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ELF/VLF EMISSIONS AT MOSHIRI (L = 1.56) OBSERVED IN THE STORM RECOVERY PHASE ON FEBRUARY 9, 1986

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It is commonly understood that the occurrence of low- and middle-latitude ELF/VLF emissions is definitely associated with a world-wide geomagnetic storm (Tanaka et al., 1974; Hayakawa et al., 1975). According to the statistical analysis for four-year observations, plasmaspheric ELF hiss with the lower frequency range ($\leq$ 3 kHz) observed at Moshiri (geomagnetic latitude = 35° N) is typically a daytime phenomenon (0400–1800 LT) during disturbed periods ($K_p = 4 - 7$). The K_p and LT dependence of the occurrence is consistent with the hiss generation within the plasmasphere as it expands into the intensified belt of outer zone electrons during the storm recovery phase (Hayakawa et al., 1985). The occurrence of mid-latitude VLF emissions (unstructured hiss) with higher frequency range (3–10 kHz) at Moshiri shows, statistically, the main peak in the dawn (5–9 h LT) and the secondary peak in the dusk (15–19 h LT), and also shows the time delay behind geomagnetic storm ($\Sigma K_p = 20 - 30$). Observational results mentioned above enable us to estimate that the resonant electron energy of ~5 keV at L = 3 – 4 in the ring current to the Earth tends to drift eastward (Hayakawa et al., 1986). On a severe geomagnetic storm (maximum ΔH at Kakioka, 509 nT) on May 25–27, 1967, weak VLF hiss appeared in the initial to main phases. Then, the relatively strong VLF hiss appeared during the interval from afternoon to evening. Strong intensity variations were observed in the main and recovery phases (Hayakawa et al., 1975). The present paper shows ELF/VLF emissions observed at Moshiri, associated with a severe magnetic storm (maximum ΔH at Kakioka, 310 nT) during February 6–11, 1986.

Figure 1 shows the occurrence time of ELF/VLF emissions superposed on the time-plot of the geomagnetic field strength (H–component) at Kakioka (geomagnetic latitude, 27° N) during February 5–11, 1986. The initial phase of the geomagnetic storm which commenced at 0618 UT on February 6 lasted for more than two days. Weak and strong ELF hiss (1.5–2 kHz) and weak VLF hiss (3–5 kHz) appeared around 20 h UT (UT=JST–9 h) on February 7, associated with multiple occurrence of substorms, and weak wide-band hiss (1.5–5 kHz) appeared during 0–6 h UT on February 8. Thereafter, strong ELF hiss (1.5–2 kHz) appeared during 8–10 h UT on February 8. These emissions are daytime phenomena which are characterized by the LT dependence of ELF hiss occurrence in moderate (3 $\leq$

$K_p \leq 5_+$) geomagnetic activities (Hayakawa et al., 1985). Discrete VLF emissions (hook type) were observed by the routine-based observations during 0650–0652 UT on February 8. In the recovery phase, after the maximum depression (~0 h UT, February 9) of the geomagnetic field strength, ELF/VLF emissions were observed for about 11 hours in the daytime, which are the subject of this paper. Strong ELF hiss or chorus (0.8–1.5 kHz) and weak VLF hiss (3–5 kHz) were observed, in association with a sudden impulse (SI) of the geomagnetic field just before 18 h UT on February 9. Furthermore, weak ELF hiss (1.5 kHz) was observed in the nighttime (1630–1730 UT) on February 11, in association with an isolated substorm during the quiet interval of the geomagnetic field.

