Polarization Characteristics of Geomagnetic Pi 2 Micropulsations

著者	Sakurai Tohru
雑誌名	Science reports of the Tohoku University. Ser. 5, Geophysics
巻	20
号	3
ページ	107-118
発行年	1970-12
URL	http://hdl.handle.net/10097/44703

The Science Reports of the Tôhoku University, Ser. 5, Geophysics, Vol. 20, No. 3, 1970

Polarization Characteristics of Geomagnetic Pi 2 Micropulsations

TOHRU SAKURAI

Geophysical Institute, Tôhoku University Sendai, Japan
(Received December 1, 1970)

Abstract: From the analysis of 108 events, two main polarization rules of Pi 2 are derived. First, on the both statistical and individual bases, the Pi 2 polarization is found to be clockwise at the higher latitude of auroral zone, whereas it is counterclockwise at subauroral-zone stations. At typical auroral-zone station, such as College, however, the Pi 2 polarization is counterclockwise in the pre-midnight hours and clockwise in the post-midnight hours. Second, the rotational sense of the Pi 2 at auroral-zone stations in the northern hemisphere shows a clear reversal to that at the same latitudes on the opposite hemisphere. These characteristics suggest that the Pi 2 polarization may be due to a field-line motion associated with a torsional oscillation of the field-lines passing through the vicinity of the inner boundary of the plasma sheet caused by a plasma instability there.

1. Introduction

Many contradicting observational results have been reported on the polarization characteristics of geomagnetic Pi 2 pulsations. The results obtained at a low-latitude station, Onagawa, (Kato, *et al.*, 1956) indicate that Pi 2's are polarized in a counterclockwise sense in local pre-midnight hours and in a clockwise sense in post-midnight hours. On the other hand, the polarization at subauroral zones on the both hemispheres shows the opposite sense, being predominantly counterclockwise at Canadian stations (Rostoker, 1967) and clockwise at New Zealand stations (Christoffel and Linford, 1966), regardless of the local time. A question will arise from the results mentioned above; how can the relation between the observational location and the Pi 2 polarization be explained? Rostoker (1967) pointed out that the presence of the occasionally reversal polarization in each hemisphere could not be explained only by the Alfvén mode, and suggested the ionospheric screening effect on the propagation.

Table 1. Studied data during this investigation.

Station	Geomagnetic Latitude	Magnetic Data		Data Epoch
		Ordinary Magnetogram	Rapid-run Magnetogram	
Point Barrow	68.6°	○	○	Jan.～July, 1964
College	64.7°	○	○	Jan.～July, 1964
Sitka	60.0°	○	○	Jan.～July, 1964
Canadian Stations	54.2°～58.8°			Summer in 1965
Onagawa	28.3°	○	○	December, 1966
New Zealand Stations	～−45°			July, 1964
Macquarie Island	−61.0°	○	○	Jan.～July, 1964

Table 2. List of the Pi 2 used for the polarization study.

Date	U.T.	L.T.	Rotation Sense	
			College	Point Barrow
Jan. 5, 1964	13 43	03 43	C.W	×
6	09 00	23 00	C.W	×
	09 25	23 25	△	×
7	06 47	20 47	C.C.W	C.W (linear)
	06 22	22 22	C.C.W	×
	08 29	22 29	C.C.W	×
	07 38	21 38	C.C.W	C.W
16	07 18	21 18	C.C.W	—
	07 37	21 37	C.C.W	—
18	07 50	21 50	C.W	—
	13 51	03 51	C.W	—
Feb. 17, 1964	07 00	21 00	C.C.W	C.W
22	06 55	20 55	C.C.W	×
	07 10	21 10	C.C.W	△
24	08 25	22 25	C.C.W	×
Mar. 18, 1964	09 30	23 30	C.C.W	△
	10 30	00 30	C.W	×
	10 45	00 45	C.C.W	×
	11 01	01 01	C.C.W	△
	11 10	01 10	C.C.W	C.W
19	06 45	20 45	C.C.W	×
	13 13	03 13	C.W	×
	13 32	03 32	C.W	C.W
	13 55	03 55	C.C.W	×
31	06 50	20 50	C.C.W	C.W
	10 50	00 50	△	×
	11 07	01 07	C.C.W	△
	11 32	01 32	C.W	C.W
	13 30	03 30	C.C.W	×
Apr. 12, 1964	05 47	19 47	C.C.W	×
	11 07	01 07	C.C.W	△
	11 29	01 29	C.C.W	△
13	08 57	22 57	C.C.W	C.W
18	07 48	21 48	C.C.W	C.W
19	08 33	22 33	C.W	C.W
22	09 25	23 25	C.C.W	△
	09 41	23 41	C.C.W	C.W
30	09 12	23 12	C.C.W	C.W
	09 41	23 41	C.C.W	△
May 5, 1964	03 23	17 23	C.C.W	△
	04 57	18 57	C.W	×
	09 07	23 07	C.C.W	C.W
19	08 30	22 30	C.C.W	C.W
	08 59	22 59	C.W	×
20	08 50	22 50	C.W	△
	09 18	23 18	C.W	C.W
21	09 40	23 40	C.C.W	C.W
	13 29	03 29	C.W	C.W
22	12 48	02 48	C.C.W	△
26	10 28	00 28	C.W	C.W
	10 50	00 50	C.W	△
	09 39	23 39	C.W	△
Jun. 1, 1964	08 59	22 59	C.W	C.W
3	07 52	21 52	C.C.W	△
	09 47	23 47	C.W	C.W
	07 29	21 29	C.C.W	△
15	11 06	01 06	C.W	△

