Memoirs of the Kakioka Magnetic Observatory Vol. 23 No. 1 1989

WAVE CHARACTERISTICS OF SSC ASSOCIATED MAGNETIC PULSATIONS (Psc)

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(Received January 7, 1989;Revised January 18, 1989)

Abstract

Observational results from a latitudinal array of ground-based magnetometer stations extending from L~6 to L~1.5 indicate that the damped-type magnetic oscillations excited by storm sudden commencement (SSC) of various periods occur simultaneously;longer periods (~300sec) in high latitudes and shorter periods (30sec) in low latitudes. From a more detailed study based on the observation in the auroal region, it is suggested that there exist the decoupled magneto-hydrodynamic (MHD) oscillation of individual magnetic shell asso-c iated with SSC.

1. Introduction

For a solution of field line oscillation responsible for geomagnetic pulsations, Dungey (1954) derived the axisymmetric toroidal MHD wave mode with an azimuthally (east-west) polarized magnetic field in the magnetosphere. By this model, the MHD field oscillation of adjacent magnetic shell is regarded to be decoupled with each other in a dipole magnetic field. A set of magnetic shells can therefore be impulsively excited to "ring" simultaneously at their separate eigen periods (Allan and Poulter, 1984). In such a condition, periods of magnetic pulsations vary continously with latitude. For ringing toroidal mode resonance, the azimuthal wave number "m" is expected to be small in order to satisfy the axisymmetry condition. Coupling of magnetospheric impulse to ringing toroidal oscillations was enveloped theoretically by Chen and Hasegawa (1974b) as a term of "noncollective mode". The origin to generate ringing toroidal oscillations is expected to be impulsive response of the magnetosphere to shocks in the solar wind (SSC).

Existence of decoupled oscillations of individual magnetic shells has firstly been suggested by Saito (1969), who studied occurrence characteristics of MHD waves associated with SSC. Magnetic pulsations associated with SSC are generally named as Psc. Psc is further classified into Psc 1 - Psc 6, according to the corresponding period of Pc's. As shown in Fig.57 of Saito (1969), Psc 5, Psc 4 and Psc 2-3 were observed with damped-type wave forms at the high-, middle- and low-latitudes, respectively, Characteristics of Psc have been further studied for the Psc 4-5 events using the data observed at the high-latitude stations (Kuwashima, 1972). Existence of decoupled oscillation associated with SSC has firstly been suggested experimentally by the result of STARE (Scandinavian Twin Auroral Raner Experiment) observations of ionospheric electric fields (Poulter and Nielsen, 1982) and by the results of SMA (Scandinavian Magnetometer Array) observations. According to the observation by STARE (Poulter and Nielsen, 1982), the Psc 5 period variation is essentially continuous over the 0.2° latitude intervals, suggesting the oscillation of decoupled field shells. The observed Psc 5 period variation is also consistent with toroidal eigen periods calculated for the dipole field model (Allan and Knox, 1982). The general behavior of these variable period event is consistent with geomagnetic field shells "ringing" independently at their own resonant periods associated with an impulsive stimulus, SSC for example. However, the above mentioned results are based on the observation in the localized area in the auroral region. In the present study, the existence of the SSC-associated decoupled magnetic oscillation will be examined based on the latitude array observation extending from L~6 to L~1.5. The latitude and longitude dependence of the Psc wave will be also examined to study the axisymmetric condition for the Psc resonance.

2. Latitudinal dependence of wave forms and power spectra of Psc

On March 22,1979, around 0826UT, an interplanetary shock reached the dayside of the very quiet magnetosphere causing SSC. Consequently, a sharp onset of the SSC and a well shaped Psc were observed over the wide-latitudinal range on the ground, as well as at the geosynchronous altitude in the magnetosphere. Records of that Psc event at Syowa and Hermanus are shown in Fig.1. As shown in the