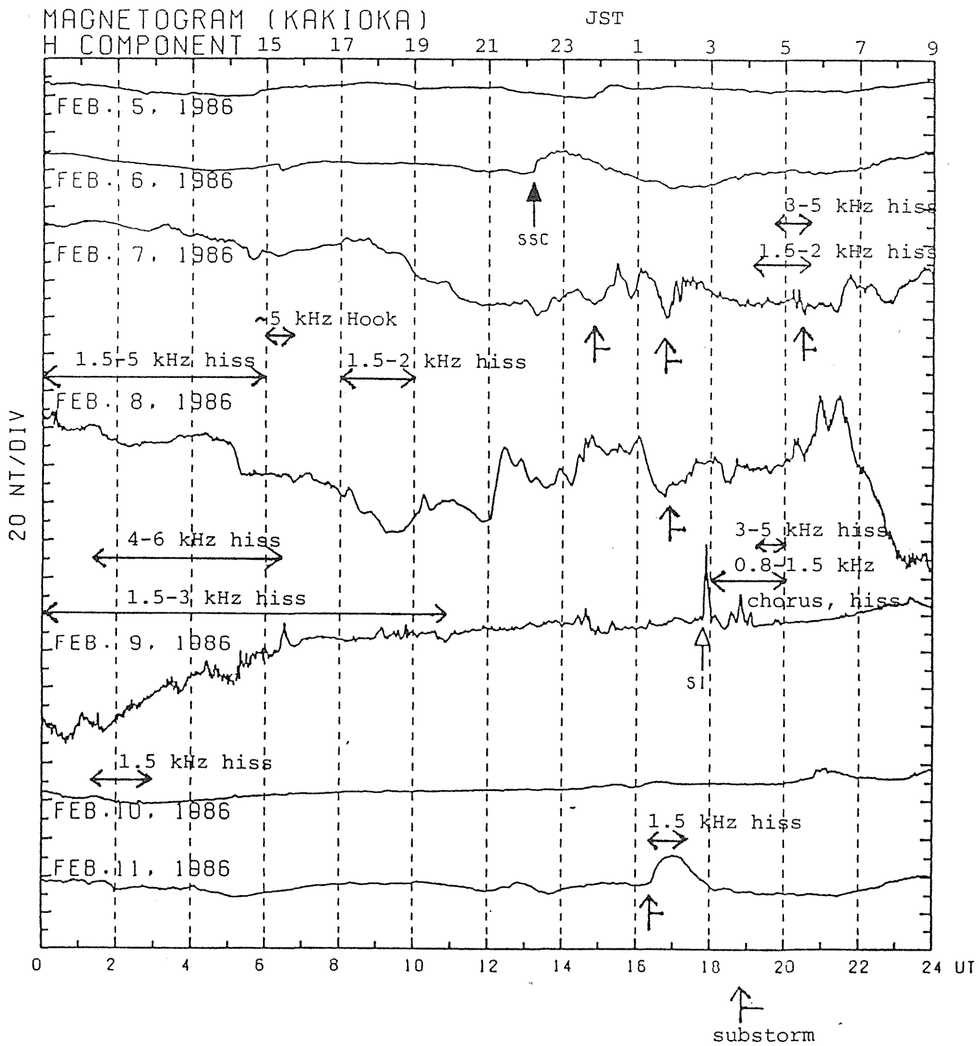

Fig. 1 Whole aspect of the occurrence of ELF/VLF emissions on the evolution of the geomagnetic field (H–component) at Kakioka (geomagnetic latitude, 27° N) during February 5–11, 1986.

Figure 2 shows the geomagnetic H-component at Kakioka in the recovery phase on February 9, the intensity pen-records of ELF/VLF emissions on the three frequency channels (0.8, 1.5 and 8 kHz) and ULF magnetic pulsations at Onagawa (L=1.3), respectively. It is found, as a whole, that gradual increase of ELF emissions (0.8, 1.5 kHz) during 2–10 h UT took place when the geomagnetic H-component was continuously increasing. It is also found that an impulsive event around 0630 UT and a small fluctuation around 1430 UT showed a remarkable correlation with transient geomagnetic disturbances. On the other hand, the intensity of VLF hiss (5 kHz) shows intermittently quasi-periodic fluctuations in the relatively steep recovery phase of H-component (2–6 h UT). These fluctuations are distinctly correlated with strong ULF magnetic pulsations, shown in the lower panel.