Table 2. (Continued)

Date	U.T.	L.T.	Rotation Sense	
			College	Point Barrow
	11 20	01 20	C.W	△
	11 35	01 35	C.W	△
	11 48	01 48	C.W	△
27	11 30	01 30	C.C.W	△
	11 49	01 49	C.W	—
Jul. 5, 1964	11 58	01 58	C.C.W	—
21	11 20	01 20	C.W	—
	11 35	01 35	△	—
23	13 25	03 25	C.W	—
24	09 01	23 01	C.C.W	—
	09 37	23 37	C.C.W	—

C.W: clockwise　　C.C.W: counterclockwise
△: uncertain　　×: impossible to read the microfilm

However, the ionospheric screening effect seems to be insufficient to give a characteristic reversal of the polarization sense at about the local midnight at low latitudes, if Pi 2 propagates from the auroral latitude to the observational station. As for Pi 2's especially at the auroral zone, the characteristics of the polarization have not yet been cleared.

In the present paper, the general characteristics of the Pi 2 polarization are described on the basis of the both statistical and individual analyses of the data obtained at the auroral zone and an answer is given to the question mentioned above in the case of the auroral-zone Pi 2's. In the first place, the spatial distribution of the Pi 2 polarization at the auroral-zone stations, Point Barrow and College, is studied in Section 2. Section 3 describes the characteristics of the polarization at the conjugate stations, College and Macquarie Island, being connected by the outermost part of the closed field-lines in the night side magnetosphere. A possible mechanism for characterizing the polarization of the higher latitude Pi 2 is proposed in Section 4.

The Pi 2 considered in the present paper is defined as the pulsation of a damped type waveform, with periods ranging from 40 sec to 200 sec, and associating essentially with magnetic substorms. The stations and the epoch referred to in the paper are listed in Table 1. The individual 108 Pi 2 events given in Table 2 are analyzed statistically on the basis of the data from Point Barrow and College, from January to July in 1964.

2. Spatial distribution of Pi 2 polarization

Fairly regular Pi 2's associated with weak substorms are analyzed using the rapid-run magnetograms obtained at Point Barrow and College. A horizontal disturbance hodgraph is drawn by reading the data points, at every 15 sec interval, of the H- and D-components of enlarged rapid-run magnetograms. The results are displayed in Figure 1 together with those at Canadian and New Zealand stations, which have been reported by Rostoker (1967), and Christoffel and Linford (1966), respectively.