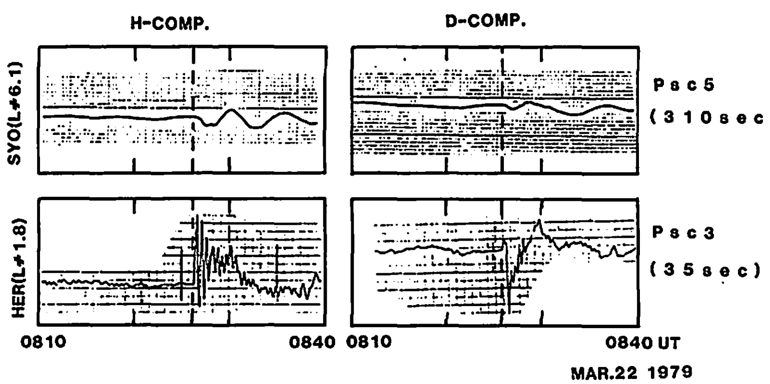

Fig. 1 : Wave forms of magnetic oscillations excited by SSC started around 0826 UT on March 22, 1979. Psc 5 (300sec) was observed at the high-latitude, Syowa Station (SYO, L=6.1), while Psc 3 (35sec) was excited at the low latitude, Hermanus (HER, L=1.8)

figure, the Psc phenomena were simultaneously observed at both stations, while the period of Psc was longer (310sec) at the high latitude, Syowa Station (SYO, L~6.1), while that of the low latitude, Hermanus (HER, L~1.8) was short (35sec). The two stations are located almost along the same geomagnetic meridian as shown in Table 1 (Kuwashima and Saito, 1981). Such thesimultaneous excitation of the SSC-associated magnetic oscillations with various perids ranging from Psc 5 (around 300sec) to Psc 3 (around 30sec) has been predicted theoretically (Dungey, 1954;Chen and Hasegawa, 1974b;Allan and Knox, 1982). That theoretical prediction has been supported by the observation in the auroral region for the Psc 4-5 phenomena (Poulter and Nielsen, 1982;Glassmeier et al., 1984). However, the simultaneous appearance of Psc over the wide period range from Psc 5 to Psc 3 has not yet been confirmed experimentally untill the present study. The result shown in Fig.1 is the first experimental evidence for the simultaneous excitation of the Psc phenomena with the wide period range from Psc 5 to Psc 3.

Characteristics of the Psc event shown in Fig.1 are studied in more detailed using the observational results from a latitudinal array of ground-based stations extending form L~6 to L~1.5, and the results are shown in Fig.2. As shown in the figure, power specra obtained at each station have many spectral peaks. The dominant spectral peaks shown in Fig.2 are summarized in Table 2, in which each dominant spectral peak appears to correspond to each own resonance period of the field lines anchoring the stations. The relationships between the dominant period of Psc and the location of the observing station are summarized in Fig.3. It is evident in the figure that various Psc waves were simultaneously excited in association with SSC. It is also evident that the period of the Psc wave becomes longer with increasing the latitude of the observing station. The results summarized in Fig.3 indicate that various MHD waves are simultaneously associated with SSC at various regions in the magnetosphere.

Table 1 Locations of the used stations in Figs.1 and 2.

Station	Geographic		Geomagnetic		L
	Latitude	Longitude	Latitude	Longitude	
Syowa	69.0 S	39.6 E	−69.8	79.4	6.1
Kiruna	67.8 N	20.4 E	65.2	116.6	5.4
AFGL	48.3 N	117.0 W	55.2	300.8	3.0
Hermanus	34.4 N	19.2 E	−33.4	79.9	1.8
Memambetsu	43.9 N	144.2 E	34.0	210.2	1.5

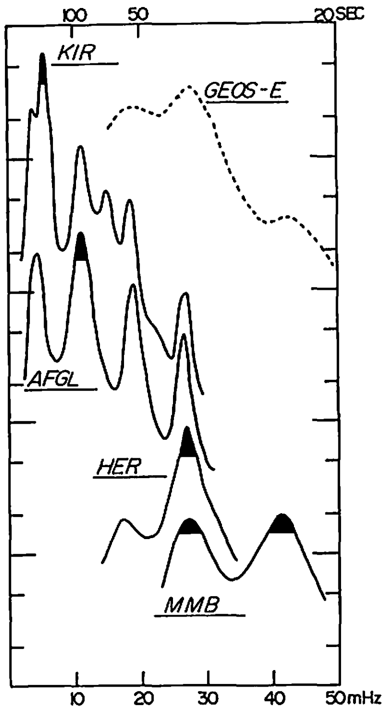

Fig. 2 : Power spectra of the Psc event excited simultaneously over the wide latitudinal range associated with the SSC event on March 22, 1979. Each spectral peaks associated with various resonant regions. It should be noted that the dominant spectral peaks at each station show the significant latitudinal dependence. (The scale in the ordinate is aribtrary)