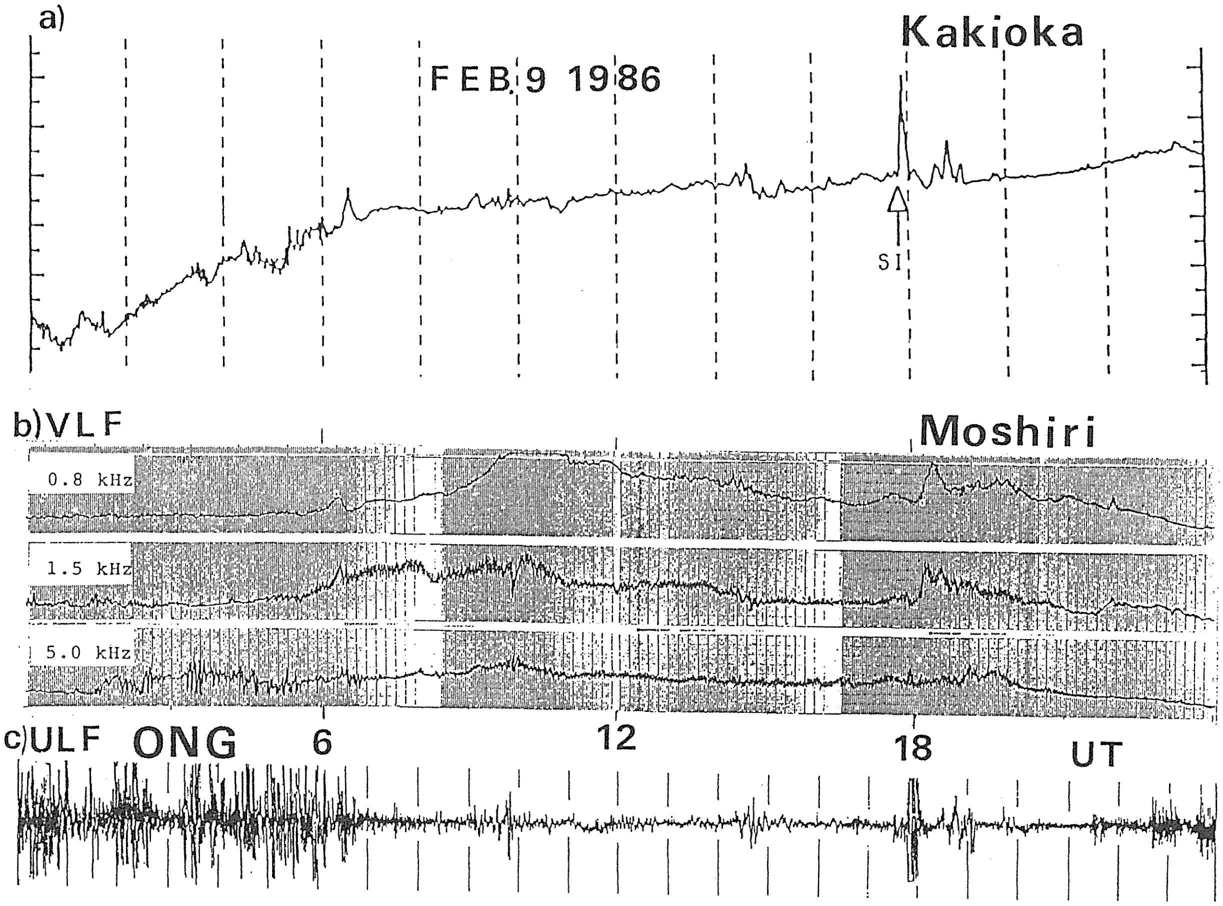

Fig. 2 (a) The geomagnetic H–component in the recovery phase on Feb. 9. (b) Intensity pen-records of ELF/VLF emissions on the three frequency channels (0.8, 1.5 and 8 kHz). (c) ULF magnetic pulsations at Onagawa (L = 1.3).

Figure 3 shows detailed time variations of the 1.5 kHz hiss intensity and ULF magnetic pulsations during 5–6 h UT in the recovery phase and a dynamic spectrum of ELF hiss during 0550–0552 UT obtained by the routine MT observations, respectively. The intensity of the 1.5 kHz hiss with small amplitudes fluctuates with a period of several minutes. These fluctuations seem to be in good correlation with the time variation of ULF magnetic pulsations shown in the middle panel, although the correlation is not as definite as that on VLF hiss shown in the next figure (Figure 4). The spectrum of ELF hiss has the upper limit in the frequency at around 3.5 kHz, and the clear lower-frequency cutoff of about 1.8 kHz, which corresponds to the first-order cutoff frequency of the waveguide-mode propagation between the earth and the lower ionosphere.