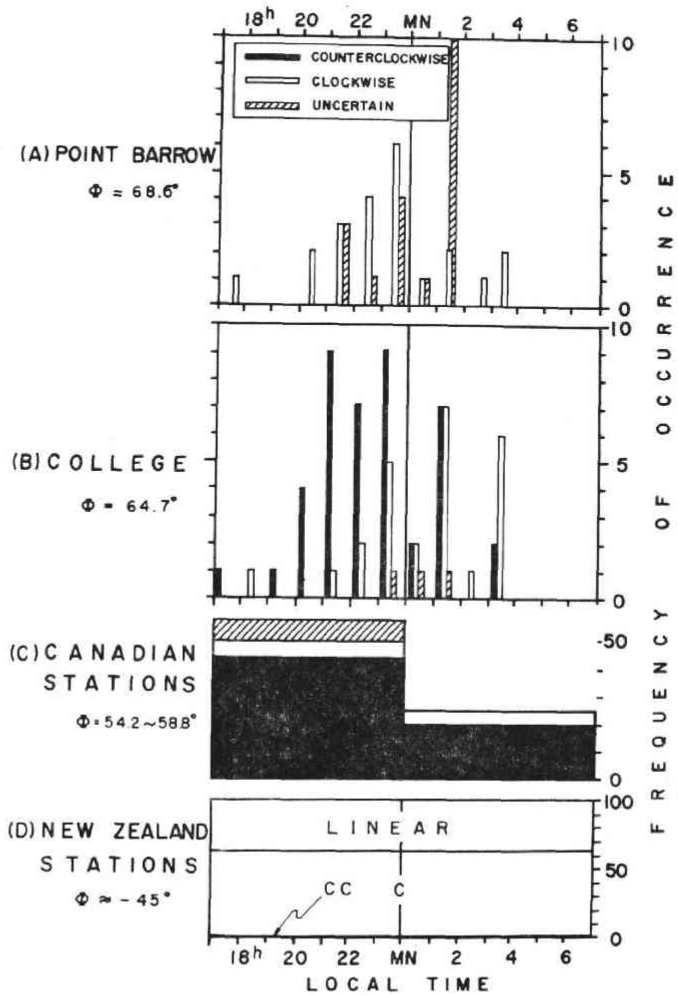

Fig. 1. Diurnal distribution in the polarization of the Pi 2 horizontal disturbance hodgraph. (C) and (D) are illustrated on the basis of the data by Rostoker (1967) and Christoffel and Linford (1966), respectively.

It can be stated from the figure that the polarization is clockwise at Point Barrow, whereas it is counterclockwise at Canadian stations and clockwise at New Zealand stations. At College, however, the polarization is counterclockwise in the pre-midnight hours, while it is clockiwse in the post-midnight hours. Although the number of the data available is limited, analyses of simultaneous Pi 2's recorded at Point Barrow, College, and Sitka indicate that the individual events follow the general rule as shown in Figure 2.

It is remarkable that the Pi 2 polarization at auroral and subauroral zones has the spatial characteristics very similar to those in the case of the Pc 5 polarization (Kaneda, Kokubun, Oguti and Nagata, 1964; Kato and Utsumi, 1964).

