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HIGH RESOLUTION OPTICAL MEASUREMENTS OF ARPA PROJECT SECEDE II

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Technology International Corporation

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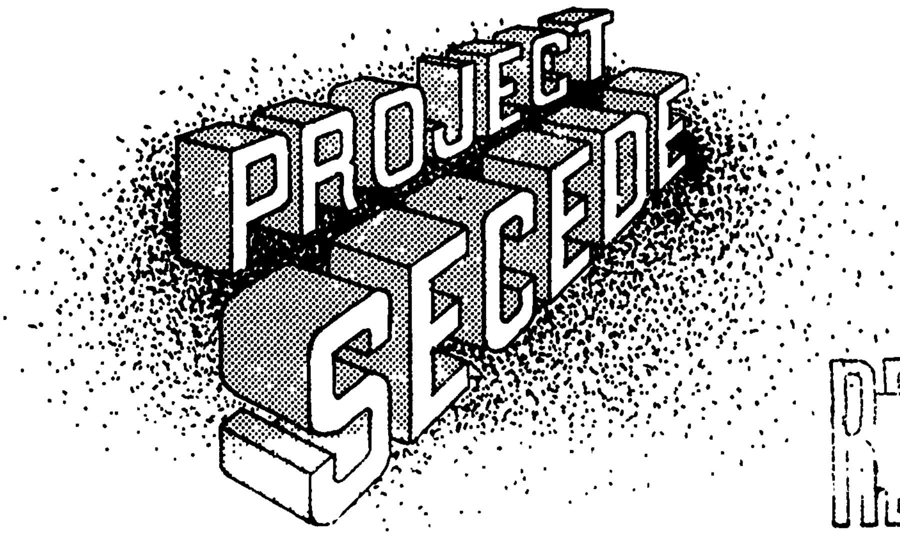

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13. ABSTRACT

High resolution optical measurements were made of a series of high altitude barium releases at Eglin AFB during January 1971. Data was obtained on the individual cloud motions (ion and neutral), morphology, and fine structure striation development viewed up the geomagnetic field lines.

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II.

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Technology International Corporation

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I INTRODUCTION

The general goals of the Secede barium release program have been geared to the development of a practical technique by which plasma interaction with the ionosphere could be experimentally studied and suitable theories of such interactions developed therefrom. The Secede experimental program has, for the most part, consisted of two coordinated aspects, that of radio frequency radar measurements and that of optical measurements. In studying barium cloud phenomenology and morphological development, optics has provided the key means of observing and recording the physical history of the release. In addition to providing photographic, radiometric, and spectrographic records after the fact, optical coverage can be displayed in real time for purposes of tracking the cloud(s) as well as for identifying morphological changes.

The main objectives of the Secede II optical measurements program were two-fold. The first of these was to provide directly complementary data for rf experimenters to aid in the interpretation and analysis of the resultant rf data. The second primary objective of the optical program was to provide a broad data base for theorists concerned with:

a) the basic theory underlying barium release phenomenology,
b) the interaction of an artificially generated plasma with the ionosphere and geo-magnetic field and, ultimately,
c) the extension of the physical phenomenology to systems requirements.

TIC was responsible for the operation of the majority of the ground based optical sites for Project Secede II. Extensive photographic coverage was obtained of a total of six main releases and an additional three "puff" releases from a series of primary and secondary optical sites located about the release vicinity.

Table I presents the salient operational data regarding the primary and puff releases. As is evident, there are planned similarities with respect to certain of the parameters and dissimilarities with respect to others. One event, denoted as Olive IV, was inadvertently produced in that the multiple twenty-two-16 kg canister release system of Olive I malfunctioned causing a single canister to remain unreleased in the payload vehicle for an additional two minutes before fortuitously igniting at essentially the same altitude. This latter release thus provided an interesting contrast to Olive I as will be seen in the following section.

Also noteworthy here is the last column of Table I in which the solar depression angle is presented for the primary events. In the Eglin Gulf Test Range region of Florida, the change in solar depression angle (SDA) varies between four and five minutes per degree. Thus, the almost two degrees between Nutmeg I and Plum I, for example, would correspond to some ten minutes difference in release time (on the same day). Assuming that stars can be photographed at somewhat less than 7^{o} SDA due to sky background (an observer can visually recognize stars at about 8^{o} SDA), the acquisition of photographic data at early times is significantly compromised, as with Nutmeg I. On the other hand, the late time data might be significantly extended due to an early release, at 6^{o} SDA, for example.

In Table II, a summary of the various categories of optical instrumentation deployed at the various primary and secondary optical sites is presented. The main optical instrumentation consisted of high resolution camera systems and cloud triangulation cameras. In addition, filter cameras, morphology cameras, and puff cloud cameras provided significant input to the data base. Cine, time lapse, and related documentary coverage also proved useful in interpreting the primary data by both theorists and rf experimenters. The majority of the instrumentation, it should be noted, utilized f/1 or faster objective optics.

TABLE I

SECEDE II OPERATIONAL DATA

EVENT	RELEASE ALTITUDE (km)	SUB RELEASE POSITION	YIELD (kgm)	DATE	RELEASE TIME	SOLAR ELEV. /AZ.
NUTMEG I	147.4	29°54.4' N 86°25.5' W	48	16 Jan 71	17:34:40	6.0°(249.3°)
PLUM I	185.9	29°52.1' N 86°21.0' W	48	20 Jan 71	17:47:06	7.9°(251 3°)
REDWOOD I	258.6	29°41.3' N 86°37.9' W	48	26 Jan 71	17:52:08	7.7°(252.8°)
OLIVE I	192.5	29°49.0' N 86°41.3' W	336	29 Jan 71	17:53:57	7.5°(253.6°)
OLIVE IV	187	29°23 N 86°38 W	16	29 Jan 71	17:55:57	7.9°(253.8°)
SPRUCE	192.6	29°43.1' N 86°34.2' W	48	01 Feb 71	17:52:04	6.7°(254.2°)
PLUM II	184.6	28°47.3' N 85°26.5' W	1	20 Jan 71	17:51:23	
REDWOOD II	188.8	28°55.7' N 86°27.4' W	1	26 Jan 71	17:55:42	

TABLE II

SECEDE II OPTICAL INSTRUMENTATION

(NOMINAL PARAMETERS)

CATEGORY	FOCAL LENGTH	FIELD OF VIEW	FORMAT	FILM
HIGH RESOLUTION	300mm	12°	70mm	Color B/W
INTERFERENCE FILTER	105mm	20°	70mm	B/W
MORPHOLOGY	100mm	42°	70mm	Color
PRIMARY CLOUD TRIANGULATION	180mm	36°	5 inch	Color (B/W)
PUFF CLOUD TRIANGULATION	50mm	46°	70mm	Color
TIME LAPSE	50mm	20°	35mm	Color
CINE	50mm 25mm	20° 10°	35mm 16mm	Color Color
DOCUMENTARY	50mm	20°	35mm	Color

Figure 1 shows the location of the three primary optical sites at Eglin AFB, Fla., Tyndall AFB, Fla., and Barin Field, Ala. with respect to the launch site and the sub-release points of the six primary releases. As will be evident later, the Eglin AFB C-6 site was viewing the eastwardly drifting ion clouds of Nutmeg I, Redwood I, and Spruce events essentially up the field lines at or near the time striations formed for the respective events. This fact allowed a vast amount of unique and significant data to be acquired on the early geometry of new striations.

The three one kg secondary, or puff, releases were incorporated into the Secede II operational plan to provide a reference release - i.e., one not itself disturbing the local ionosphere - for comparison with the development of the primary releases. These releases are denoted as Nutmeg II, Plum II, and Redwood II. Good data was obtained for the latter two, but cloud cover obscured the first puff release for much of its visible history and little data was obtained as a result.

