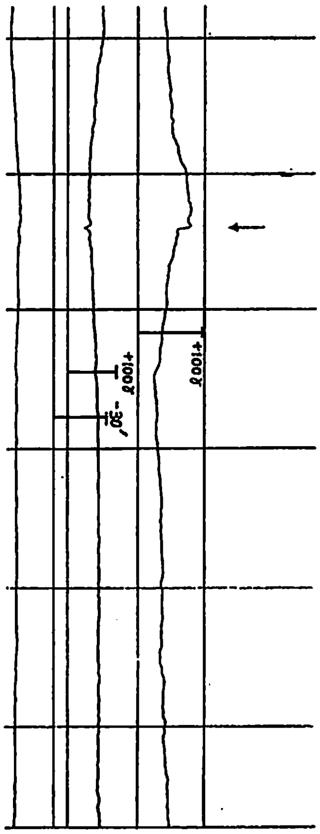

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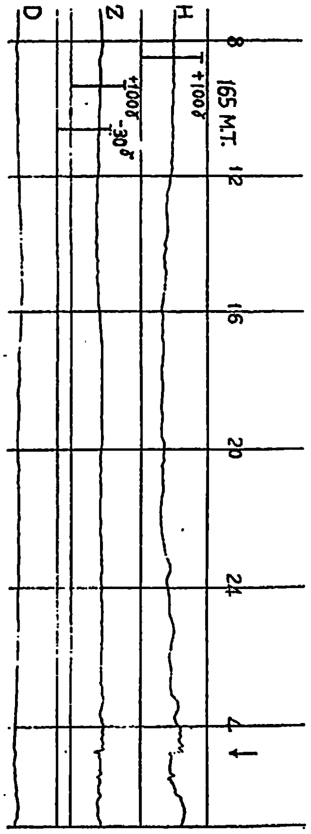

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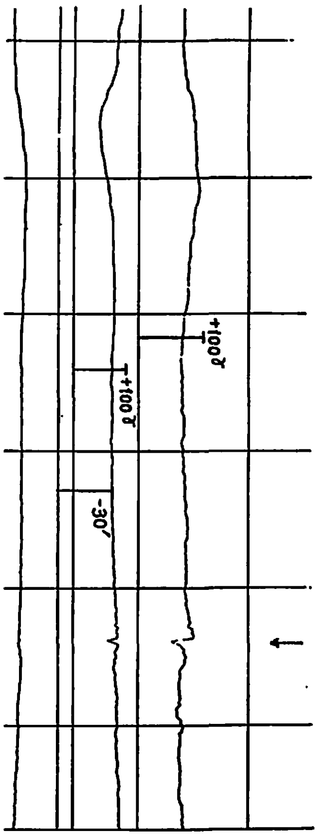

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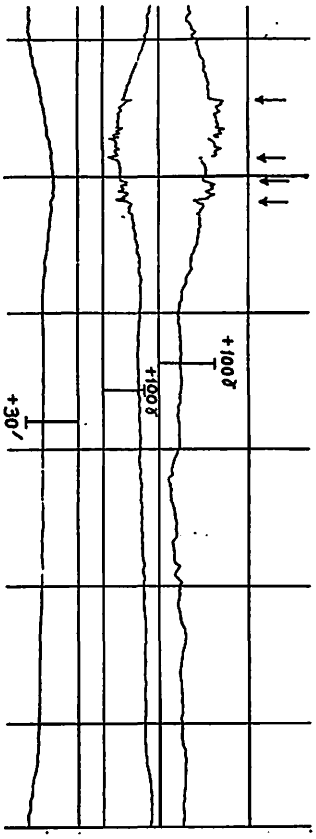

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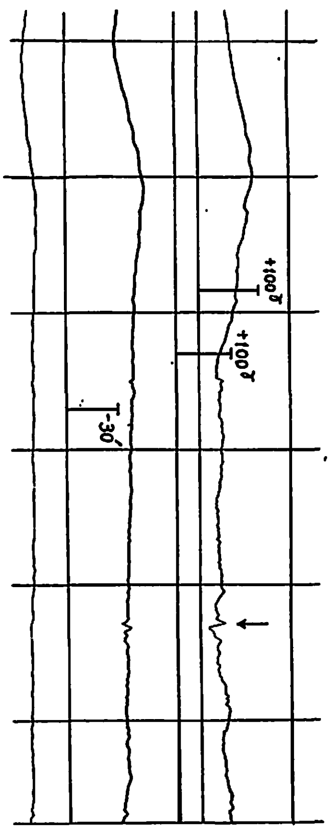

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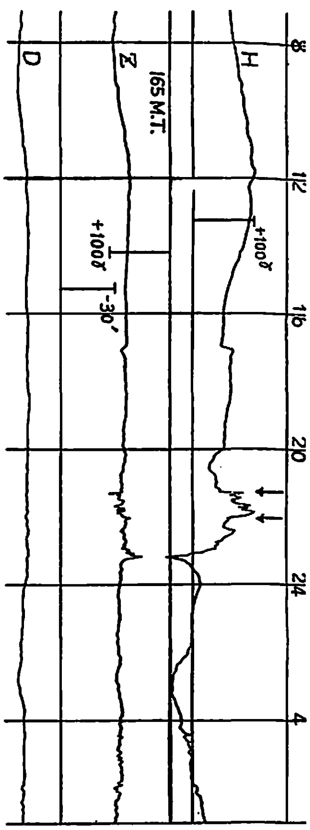