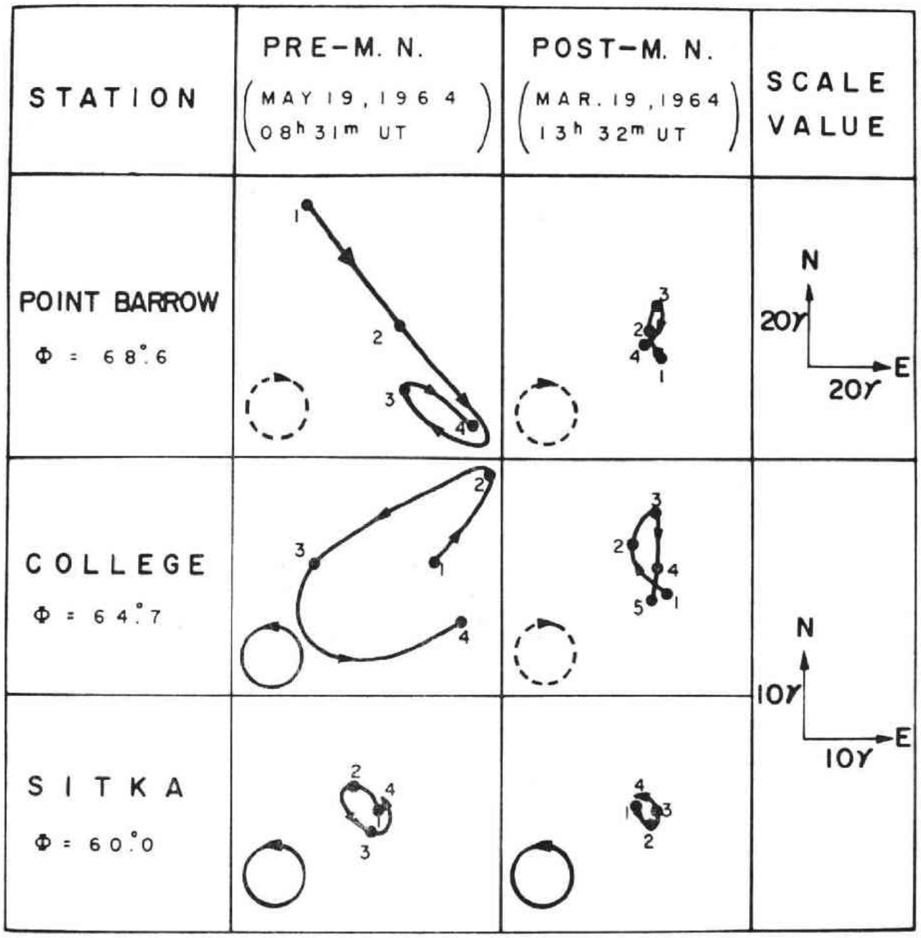

Fig. 2. Simultaneous polarization of the Pi 2 at Point Barrow, College and Sitka indicates that the statistical rule shown in Figure 1 applies also to the individual event.

3. Three-dimensional characteristics of the Pi 2 polarization at a pair of conjugate stations

Statistical study of the Pi 2 polarization at subauroral-zone stations (New Zealand stations) in the southern hemisphere indicates that the polarization sense is opposite to that at the conjugate stations (Canadian stations) in the northern hemisphere. A typical example of the waveform of the simultaneous Pi 2's at College and its conjugate station, Macquaire Island, is shown in Figure 3. The reverse sense of the three-dimensional polarization is evident in both the horizontal and meridian planes as indicated in Figure 4. It is notable in the figure that the hodgraphic plane is transverse to the field line at both sites. This fact strongly suggests that a torsional oscillation of the field-line is responsible for the main cause of the Pi 2.

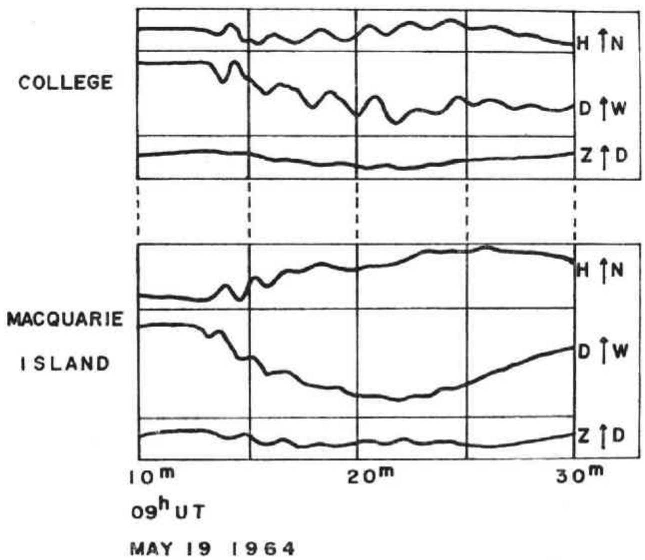

Fig. 3. An example of the simultaneous waveform of Pi 2 at College and its conjugate station, Macquarie Island.