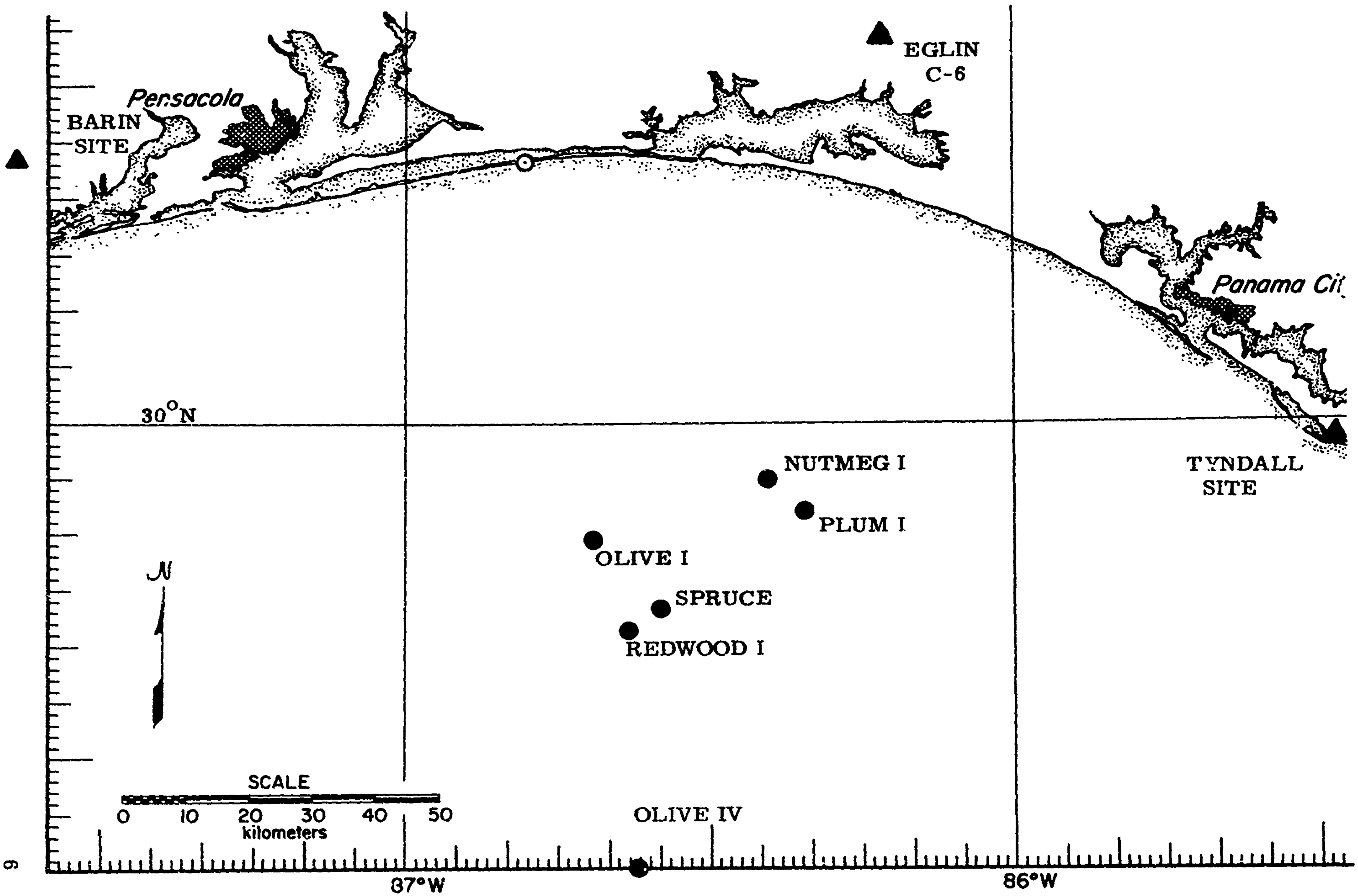
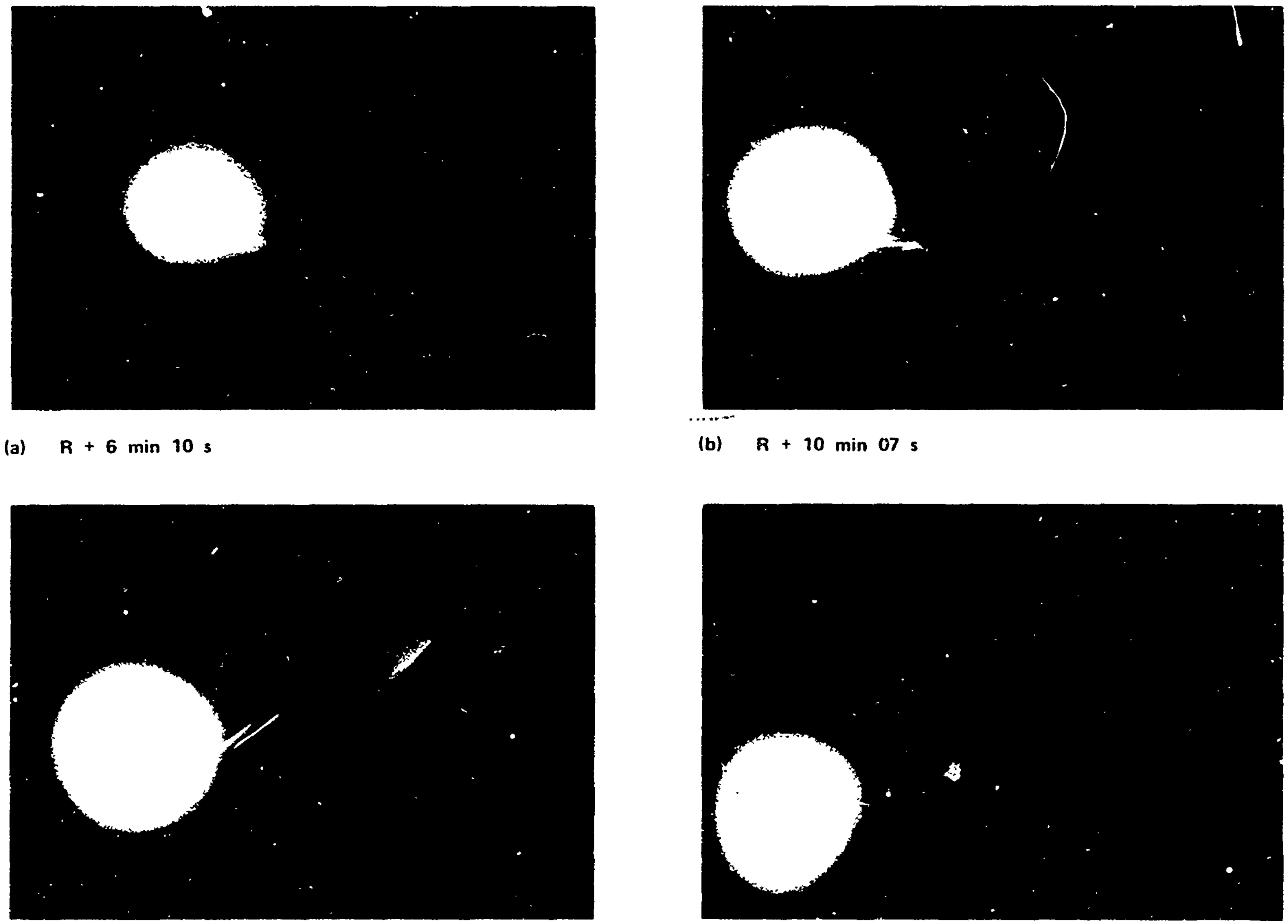


FIGURE 1 SECEDE II PRIMARY EVENT SUB-RELEASE POINTS

II ION CLOUD DEVELOPMENT HISTORY - PRIMARY RELEASES

The intent of Section II is to provide a qualitative description of the characteristic development of the six primary barium releases of the Secede II program. This will be accomplished by displaying a series of four photographic record frames of a given release from a given optical site. The times chosen for the frames presented were chosen so as to provide data (where practicable) of the early ion cloud, the cloud near striation time, the ion cloud where striations were most significant, and fourthly, the late-time cloud before sunset at cloud altitude. An attempt was made to further coordinate the frame times with respect to other events so as to permit a cursory comparison of the respective cloud histories. Since the spatial form of a given cloud at a particular time will appear to be radically different depending upon the perspective of the observer with respect to the cloud drift motion vector and magnetic meridian plane, the photographs presented here include views up the geomagnetic field lines and in several instances views from somewhat orthogonal perspectives as well. It should be borne in mind that the data record frames shown here are reproduced from color originals and lose a significant amount of information content as a result of the reproduction.

Figure 2 shows the development of the Nutmeg I event from the Eglin C-6 site. As mentioned earlier, the time of release coincided with a solar depression angle of 6^{o} and the sky background tended to wash out the earlier record frames. (It should be noted, however, that here and in similar situations the use of color film emulsions generally provides a good spectral contrast between the release and sky background if not a good intensity contrast, and should be used for photographing events released before 8^{o} SDA.) Figures 2a and 2b show the structure of the ion cloud between 6 and 10 minutes during which the view from



(a) R + 6 min 10 s

(b) R + 10 min 07 s

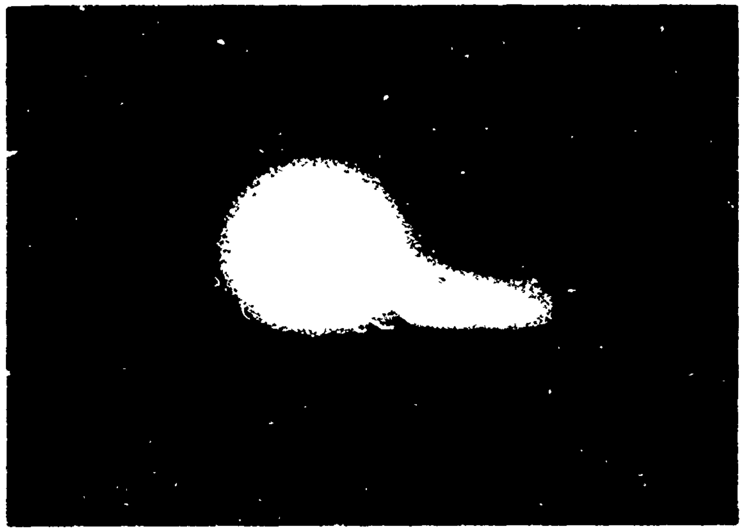
(c) R + 13 min 51 s

(d) R + 19 min 11 s

FIGURE 2 NUTMEG RELEASE, 147-km ALTITUDE - EGLIN C-6 OPTICAL SITE the C-6 site was essentially up the field lines through the ion cloud. The structure of the multiple striations at the trailing edge of the ion cloud (toward the neutral cloud) is quite distinctive during these times. In contrast with other releases, the separation of the neutral cloud and the trailing edge of the ion cloud was generally less for Nutmeg I even at late times.

Figure 3 describes the ion cloud development of the Plum I event as seen from C-6. Figure 3a shows the cloud with a steepened trailing edge, but about 2 minutes before striations have occurred. Figure 3b shows the ion cloud about 2 minutes after striations were observed. Because of the relatively high drift velocity of the clouds to the east (left in the photograph), the striations were not viewed up the field lines for this event. A large number of striations developed between 8 and 12 minutes for the Plum I event, as is also evidenced by Figure 4 showing the ion cloud development as seen from Tyndall AFB. The times of Figure 4 are made comparable to those of Figure 3 for purposes of comparison. By about 14 minutes, 40 separate apparent striations can be seen from the Tyndall site.

For further comparison, the Plum I event is shown in Figure 5 as seen from Barin Field, Ala., again at similar times as in the previous two figures. Because of the effective foreshortening of the east-west dimension of the ion cloud, the visually overlapping striations are not as evident on an individual basis and one might conclude that many fewer exist than is actually the case. All of the Plum I records show an interesting aspect of the striation development of the ion cloud; namely, the appearance of a striated type of structure more toward the leading edge of the cloud than the trailing edge in the 10 - 15 minute time regime.