Table 2 DOMINANT COMPONENT Psc ASSOCIATED WITH SSC AT 0826 UT MAR.22 1979

STATION	LOCAL TIME	Psc COMPONENT	
		SEC	mHz
SYOWA STATION (ϕm=−69.8°)	1104	310	3.2
KIRUNA (ϕm=65.2°)	0948	160	6.3
AFGL (L=2∼3)	MIDNIGHT	95	10.5
HERMANUS (ϕm=−33.4°)	0943	35	28.6
MEMAMBETSU (ϕm=34.0°)	1803	20	50.0

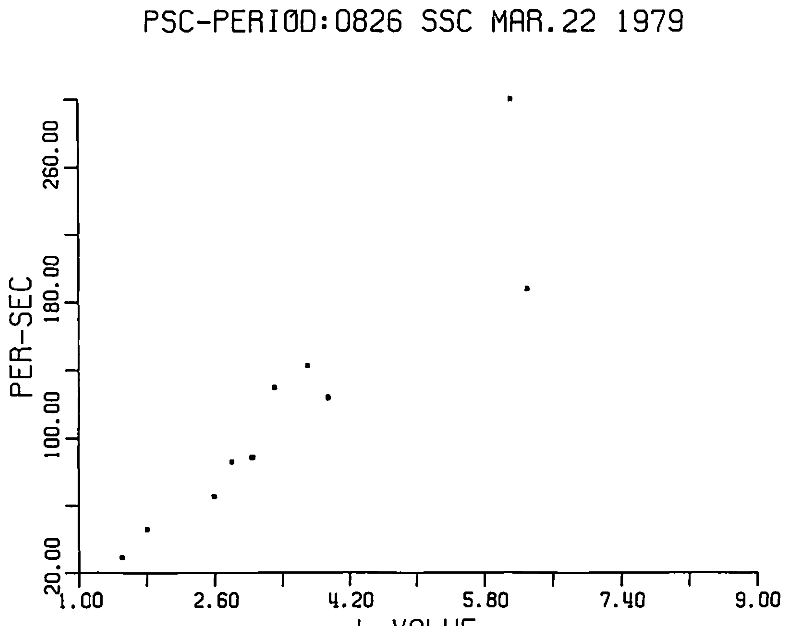

Fig. 3 : The dominant Psc periods are plotted as a function of the latitude (L value). Note that the Psc period increases with increasing the latitude.

3. Latitude and longitude dependences of Psc

The results shown in Fig.3 were only for the H component of the Psc waves. According to the results obtained around the plasmapause (Fukunishi, 1979), the latitude dependence of power spectra of Psc was quite different between the H and D components. In the present study, that problem will be examined for the results obtained in the auroral region. The locations of the used high-latitude stations are shown in Table 3. As shown in the table, the three stations are located along similar geomagnetic meridian, while their geomagnetic latitudes are -69.8° (SYO), 62.2° (TRO) and 57.8° (NUR), respectively. Power spectra are calculated with the Psc event observed at those three stations for both the H and D component and the results are shown in Fig.4. It is evident in Fig.4 that the behavior of the Psc power spertra is quite different between the H and D components. In the H component, the spectral peak shows the clear latitudinal dependence in accordance with the tendency shown in Fig.3. On the other hand, in the D component, the shape of the powar specra was very similar at all atations. Considering the 90° rotation of the magnetic polarization axis between the magnetosphere and the ground (Nishida, 1964;Inoue, 1973;Hughes and Southwood, 1976a and b), the H and D component oscillations on the ground correspond to the azimuthal and radial oscillation in the magnetosphere. The results shown in Fig.4 strongly indicate that

Table 3 Locations of the used stations in Figs.3.