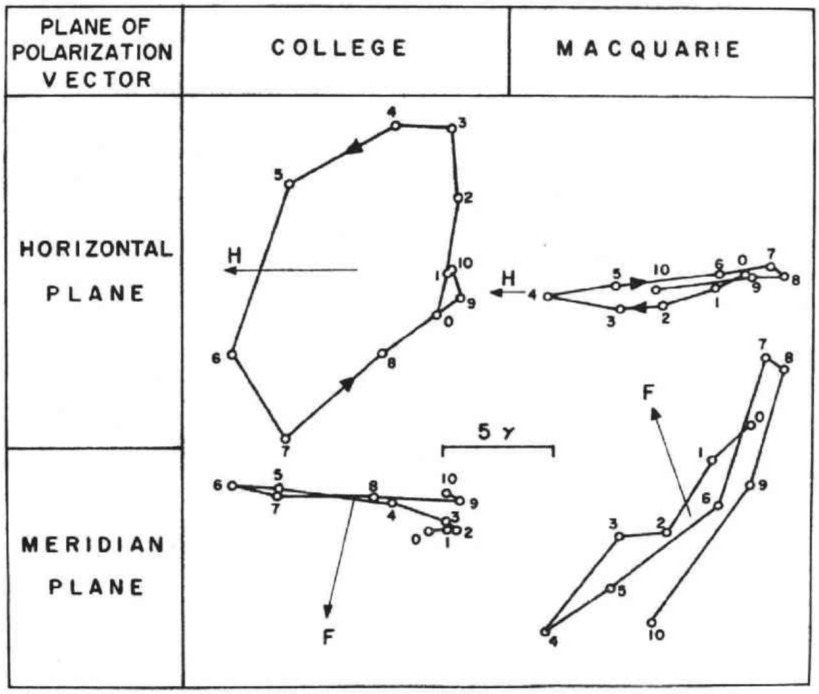

Fig. 4. Example of the locus of rotating polarization vectors for Pi 2 at College and its conjugate station, Macquarie Island.

4. A possible mechanism for the Pi 2 polarization rule

According to the statistical results given in the preceding sections, the generalized rule of the Pi 2 polarization on the earth's surface is schematically shown in Table 3. Assuming that Pi 2 observed at each of the observatories originates from the point on the magnetospheric equatorial plane intersected by the magnetic field-line through the observatory, polarizations observed on the earth's surface are projected correspondingly onto the Fairfield map (Fairfield, 1968) as shown in Figure 5. These projected

Table 3. Distribution of the polarization of Pi 2 on the earth's surface.

Station	Geomagnetic Latitude (Φ)	Pre-Midnight	Post-Midnight
Point Barrow	68.6°	◌	◌
College	64.7°	◯	◌
Canadian Stations	54.2°~58.8°	◯	◯
New Zealand Station	~−45°	◌	◌
Macquarie Island	−61.0°	◌	◯

◯ : counterclockwise sense of the Pi 2 polarization

◌ : clockwise sense of the Pi 2 polarization

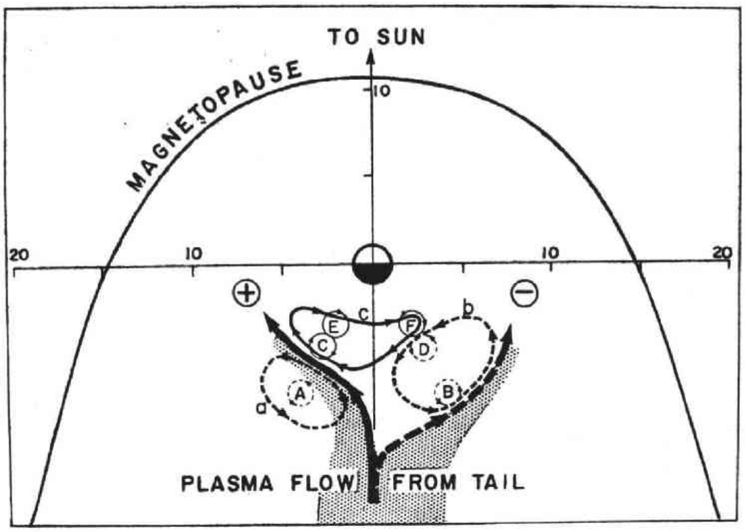

Fig. 5. Flow vortices expressed by a~c are equivalent to the flow surface of the bundle of the field-lines, whose motions with a small size indicate the observed Pi 2 polarization projected onto Fairfield map indicated by A~F. A pair of the small circles, A and B, C and D, E and F, indicates the Pi 2 polarization in the pre- and post-midnight hours at each stations on the ground listed in Table 3.