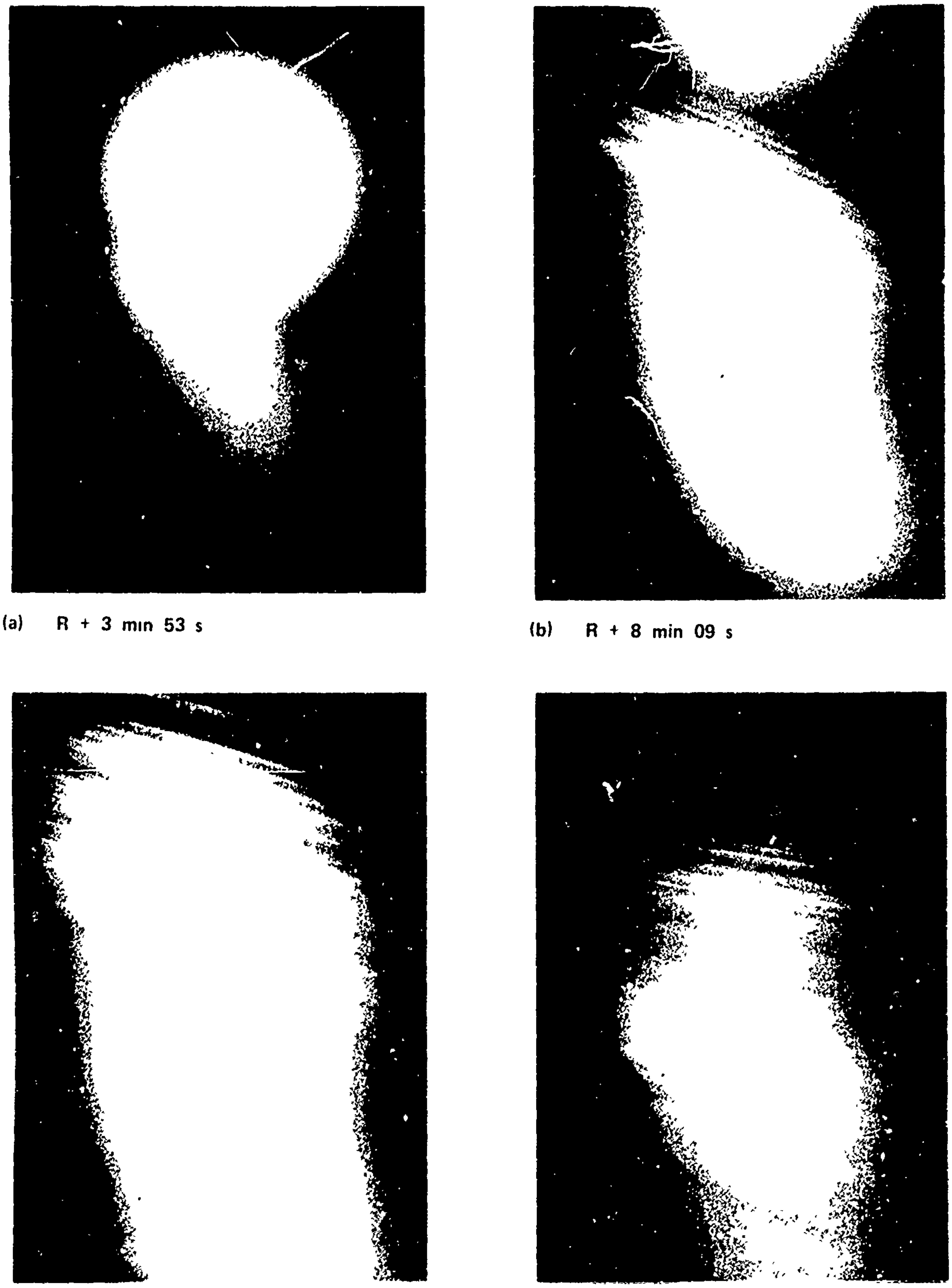
(a) R + 4 min 05 s

(b) R + 2 min 05 s

(c) R + 11 min 58 s

(d) R + 16 min 43 s

FIGURE 3 PLUME RELEASE, 186-km ALTITUDE - EGLIN C-6 OPTICAL SITE



(a) R + 3 min 53 s

(b) R + 8 min 09 s

(c) R + 11 min 53 s

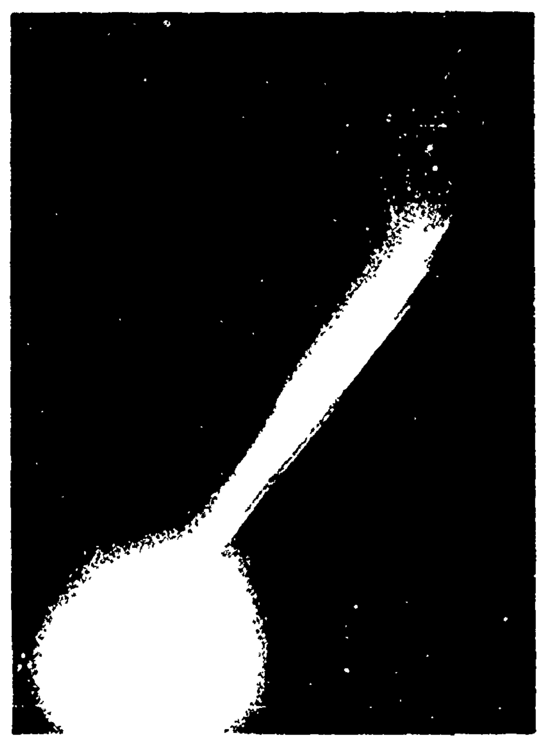
(d) R + 16 min 01 s

FIGURE 1 PLUME RELEASE, 186-km ALTITUDE - TYNDALL AFB OPTICAL SITE

(a) R + 4 min 02 s

(b) R + 8 min 04 s

(c) R + 11 min 55 s



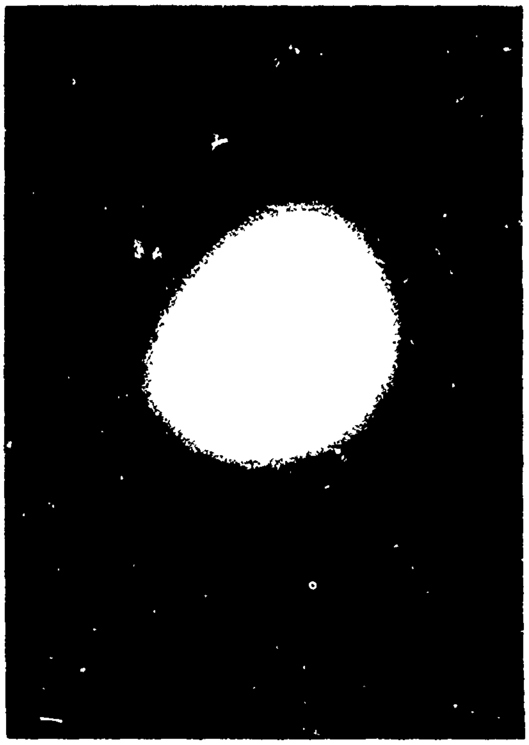
(d) R + 16 min 42 s

FIGURE 5 PLUME RELEASE, 186-km ALTITUDE - BARIN FIELD OPTICAL SITE

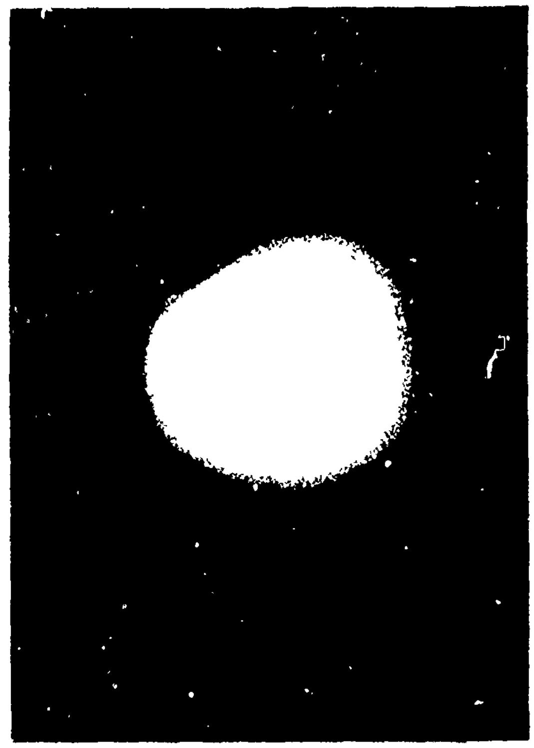
The Redwood event was the second such release which was viewed up the field lines during the onset of striations. Having been released at 250 km altitude, the cloud expanded relatively rapidly. The subsequent development saw an apparently short-lived neutral cloud develop into a large unchanging ion cloud which finally striated at about 15 minutes after the release. Figure 6 shows the development of the striations looking up the field lines over a period of 10 to 23 minutes after the release.

The Olive release was rather spectacular, as related earlier, in that separation of barium chemistry canisters caused four separate releases to occur. The first main release engulfed the second and third releases within its expanding barium vapor cloud, and, hence, they are considered to be a single release for times beyond the first few seconds, (Olive I). The fourth canister release (Olive IV) was spatially as well as temporally removed from Olive I and, therefore, exhibited a vapor cloud development of its own. Figure 7 shows the qualitative development of Olive I between 9 and 21 minutes. It is interesting to note that what striation development did occur occurred at quite late times and was, moreover, of a gross structure in nature - not the finely defined narrow striations which existed in the other releases by this time or even well before this time. Another aspect of this release was the apparently intense brightness of the neutral cloud as compared with the other releases, whereas the ion cloud was not significantly different in peak brightness from other ion clouds (Section V).