Station	Geographic		Geomgnetic	
	Latitude	Longitude	Latitude	Longitude
Syowa	69.0 S	39.6 E	−69.8	79.4
Tromso	69.7 N	19.0 E	67.0	117.1
Nurmijarvi	60.5 N	24.6 E	57.8	112.9

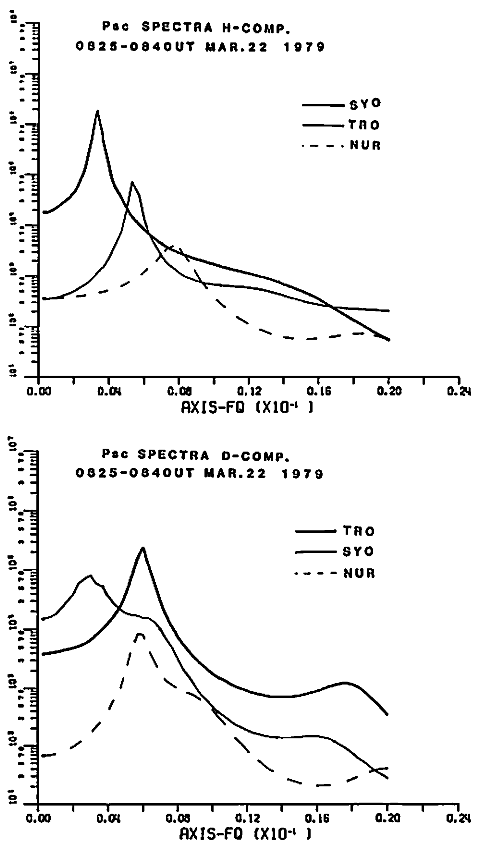

Fig. 4 : Power spectra of the Pse event observed at the high-latitude stations listed in Table 3. Note that the Latitudinal dependence of the spectral peak in the H component (upper) is quite different from that in the D component (bottom).

the azimuthal oscillations are confined to individual magnetic shell, while the radial oscillations spread across the magnetic shells. Dungey (1954) and Chen and Hasegawa (1974b) have predicted such the two kinds of MHD oscillation associated with the impulsive disturbance to the magnetosphere (like SSC) based on the theoretical viewpoint. The results shown in Fig.4 are consistent with the theoretical prediction. This is the firet experimental evidence for the theoretical prediction by Dungey (1954) and Chen and Hasegawa (1974b). According to the classification by Dungey (1954), the azimuthal and radial MHD oscillations are corresponded to the toroidal and poloidal oscillations. For the existence of the pure toroidal-mode MHD oscillations, the azimuthal wave number "m" must be very small to satisfy the axisymmetry condition. That problem has already examined using the observation at the Scandinavian Magnetometer Array (SMA) by Glassmeir et al. (1984). According to their results, the spectral peak of Psc shows the clear latitudinal dependence, while the spectral peak is very similar along the longitude suggesting the very small azimuthal wave unmber. However, the region of SMA is very small to examine the behavior on the axisymmetry condition. The range of the longitude at SMA is only~16°. In the present study, the axisymmetry condition of the Psc waves is studied using the station array with larger longitude range as shown in Fig.5. In this case, the range of the longitude is 35° , which is about twice of SM A.Fig.6 shows wave forms of the Psc event observed at the three stations illustrated in Fig.5, where Mieron (MIE, 66.1° in geomagnetic latitude and 119.7° in geomagnetic longitude) and Pello (PEL, 63.7°, 120.5°) are located almost the same geomagnetic meridian with different magnetic shell, while Pello (PEL, 63.7°, 120.5°) and Faroes

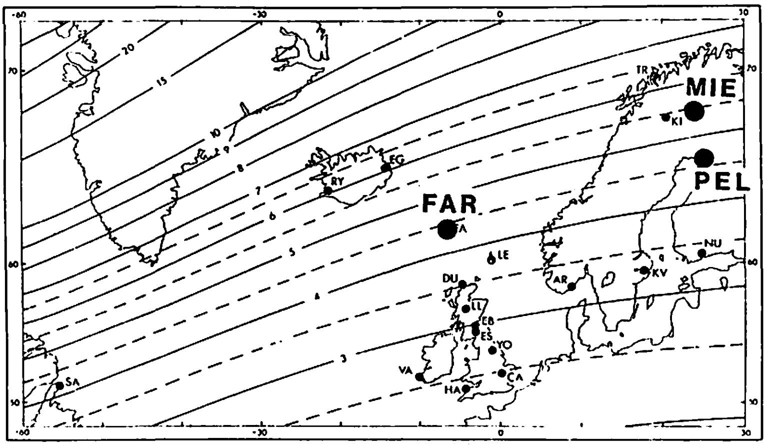

Fig.5 : Map of the stations used for the examination of the axiaymmetric condition in the Pdc excitation. In the map, MIE and PEL are located along almost the same magnetic meridian while PEL and FAR are located along almost the asme magnetic shell