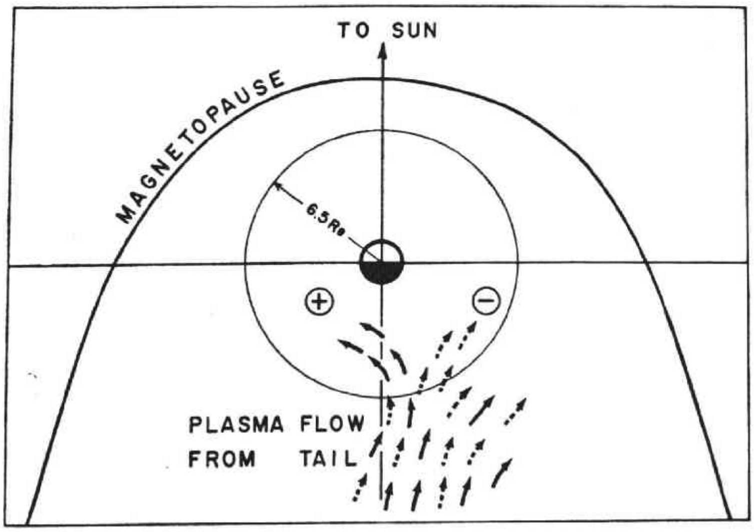

Fig. 6. A schematic representation of the plasma-flow from the tail (the thick solid and the dashed curves) shown by Freeman and Maguire (1967). The plasma is deflected eastward and westward by the curvature and gradient drifts near at the plasma sheet inner boundary.

polarization could be explained as follows. Freeman and Maguire (1967), and Vasyliunas (1968) reported an abrupt inward flow of the plasma from the magnetotail preceding a magnetic substorm. A schematic example of the inward plasma-flow from the magnetotail is shown by Freeman and Maguire (1967) in Figure 6. Since the plasma-flow approaching towards the earth is suffered by the gradient and the curvature drifts, it is deflected to the both morning and evening sides and forms the inner boundary of the plasma sheet (Alfvén layer), where the flow velocity must be highest. It is regarded that the substorm is caused by a plasma instability on the Alfvén layer near the equatorial plane accompanied by a particle precipitation along the magnetic field-lines onto the auroral-zone ionosphere. This instability may set up a sudden enhancement of the above-stated deflected plasma-flow which drags the magnetic field-lines along the Alfvén layer. The dragged field-lines must then be returned to the initial position passing along the earth- and tail-sides of the Alfvén layer. Many field-line motions with a small size are equivalent to a large vortex flowing along the surface of the bundle of the field-lines, since the plasma-flow following the field-line motions cancels to each other inside the bundle. Such the vortices might be like the solid and the dashed circles a,b, and c in Figure 5.

The above-mentioned movement of the field-lines near the equatorial plane must be propagated to the earth along the magnetic field-lines as a hydromagnetic torsional waves which can be observed on the ground as Pi 2. Since the polarization of the torsional waves is to coincide with the polarization of the field-line motions, the observed Pi 2 polarization expressed by A$\sim$F can be interpreted by the polarization expected from the flow vortices, a,b, and c.

5. Discussion

The polarization characteristics of the Pi 2's at the auroral latitudes are studied on the basis of the analysis of the 108 events of Pi 2. The polarization of a Pi 2 is characterized by the reversal of the rotational sense at about local midnight, being counterclockwise in pre-midnight hours, and clockwise in post-midnight hours. At the subauroral latitudes in the northern hemisphere, however, the majority of the Pi 2's are polarized in counterclockwise sense with occasional exceptions. As for these exceptional polarizations in clockwise sense, Rostoker (1967) has pointed out that the ionospheric screening effect may influence the direction of the polarization of a geomagnetic micropulsation. However, it is a question if the marked reversal in the polarization at the auroral latitudes at about the local midnight can be expected as the result of the phase change due to the ionospheric screening effect on geomagnetic micropulsations passing through the ionosphere. According to the study by Kato and Sato (1965) of the effect of the anisotropic conductivity on the polarization of the hydromagnetic oscillations having periods ranging from about 120 sec to 600 sec, the rotational sense of the hydromagnetic waves can not be affected by the anisotropy of the ionosphere and the local time dependence of the rotational sense of Pc 5 pulsations is not explained by this effect. Kato and Tamao (1965) presented the mechanism that the observed spatial distribution of the Pc 5 polarization is attributed to a a velocity shear on the magnetopause due to the interaction between the solar wind and the boundary of the magnetosphere. If the solar wind is replaced by the plasma flow from the tail, the polarization mechanism for Pc 5 as proposed by Kato and Tamao can be held on that for Pi 2 as presented in the preceding section.