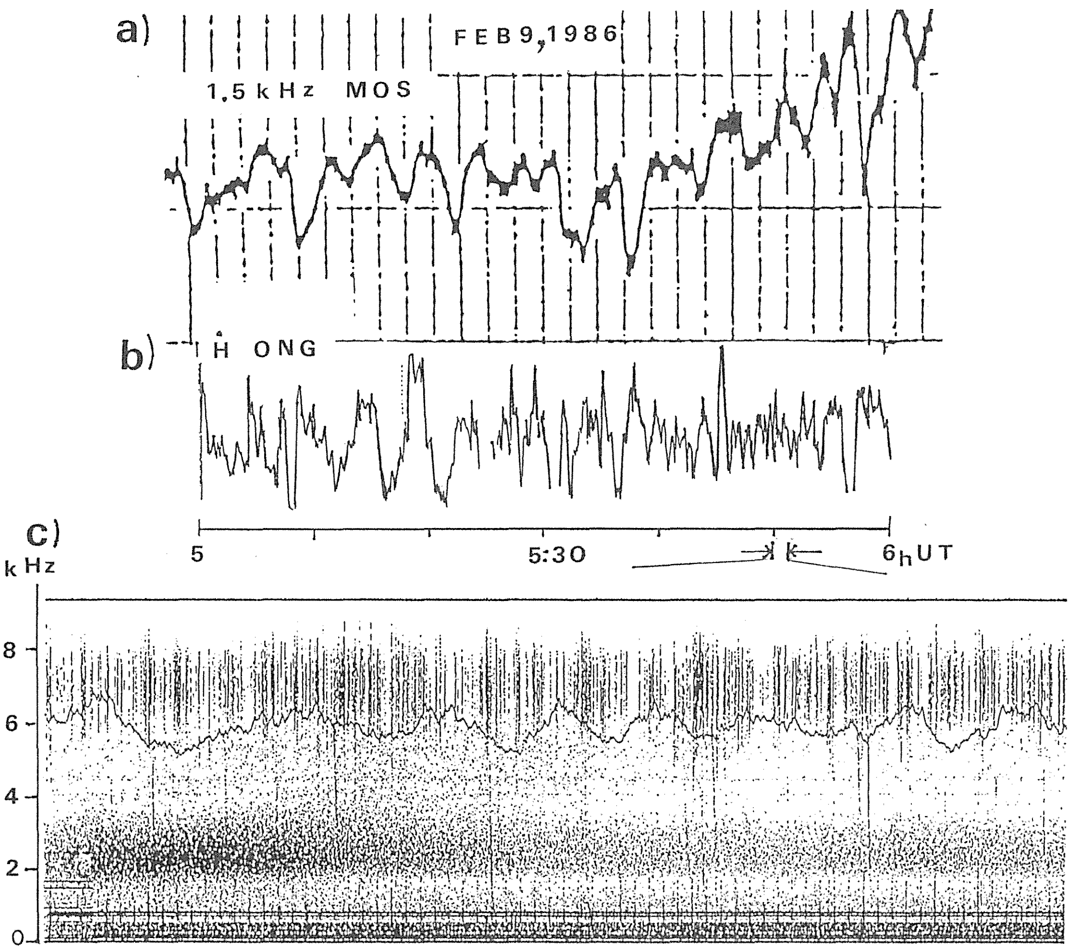

Fig. 3 (a) The expanded variations on the 1.5 kHz hiss and (b) ULF geomagnetic pulsations in the recovery phase. (c) A dynamic spectrum of ELF hiss during 0550–0552 UT obtained by magnetic tape recording. A fluctuating line around 6 kHz shows the phase variation of the waveguide-mode signals from NDT (17.4 kHz), which is not related with the discussion of this paper.

Figure 4 shows detailed time variations of the 5 kHz hiss intensity and ULF magne pulsations during 3–5 h UT in the recovery phase, and a dynamic spectrum of VLF h during 0350–0352 UT, respectively. The 5 kHz hiss intensity fluctuates with a period a few minutes during 0320–0445 UT, and the fluctuation distinctly correlates with that ULF magnetic pulsations in the middle panel. It is found from the spectrum that VLF h of the frequency band of 4–8 kHz appears intermittently during a short observation ti of 2 minutes.