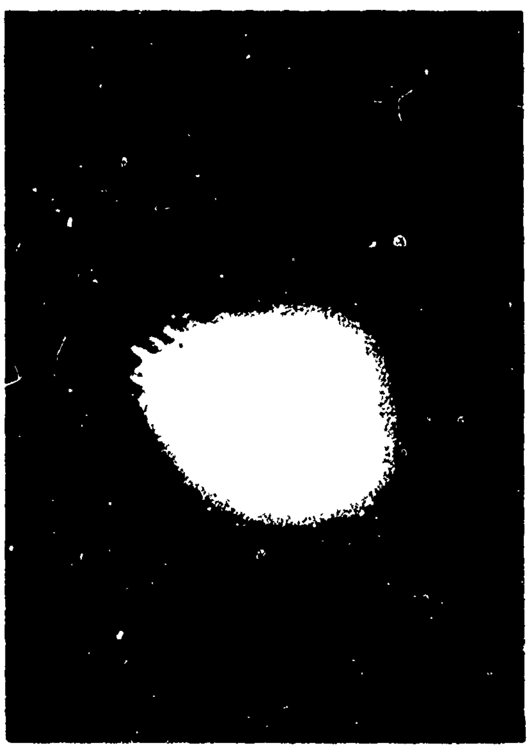
The behavior of the Olive IV event (16kg in yield) appeared in most respects similar to that of the Plum I release. Figure 8 displays the development of Olive IV as seen from Eglin AFB from about R + 3 minutes to about 15 minutes. Something like 25 individual striations were observed by 16 minutes after release. The appearance of Olive IV from



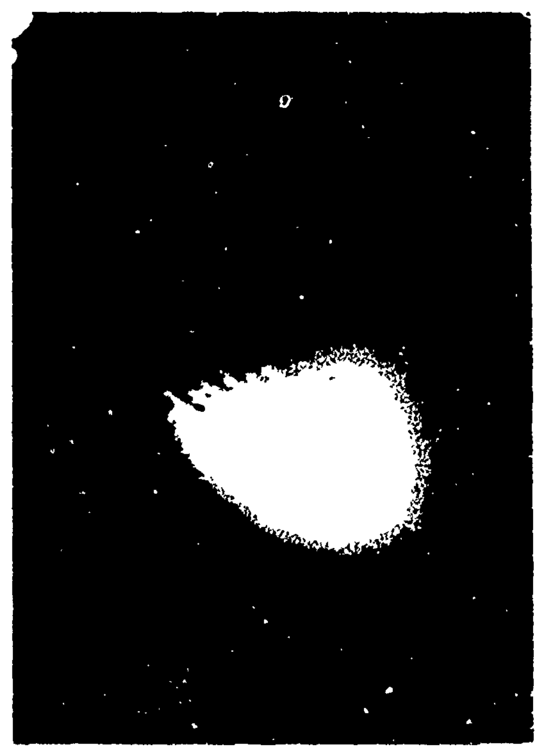
(a) R + 10 m 02 s



(b) R + 19 m



(c) R + 21 m 55 s



(d) R + 23 m 06 s

FIGURE 6 REDWOOD I RELEASE, 259-km ALTITUDE - EGLIN C-6 OPTICAL SITE

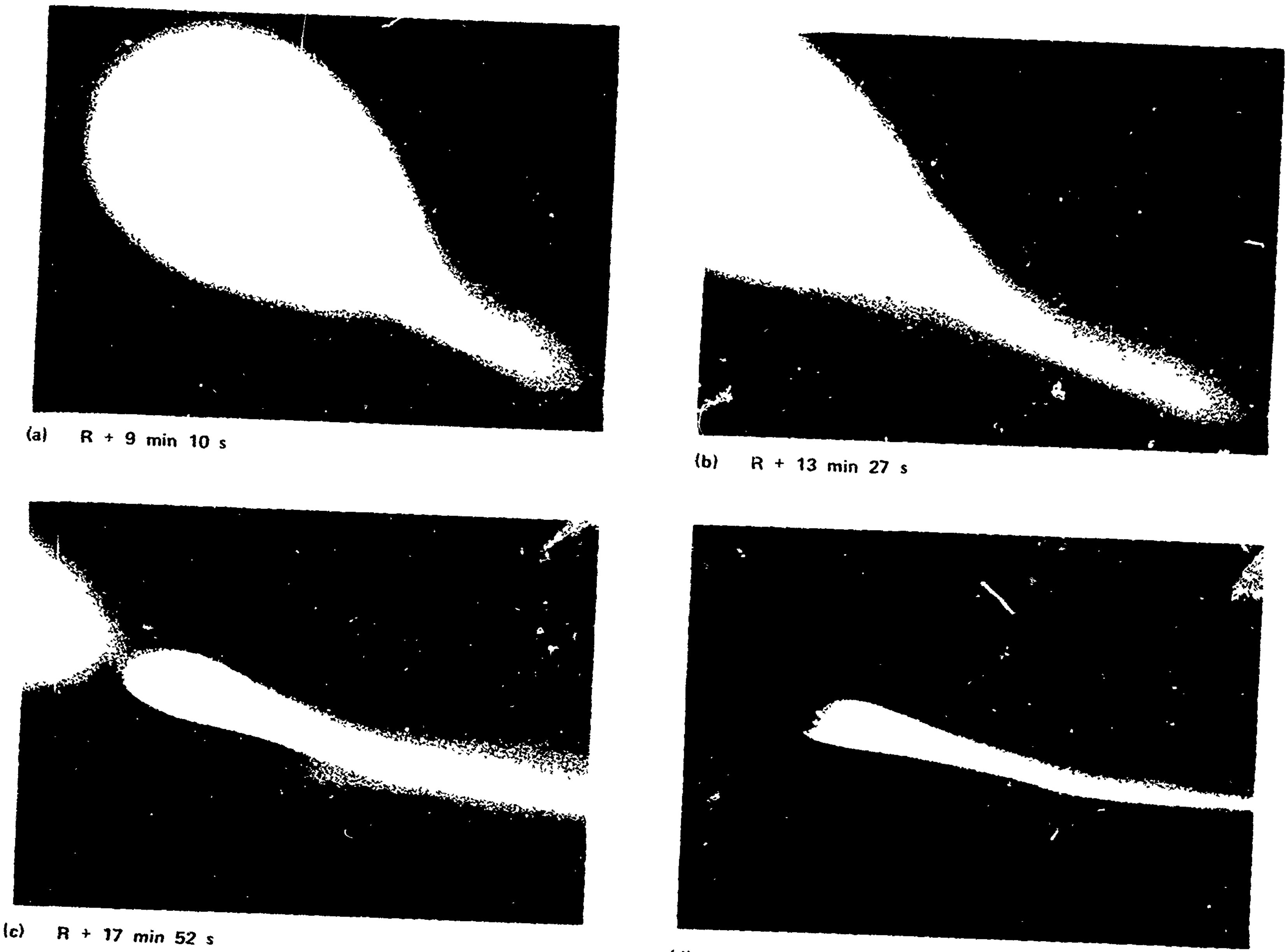
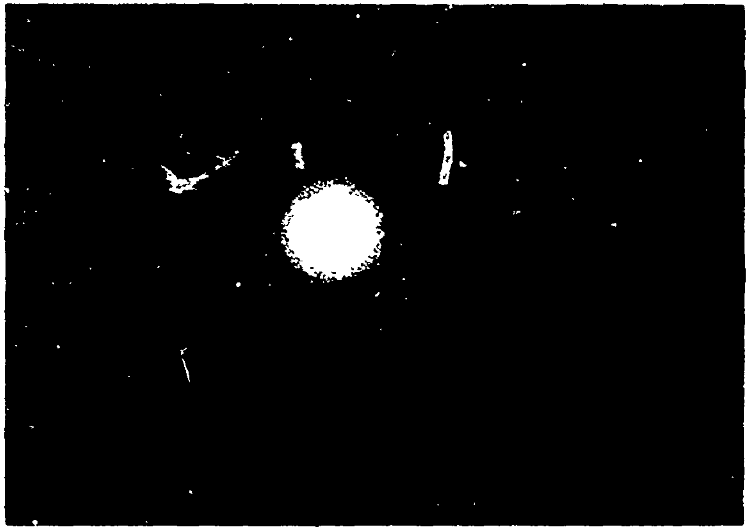
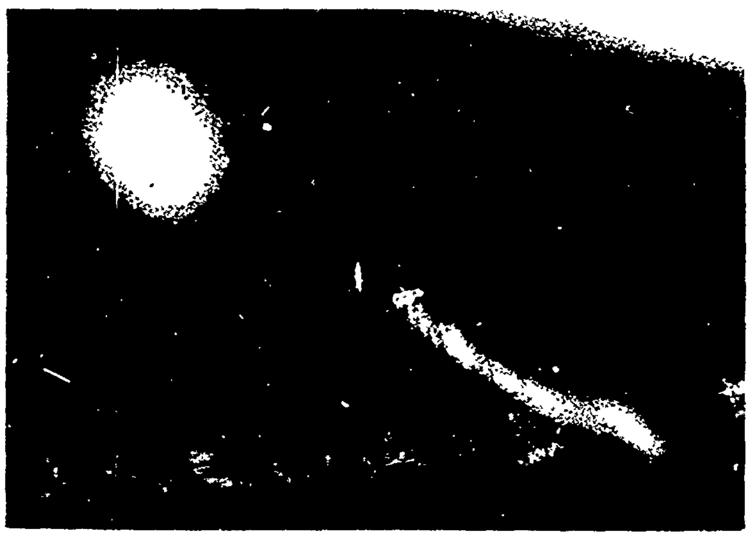


FIGURE 7 OLIVE I RELEASE, 193-km ALTITUDE - EGLIN C-6 OPTICAL SITE



(a) R + 2 min 47 s

(b) R + 8 min 07 s



(c) R + 10 min 11 s

(d) R + 14 min 18 s

FIGURE 8 OLIVE IV RELEASE, 187-km ALTITUDE - EGLIN C-6 OPTICAL SITE

Barin Field and Tyndall AFB is shown if Figures 9a, 9b, 9c, and 9d, respectively.

The Spruce release was made under operational circumstances much the same as Plum I. The major ambient difference affecting the release was the velocity of the neutral winds at the detonation altitude. The wind speeds during the Spruce event were on the order of half those during Plum as determined by the neutral and ion tracks (Section III). As a consequence of this difference, the striation onset time was approximately twice that of Plum. Figure 10 shows the development of the Spruce event as seen from the C-6 site. Again, for the third time this site was viewing the striation development up the field lines. In fact, the Spruce event is probably the best documented in this respect.