(FAR, 61.7°, 85.4°) are located along almost the same magnetic shell with the difference of longitude of 35°. The results are summarized in Table 4. The Psc periods at MIE and PEL show the clear latitudinal variation. They are 191 seconds at MIE and 155 seconds at PEL, respectively. On the other hand, Psc periods at PEL and FAR are almost similar indicating that MHD oscillations are excited along the similar magnetic shell. This result is in consistent with the axisymmetric condition, which is necessary to excite the pure toroidal-mode MHD oscillations.

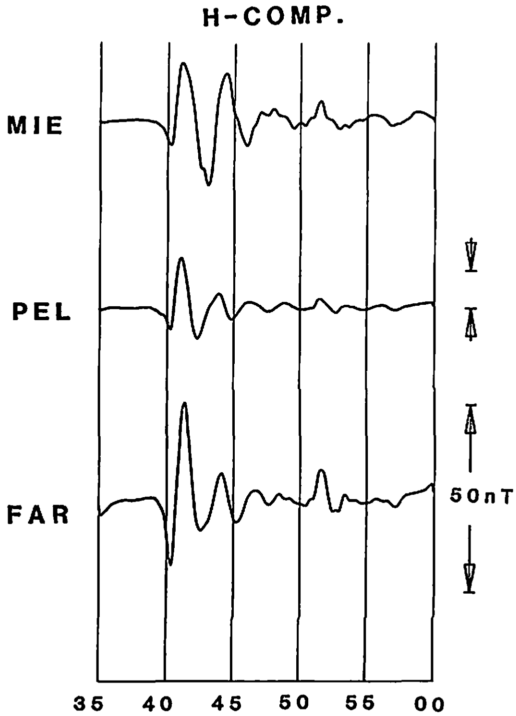

Fig.6 : Wave forms of magnetic oscillation's excited with SSC started around 0340 UT on January 9,1979. The location of the observing stations are illustrated in Fig.5.

Table 4 Psc SPECTRA ON JAN.9 1979 EVENT

	GEOMAGNETIC		L	FREQUENCY	PERIOD
	LAT.	LONG.		(mHz)	(SEC)
MIERON (MIE)	66.1	119.7	6.1	5.2	191
PELLO (PEL)	63.7	120.5	5.0	6.5	155
FAROES (FAR)	61.7	85.4	4.5	6.7	148

4. Discussion

As discussed in the previous sections, the existence of the axisymmetric toroidal mode MHD wave is strongly supported in the case of the SSC-associated magnetic oscillations. Dungey (1954) firstly derived the existence of the pure toroidal-mode and poloidal-mode MHD oscillations in the dipole magnetic field as illustrated in Fig.7. In the figure, μ is parallel to the magnetic field line, while ν and ϕ are corresponded to radial outward and azimuthal directions, respectively. In the axis-symmetric condition in the azimuthal direction, two kinds of MHD waves can exist independently with each other, which are the toroidal mode (ϕ, azimuthal oscillation of each individual magnetic shell) and the poloidal mode (ν, radial oscillations of magnetic field lines in the meridian plane). Behaviors of the two kinds of MHD waves has been further investigated by Cummings et al. (1969), Orr (1973) and Allan and Knox (1979). According to their theoretical results, the reflection of the Alfvēn wave which is associated with the toroidal mode at the highly conducting layer in the earthward boundary (ionosphere) allows the formation of the MHD standing waves along the magnetic field lines, with nodes of field line motion and electric field at the boundary. The eigen periods of these standing waves are depending on the length of the field lines and the associated mass density distribution. The periods are predicted to increase with increasing geom agnetic latitude.

In the case of axisymmetric condition, the toroidal MHD wave has an azimuthally (east-west) polarized magnetic field in the magnetosphere, and in a dipole field as shown in Fig.7, the MHD oscillation of adjacent magnetic shell is decoupled with each other. Therfore, a set of geomagnetic field oscillation will be impulsively excited to "ring" simultaneously at their separate eigen periods.