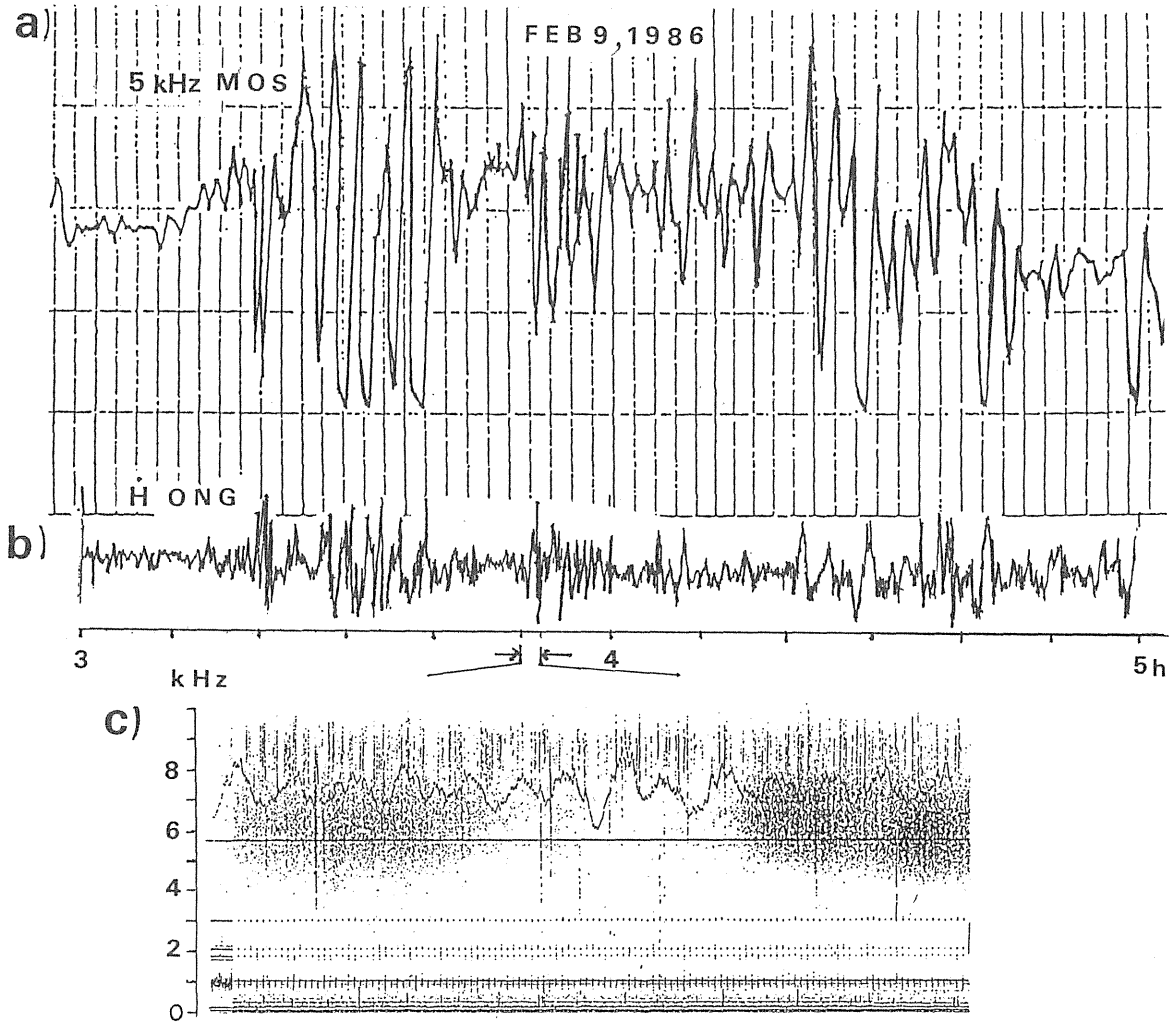

Fig. 4 (a) The expanded variations on the 5 kHz hiss intensity and (b) ULF geomagnetic pulsations during 3–5 h UT in the recovery phase. (c) A dynamic spectrum of VLF hiss during 0350-0352 UT. The fluctuating line around 7 kHz is the same as in Fig. 3.