One of the many interesting features of the Spruce data from the C-6 site is the solar shadow located between the ion and neutral clouds resulting from structural characteristics of the ion cloud, as seen in Figure 10b. A second aspect of interest is the clearly recorded development of the fine structure of the ion cloud. This is shown in more detail in Section IV. Figure 11 shows the ion cloud as seen from Tyndall AFB. From this perspective, the ion cloud development appears remarkably like both the Plum I and Olive IV events. (The bright image in the photograph is the moon.) Similarly, the perspective from Barin Field, Ala., is comparable to Plum I and Olive IV, as seen in Figure 12. The times covered by the photographs in all the Spruce figures vary from about 9 minutes through 25 minutes with similar increments between photographs to aid in the interpretation of the data.

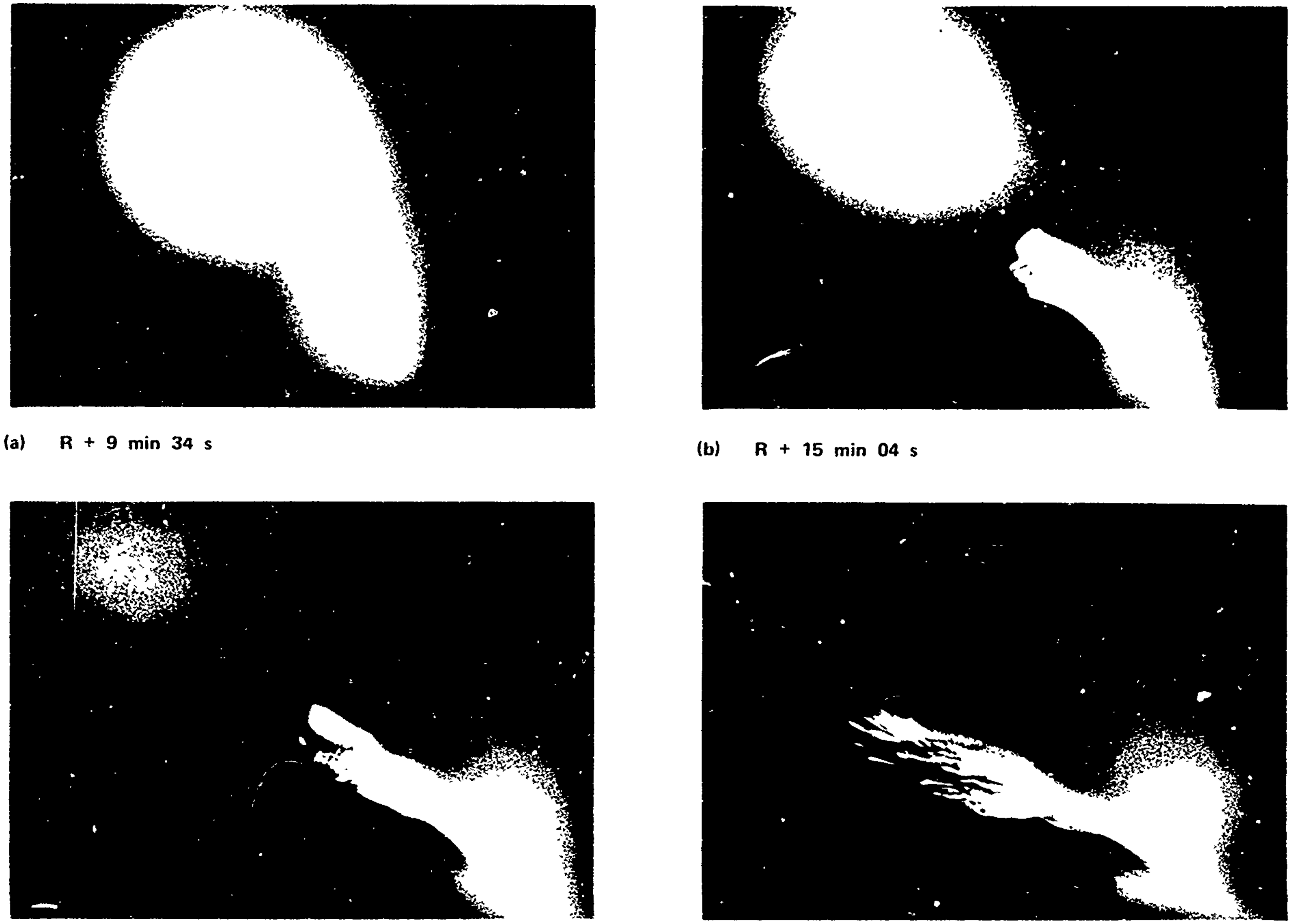
(a) BARIN SITE, R + 8 min 31 s

(c) TYNDALL SITE, R + 8 min 32 s

(b) BARIN SITE, R + 14 min 04 s

(d) TYNDALL SITE, R + 13 min 57 s

FIGURE 9 OLIVE IV RELEASE, 187-km ALTITUDE



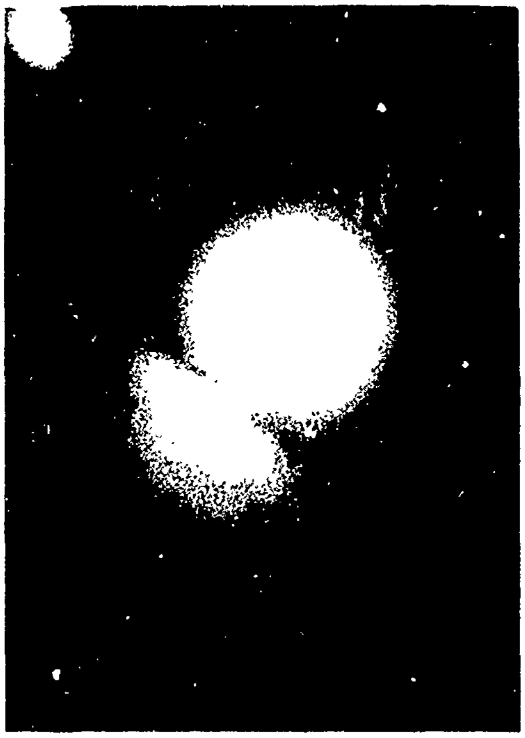
(a) R + 9 min 34 s

(b) R + 15 min 04 s

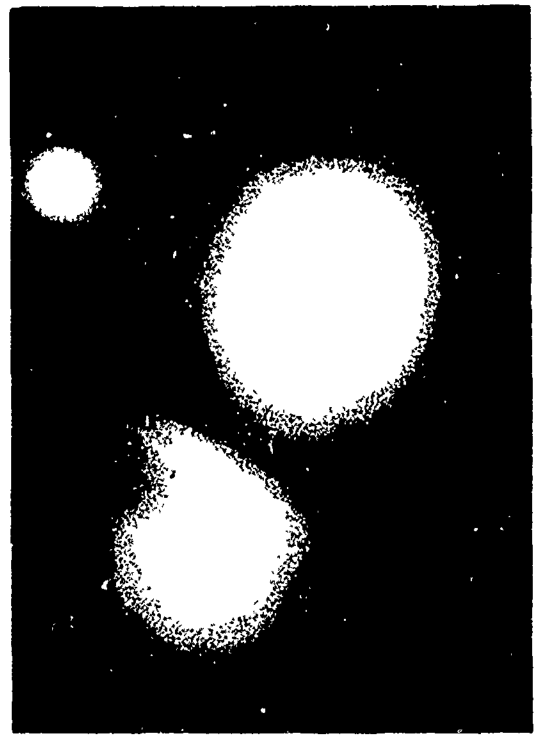
(c) R + 18 min 56 s

(d) R + 24 min 25 s

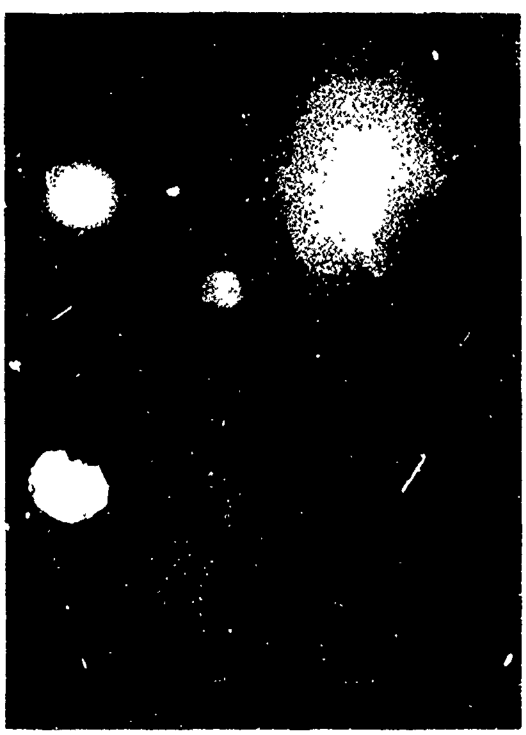
FIGURE 10 SPRUCE RELEASE, 193-km ALTITUDE - EGLIN C-6 OPTICAL SITE



(a) R + 9 m 33 s



(b) R + 15 m 05 s

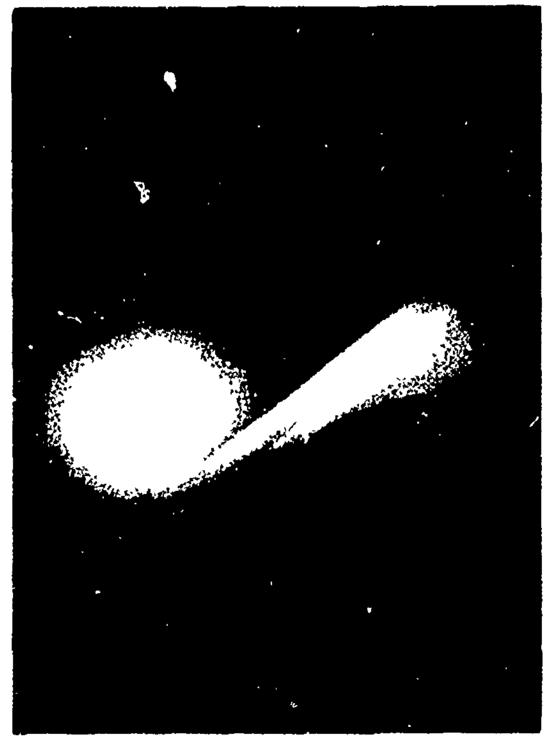


(c) R + 18 m 51 s

(d) R + 24 m 28 s

FIGURE 11 SPRUCE RELEASE, 193-km ALTITUDE - TYNDALL AFB OPTICAL SITE

(a) R + 9 min 33 s



(b) R + 15 min 06 s

(c) R + 18 min 51 s

(d) R + 24 min 17 s

FIGURE 12 SPRUCE RELEASE, 193-km ALTITUDE - BARIN FIELD OPTICAL SITE

III NEUTRAL AND ION CLOUD MOTION

The early expansion of the Secede II neutral clouds was measured from the tracking camera records to R + 30 seconds and is presented in Figure 13. Perhaps the first aspect of this data to identify is the fact that the Plum I and Spruce events exhibit much the same expansion characteristics. Allowing for a time-base error bar of about 2 seconds, the two curves in mention could in fact overlie. Starting with this nominal release (185 km, 48 kg), it can be seen that the same yield, lower altitude release (Nutmeg I) or lower yield, same altitude release (Olive IV) expands more slowly (as expected). Similarly, the same yield, higher altitude (Redwood I) or larger yield, same altitude (Olive I) release expands more rapidly than the nominal release.