Chen and Hasegawa (1974b) further developed that problem. According to their theoretical results, the impulsive driving force in the magnetosphere can excite the

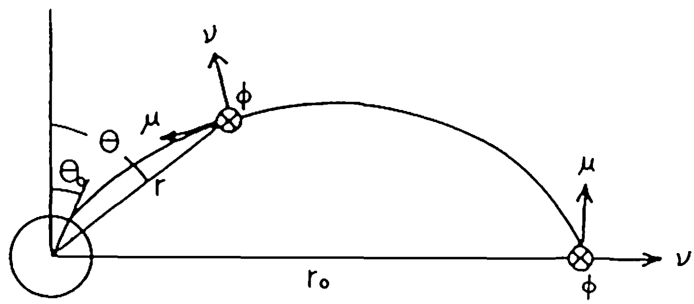

Fig.7 Coordinate system of the dipole field wheld μ is parallel to the magnetic field lines, ν and ϕ are radial outward and azimuthal directions, respectively.

eigen oscillation ofthe local field lines in various regions in the magnetosphere. Like the results in Fig.4, the spectral peaks in the H component specra should have the latitudinal dependence because of the decoupled oscillations of individual magnetic shells, while in the D component the shape of the power spectra should be similar for different latitudes. Considering the 90° rotation of the magnetic polarization axis between the ionosphere and the ground (Nishida, 1964; lnoue, 1973; Hughes and Southwood, 1976a and b), the H and D component oscillations on the ground correspond to the azimuthal and radial oscillations in the magnetosphere, respctively. Then, it is likely that the azimuthal oscillations are confined to individual magnetic shell, while the radial oscillations spread across magnetic shell.

Although many theoretical predictions have suggested the existence of the MHD decoupled oscillations of individual magnetic shell, its experimental confirmation is not sufficient because of the lack of the observation at the latitudinal and longitudinal array stations. The results shown in Fig.3 and in Fig.6 are the first experimental evidences with the simultaneous excitaion of the decoupled MHD oscillations of individual magnetic shell. A set of magnetic shell is impulsively excited to "ring" simultaneously at their separate eigen periods.

Gough and Orr (1984) showed theoretically the ocurrence of forced oscillations of individual magnetic shell driven by magnetosonic fast mode wave in association with the impulsive response of the magnetosphere (SSC). In their model, each individual magnetic shell responds independently to the driving force, which is assumed to originate in a disturbance at the dayside magnetopause. The disturbance will generate a fast mode MHD wave which propagates towards the earth coupling to a transverse mode MHD wave associated with individual magnetic shell. Their theoretically expected periods of MHD waves are consistent with the observed Psc events disussed by Siebert (1984). The existence of propagating fast mode MHD wave is confirmed by the observation in the magnetosphere by Kuwashima and Fukunishi (1985) and Kuwashima et al. (1985). They studied the behavior of the onset time of SSC at geosynchronous altitude using the onset time indentified from the ground observation as a reference signal. Their results indicate that the SSC signal propagates with the velocity of 400-700 km/s across the field lines in the magnetosphere. Those fast mode ssc signal might be driving forces to excite the transverse MHD oscillations of individual geomagnetic field in the magnetoshpere.

5. Conclusion

In the present study, the existence of the decoupled MHD oscillations which have been predicted theoretically is confirmed experimentally by the observations at latitudinal and longitudinal arraies of ground-based magnetic stations.

Acknowledgement

The author would like to express his appreciation to Drs. W.F.Stuart of British Geological Survey, H.J. Singer of Air Force Geophysics Laboratory and K.H.Glassmeier of University of Koln for their data providing with the autor's request.

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SSCに伴う地磁気脈動（Psc)の波動特性

桑 島 正 幸

概　　要

SSCに伴って出現する地磁気脈動（Psc）の特性を，高緯度（L＝６）から低緯度(L＝1.5)にわたる観測点網での資料を使って調査した．その結果,SSCに伴って高緯度ではPsc 5（周期が300秒）が，また低緯度ではPsc 3（周期が30秒）が同時に出現することが確かめられた．このことから，SSCが発生すると，磁気圏内の磁力線がそれぞれ独立にしかもいっせいに振動することが示唆された．