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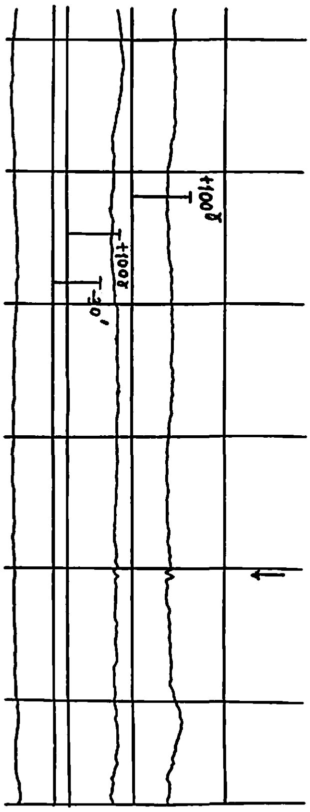

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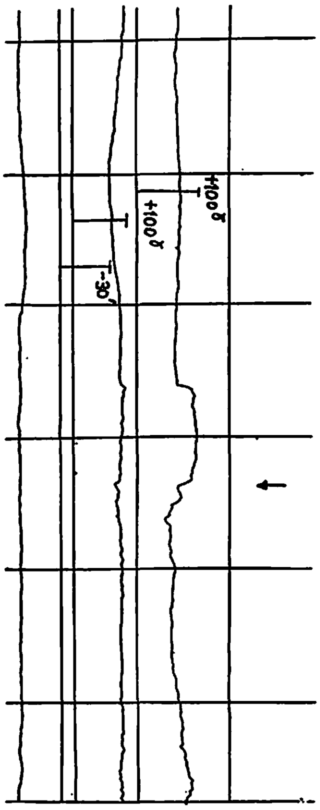

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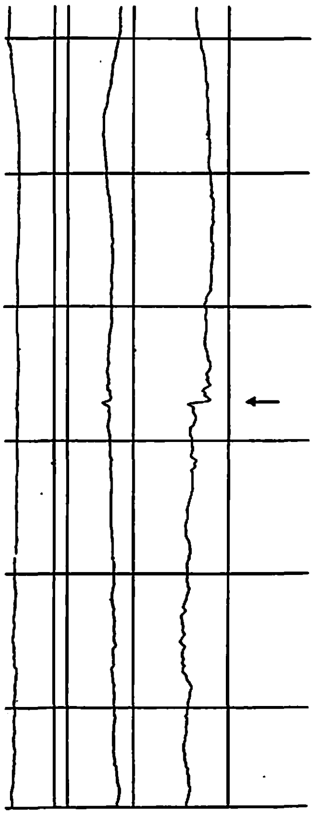

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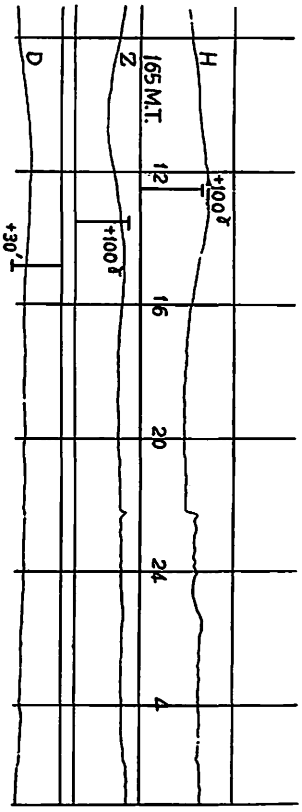

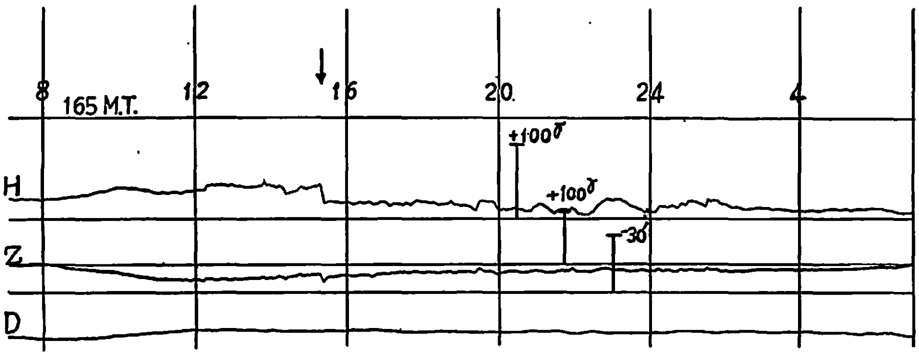
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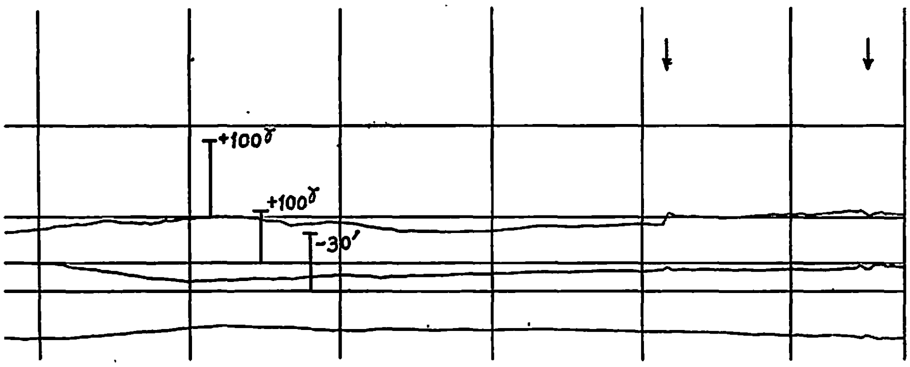
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