Determining the track of a barium neutral or ion cloud is at least partially a subjective process, and it is important to discuss this when presenting tracking data. Since one must first define the common point which is to be triangulated from two or more optical site records, applicable definitions of cloud features must be first evolved. In Figure 14 are presented simultaneous views of the Spruce event at R + 16 - 1/2 minutes from Tyndall AFB and Eglin C-6 optical sites respectively. Clearly there is the possibility that somewhat different features might be defined as the end of a trailing edge, for example. It is important therefore, that a geometrical model be defined and rigorously followed throughout the data reduction so as to provide consistency among the resulting data of each event. In order to partially explain the technique used for the data presented herein, Figure 15 is presented to show the features used to define the ends of the trailing edge visually on an original (color) data record and where these "points" lie on a densitometric trace of a comparable (black and white) data frame. (Note that Figures 15a and 15b are only approximately equal in scale and orientation.)

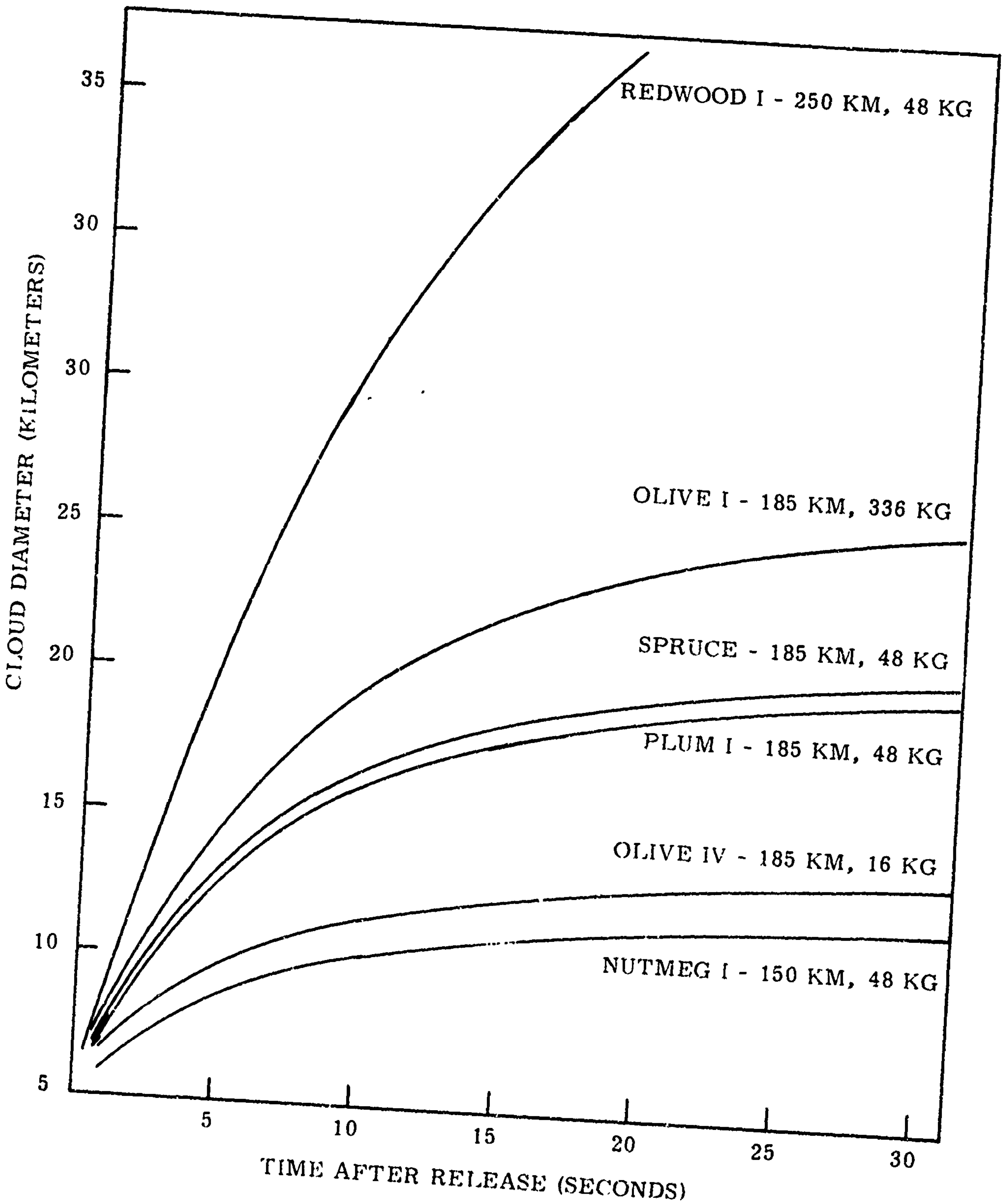
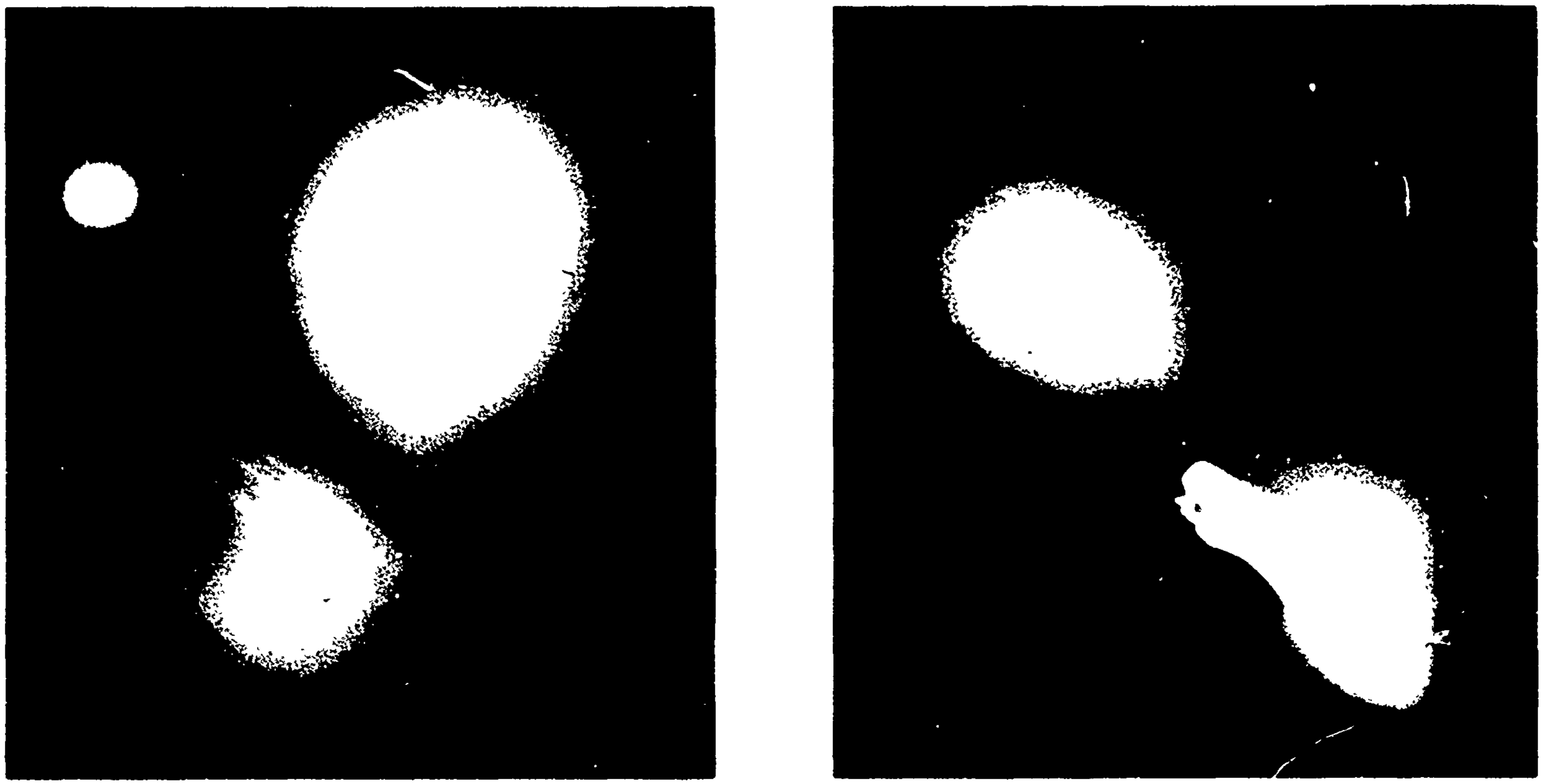