In the analysis of a limited number of data (Saito, 1969), quite a same pattern is seen in the dynamic spectra of the Pi 2 at Great Whale River and at its conjugate station, Byrd. The amplitude of Pi 2's associated with weak substorms is found to be maximum at auroral latitude (Saito and Sakurai, 1970). When the amplitude of Pi 2's observed on the earth's surface is projected onto the Fairfield map (Fairfield, 1968), the maximum Pi 2 is found to be at the geocentric equatorial distance $R \approx 9.5$ when $Kp=1$. The relation between the location of the maximum Pi 2 on the Fairfield map and the magnetic activity-Kp is similar to the relation between the equatorial distance of the inner boundary of the plasma sheet and the magnetic activity-Kp. Thus, the Kp-dependence of the maximum Pi 2 location clearly differs from the relation between the equatorial distance of the plasmapause and the magnetic activity-Kp as shown in Figure 9 of Saito and Sakurai (1970).

In view of the polarization rules derived in this paper and the relation between the maximum Pi 2 location and Kp, a Pi 2 is convinced to be generated by the torsional oscillation of field lines passing through a region near the Alfvén layer due to a hydromagnetic instability caused by an abrupt plasma flow from the tail magnetosphere at the onset of a substorm.

MacPherron, *et al.* (1968) have reported that ATS-1 magnetometer indicates magnetic oscillations with periods similar to those of Pi 2's during the substorm. The

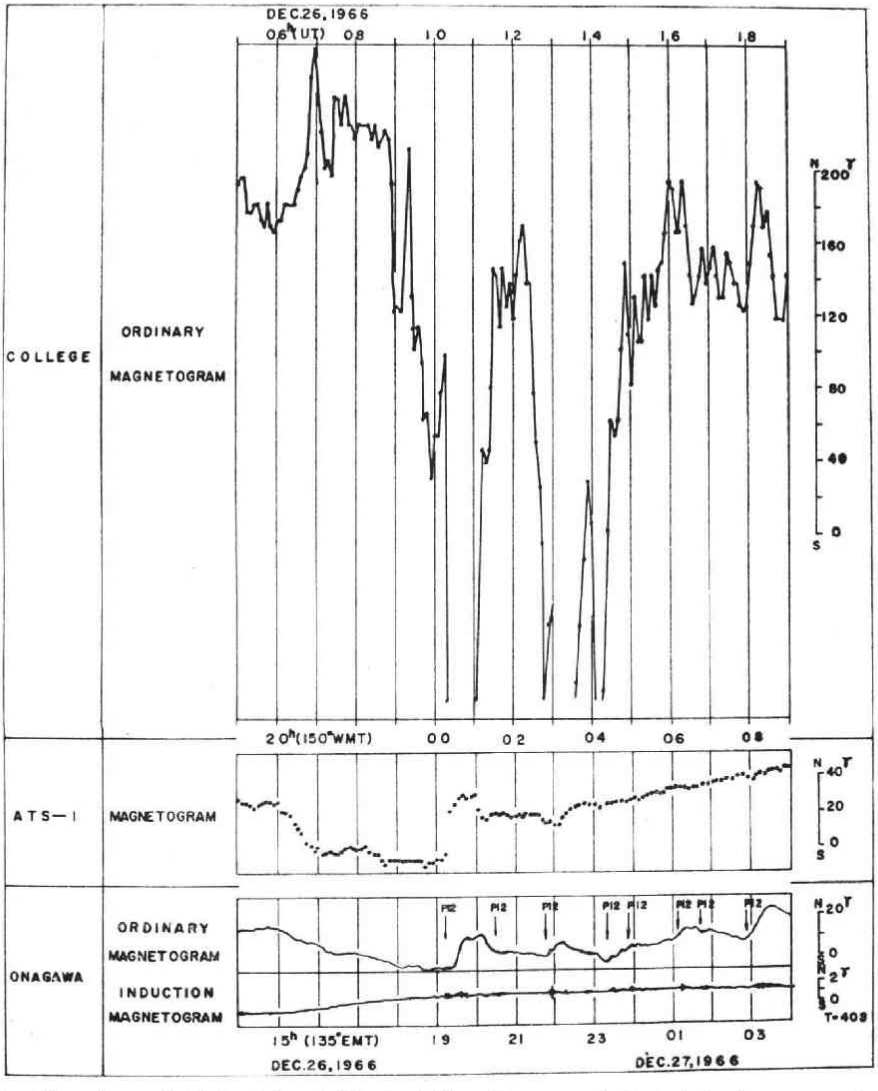

Fig. 7. The observed Pi 2 at low latitude station, Onagawa, indicated by the arrows in the lowest diagram ouccurs to be closely related to the sharp variations on the magnetograms obtained both at the location of the ATS-1 and also at the auroral latitude station, College.