The observational results of ELF/VLF emissions in the storm recovery phase, associated with the geomagnetic variation or pulsations maybe summarized as follows:

1) The fluctuation of ELF hiss (1.8–3.5 kHz) appeared in association with a slowly varying geomagnetic H–component or ULF magnetic pulsations with a long period of several minutes, and

2) The fluctuation of VLF hiss (5–8 kHz) is associated with ULF magnetic pulsations with the relatively short period of a few minutes.

Sato and Fukunishi (1973) observed quasi-periodic (QP) VLF emissions associated with geomagnetic pulsations (GP) at Syowa Station (L=6), Antarctica. According to the review paper by Kimura (1974), QP emissions at high latitudes are generally observed in the recovery phase of magnetic substorms, and a diffusive frequency spectrum whose upper limit frequency is confined below 1.5 kHz with a period of 20–60 sec. However, we have never identified ELF/VLF emissions at low latitudes such as Moshiri associated with the geomagnetic fluctuation so far, as shown in Figure 3 and 4.

Matsumoto and Kimura (1971) estimated the upper limit frequency of VLF emissions based on the generation mechanism of cyclotron instability developed by Kennel and Petchek (1966). The upper limit frequency is ranged from 3.8 to 0.5 kHz for the equatorial magnetospheric region of L = 3.5 to 6. The upper limit frequency (3.5 kHz) of the ELF hiss illustrated in Figure 3 is close to that at L = 3.5. This suggests that the generation of ELF hiss takes place in the magnetospheric equatorial region around L = 3.5. The lower frequency cutoff at 1.8 kHz of ELF hiss resulted from the waveguide-mode propagation over long distance, indicating that the emergence from the ionosphere takes place at higher latitudes than that of Moshiri. At 0650–0652, 0750–0752 and 0850–0852 UT, when the 1.5 kHz hiss was intensified, frequency-spectra of ELF hiss show that the emission with the lower cutoff frequency mixed with the emission without the cutoff frequency which extends below 1 kHz, whereas the upper limit frequency was constant at each observation time. For non-lower frequency-cutoff hiss, ELF hiss generated around L = 3.5 in the plasmasphere propagates to the inner radiation zone (L$\sim$2), and penetrates through the ionosphere to the ground at lower latitudes. Ondoh et al. (1982) observed the storm-associated plasmaspheric hiss below $\sim$2 kHz in the daytime topside ionosphere at low- and middle-latitudes by ISIS satellites, which seems to correspond to the non-lower frequency-cutoff hiss observed on the ground. At 0950–0952 UT, when the 1.5 kHz hiss intensity abruptly dropped, the spectrum of ELF hiss was separated into two frequency bands of 3.5–1.8 kHz and of $<$ 1 kHz. The emission in the upper band resulted from the waveguide-mode effect. The lower frequency band below 1 kHz may correspond to the plasmaspheric hiss ($\sim$550 Hz) observed in the wide range of L = 1 to 6 during the recovery phase of magnetic storms observed at OGO–6 satellite from other events (Smith et al., 1974).

Coroniti and Kennel (1970) have indicated theoretically that geomagnetic micropulsations of small amplitude can cause large amplitude precipitation pulsations of electrons, which simultaneously modulate the growth rate of VLF emissions generated by the cyclotroı instability due to pitch angle diffusion. In order to elucidate whether the fluctuation of th 1.5 kHz hiss intensity in Figure 3 is explained by the above-mentioned theory or not, it i necessary to examine the phase relation (coherency and delay time) taking into account ; difference in the propagation time of the whistler-mode wave and that of Alfvén- or modifie(Alfvén-mode wave from the interaction region to the observing point on the ground.

As shown in Figs. 2 and 4, the intensity fluctuations at 5 kHz correlate distinctly witl geomagnetic pulsations (Pc 3–4) with a period of about 120 sec. Hayakawa et al. (1986 have shown that lower energy electrons (~5 keV), drifting eastward to the low-latitud(magnetosphere (L ~2), generate VLF hiss at the duskside asymmetric plasmaspheric bulge Then, VLF hiss observed during the recovery phase may be modulated by the pitch angl(diffusion which resulted from the periodic geomagnetic compression. The detailed mecha- nism should be investigated through analyses of the phase relation between VLF and ULI emissions, as well as that between ELF hiss and ULF emissions.

Acknowledgement

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