FIGURE 13 SECEDE II CLOUD DIAMETER VS. TIME

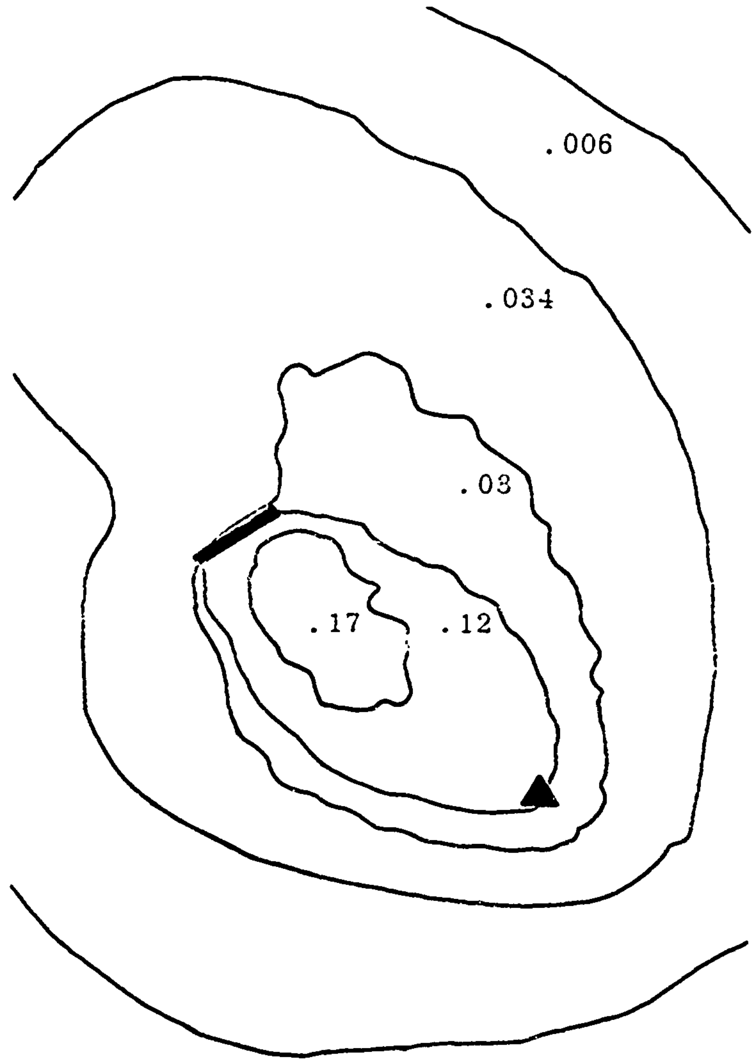


(a) TYNDALL SITE, R + 16-1/2 min

(b) EGLIN C-6 SITE, R + 16-1/2 min

FIGURE 14 ORTHOGONAL VIEWS OF SPRUCE CLOUD STRUCTURE

(a) DEFINED TRIANGULATION POINTS (SPRUCE)



(b) POINTS OVERLAYED ON ISO-RADIANCE CONTOUR

FIGURE 15 TRIANGULATION FEATURES USED FOR ANALYSIS

The import of this discussion is to indicate that although the choice of somewhat different criteria might result in a comparable difference in cloud track data, strict consistency in the application of a given technique will provide data appropriate for theoretical evaluation and interpretation in a meaningful way.

The reduction of cloud-photograph data to cloud positions consists of (1) determination of the mid-exposure time for each frame of the photographic sequence, (2) determination of camera attitude (azimuth, elevation, and roll), (3) determination of the optical transformation (focal distance and optical-axis location relative to film), and (4) triangulation. Camera attitude is determined from star pairs identified in any frame between attitude changes. The camera axes are related to a stellar-axis system by means of film coordinates of the star images. The stellar-axis system is in turn related to the local-station axis system through star positions, time, and station longitude and latitude. In triangulation, two optical station positions are referred to the geocenter using the Clarke spheroid of 1866, with all vectors being resolved along an equatorial axis system. Two optical sites are employed, and the problem of skew lines of sight is resolved by taking the solution to be the mid-point of the shortest line segment between these two lines. The "miss-distance" is determined as an indication of consistency. The cloud position is finally expressed in terms of its geodetic coordinates in accord with the Clarke spheroid.

Using the technique described in part above, the tracks of the neutral and ion clouds of the six primary and two visible puff releases are presented in Figures 16 through 22. Where practical, the track plots show the burst point (solid circle), the motion of the center of the neutral cloud (open circle), the center of the leading edge (open triangle), and the top and bottom of the trailing edge (solid broad line of length