H-component of the magnetic field measured simultaneously at College, Alaska, near the base of the magnetic field-lines intersecting the location of the ATS–1 is shown in Figure 7 (Cummings, Barfield, *et al.*, 1968). The Pi 2's observed at Onagawa are indicated by the arrows in the lowest diagram. From the figure, it is evident that, in general, Pi 2's coincide with sharp increases of the H-component of the ATS-1 magnetic field and sharp negative excursions of the H-component at College. Thus Pi 2's on the earth's surface even at middle and low latitudes are suggested to be closely related to the mechanism for causing magnetospheric substorms observed both at the location of the ATS-1 and also at the auroral latitude station, College.

Acknowledgements: I would like to express my gratitute to Prof. Y. Kato who suggested and encouraged this investigation. I am also indebted to Prof. H. Kamiyama for his valuable critique of my manuscript and to Dr. T. Saito for his constant guidance during the course of this work.

REFERENCES

Cummings, W.D., J.N. Barfield, and P.J. Coleman, Jr., 1968; Magentospheric substorms observed at the synchronous orbit, *J. Geophys. Res.*, **73**, 6687–6698.

Christoffel, D.A. and J.G. Linford, 1966; Diurnal properties of the horizontal geomagnetic micropuslation field in New Zealand, *J. Geophys. Res.*, **71**, 891–897.

Fairfield, D.H., 1968; Average magnetic field configuration of the outer magnetosphere, *J. Geophys. Res.*, **73**, 7329–7338.

Freeman, J.W., Jr. and J.J. Magurie, 1967; Gross local-time particle asymmetries at the synchronous orbit altitude, *J. Geophys. Res.*, **72**, 5257–5264.

Kaneda, E., S. Kokubun, T. Oguti, and T. Nagata, 1964; Auroral radar echo associated with Pc 5, *Rep. Ionos. Space Res. Japan*, **18**, 165–172.

Kato, Y., J. Ossaka, M. Okuda, T. Watanabe, and T. Tamao, 1956; Investigation on the magnetic disturbance by the induction magnetograph, Part V, On the rapid pulsation, p.s.c., *Sci. Rep. Tohoku Univ., Ser.* **5**, *Geophys.*, **7**, 136–146.

Kato, Y. and T. Tamao, 1965; On the possible mechanism for the rules of polarization of Pc 5 geomagnetic pulsations, *Sci. Rep. Tohoku Univ., Ser.* **5**, *Geophys.*, **16**, 15–36.

Kato, Y. and T. Utsumi, 1964; Polarization of the long period geomagnetic pulsation, pc 5, *Rep. Ionos. Space Res. Japan*, **18**, 214–217.

Kato, Y. and Y. Sato, 1965; Effect of the anisotropic ionosphere on the hydromagnetic oscillations, *Sci. Rep. Tohoku Univ., Ser.* **5**, *Geophys.*, **16**, 123–145.

MacPherron, R.L., W.D. Cummings, and P.J. Coleman, Jr., 1968; Oscillations of the magnetic field observed at a synchronous equatorial orbit during magnetospheric substorms, *Publication No.* **711**, *Department of Planetary and Space Science and Institute of Geophysics and Planetary Physics, University of California, Los Angels.*

Rostoker, G., 1967; The polarization characteristics of Pi 2 micropulsations and their relations to the determination of possible source mechanisms for the production of nighttime impulsive micropulsation activity, *Can. J. Phys.*, **45**, 1319–1335.

Saito, T., 1969; Geomagnetic pulsations, *Space Science Reviews*, **10**, 319–412.

Saito, T. and T. Sakurai, 1970; Mechanism of geomagnetic Pi 2 pulsations in magnetically quiet condition, *Sci. Rep. Tohoku Univ., Ser.* **5**, *Geophys.*, **20**, 49–70.

Vasyliunas, V.M., 1968; A survey of low energy electrons in the evening sector of the magnetosphere with OGO 1 and OGO 3, *J. Geophys. Res.*, **73**, 2839–2884.