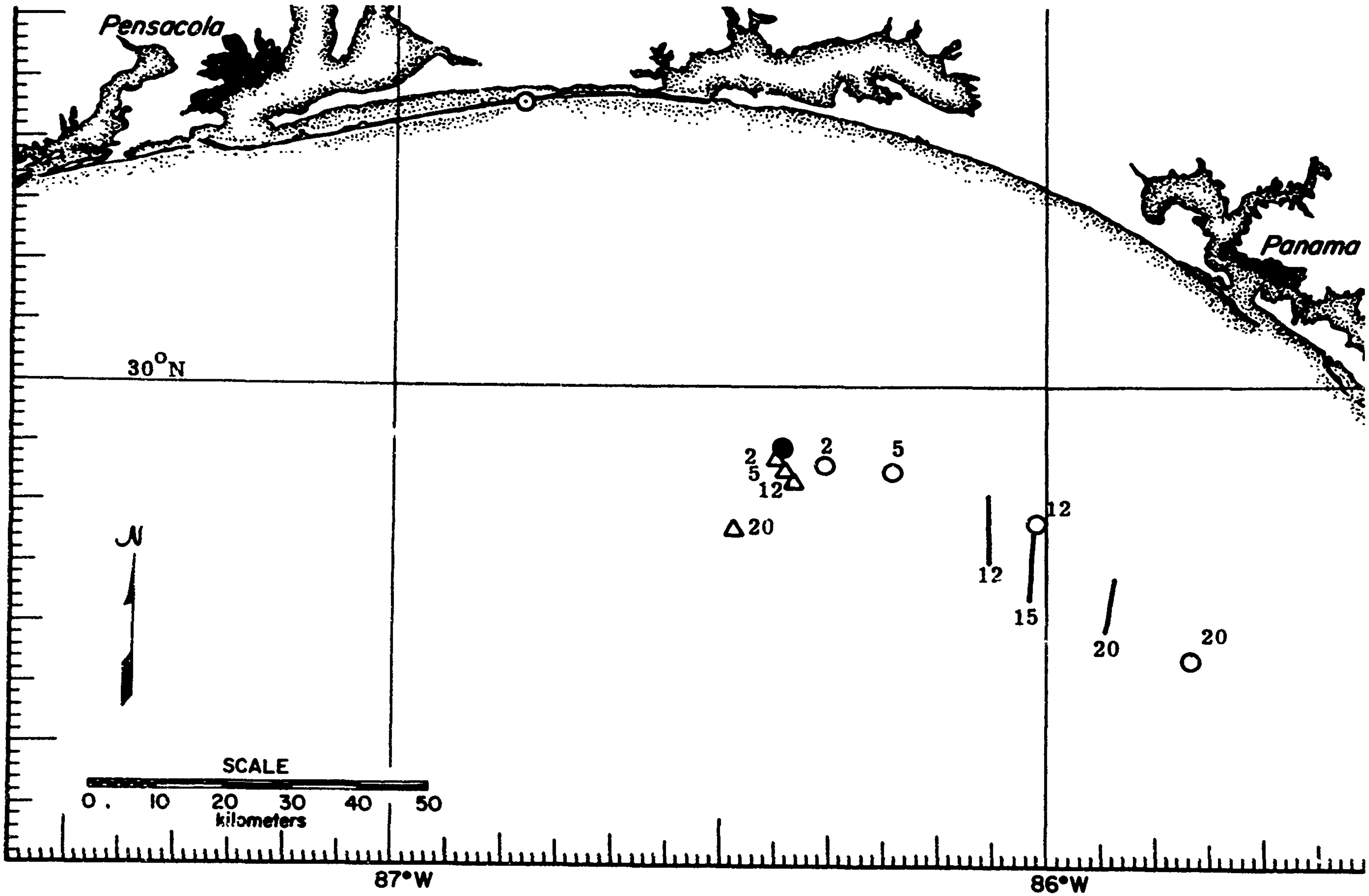


FIGURE 16 NUTMEG I CLOUD TRACKS

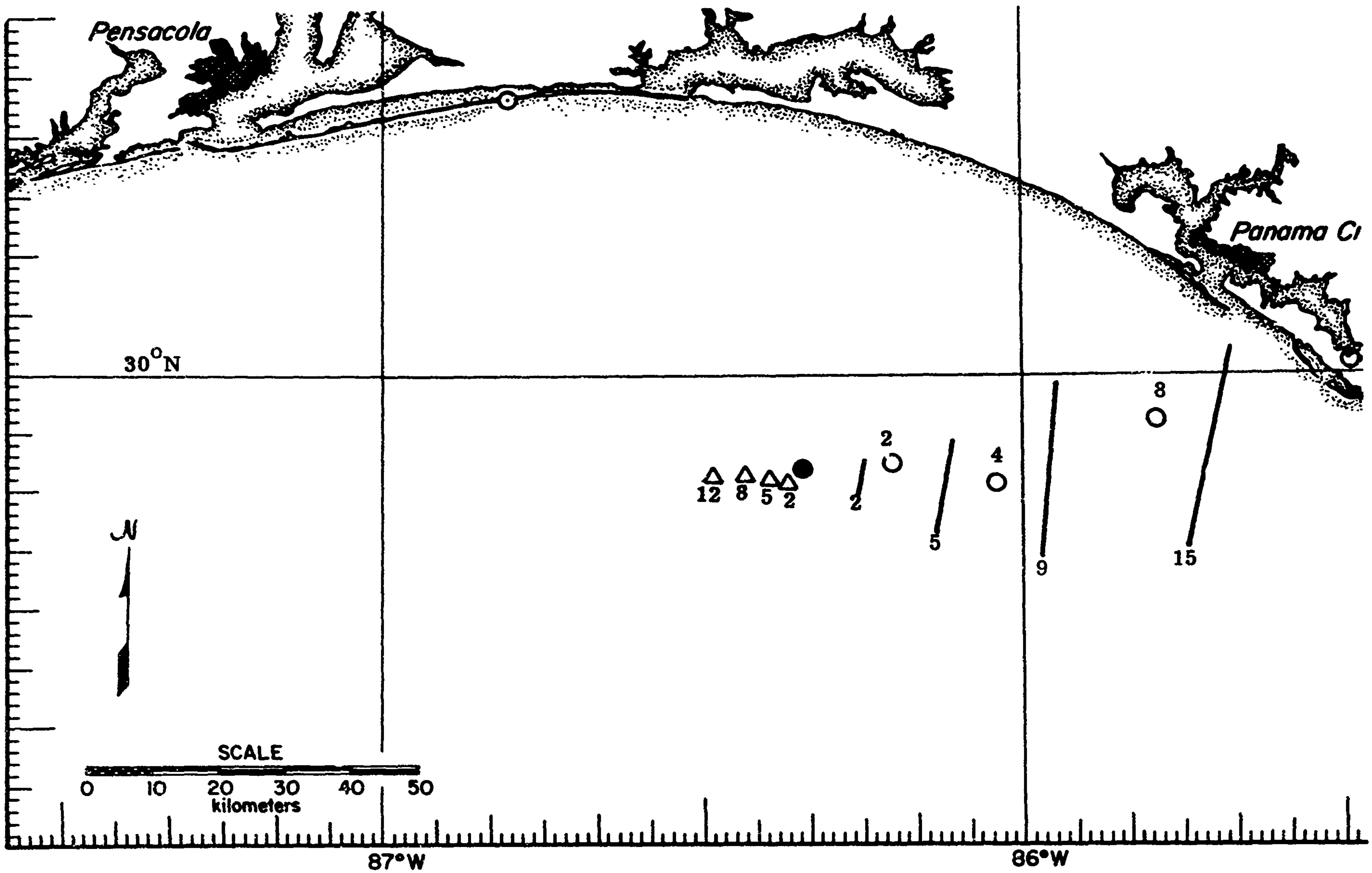


FIGURE 17 PLUM I CLOUD TRACKS

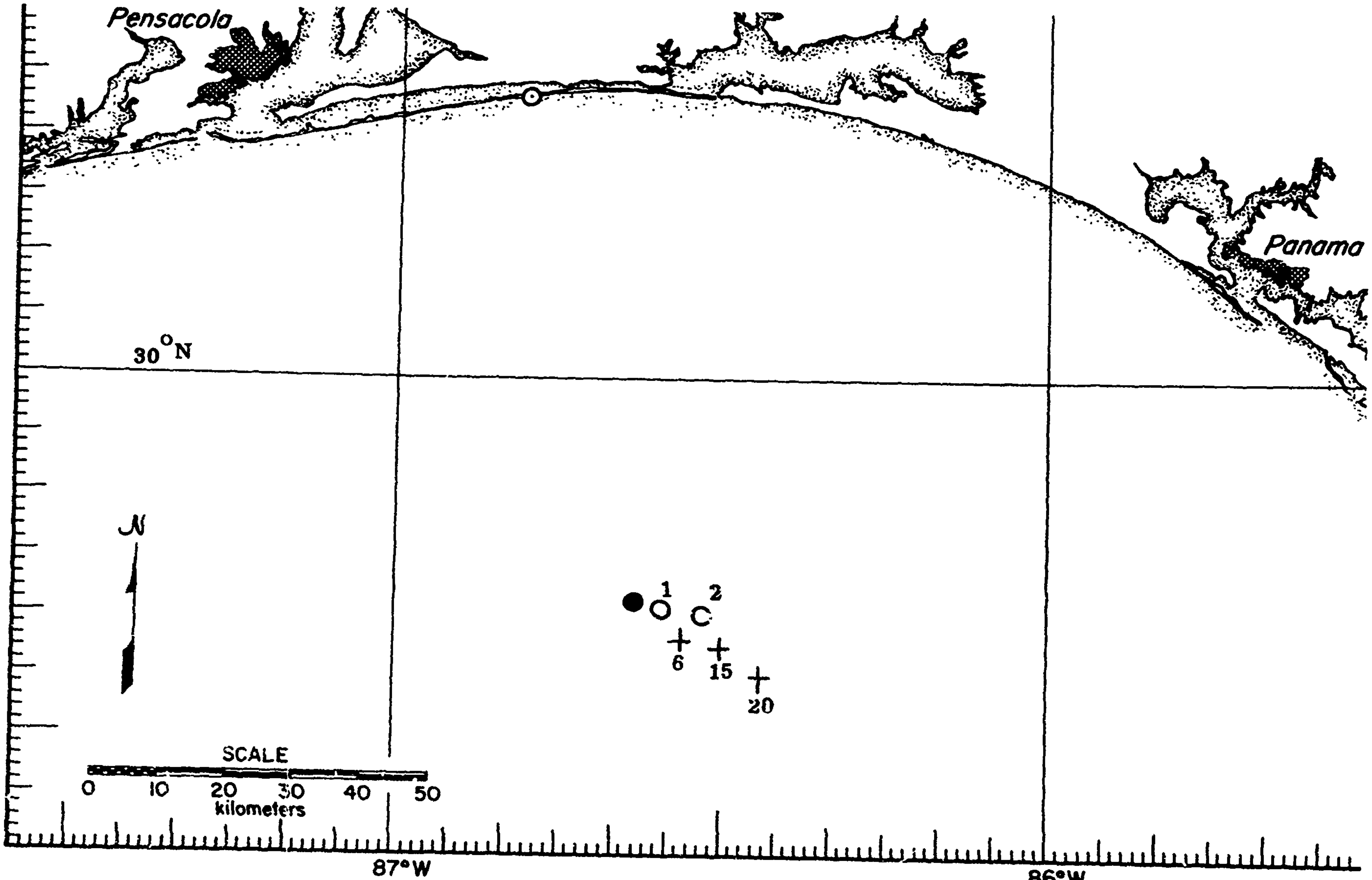


FIGURE 18 REDWOOD I CLOUD TRACKS

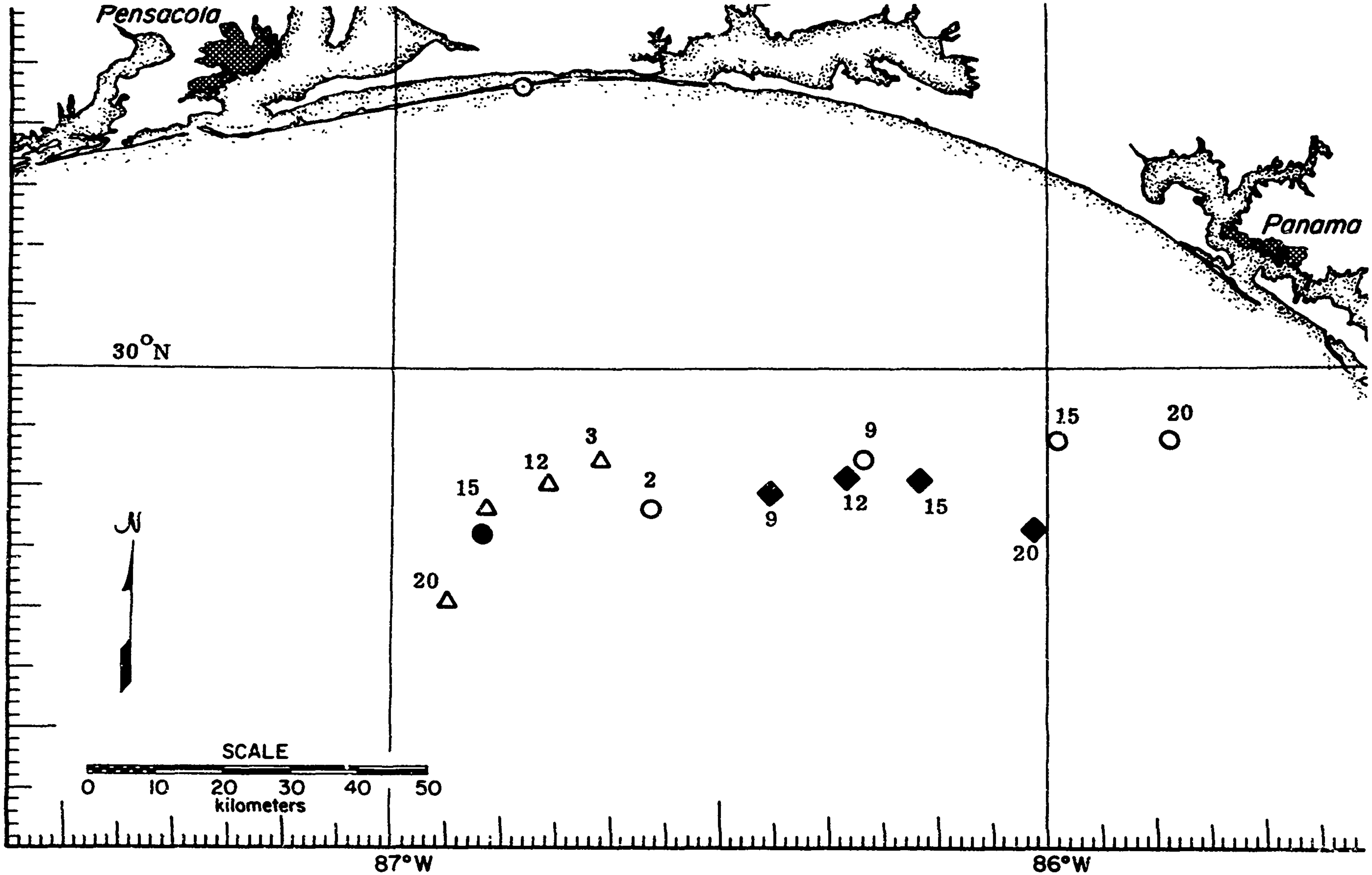


FIGURE 19 OLIVE I CLOUD TRACKS

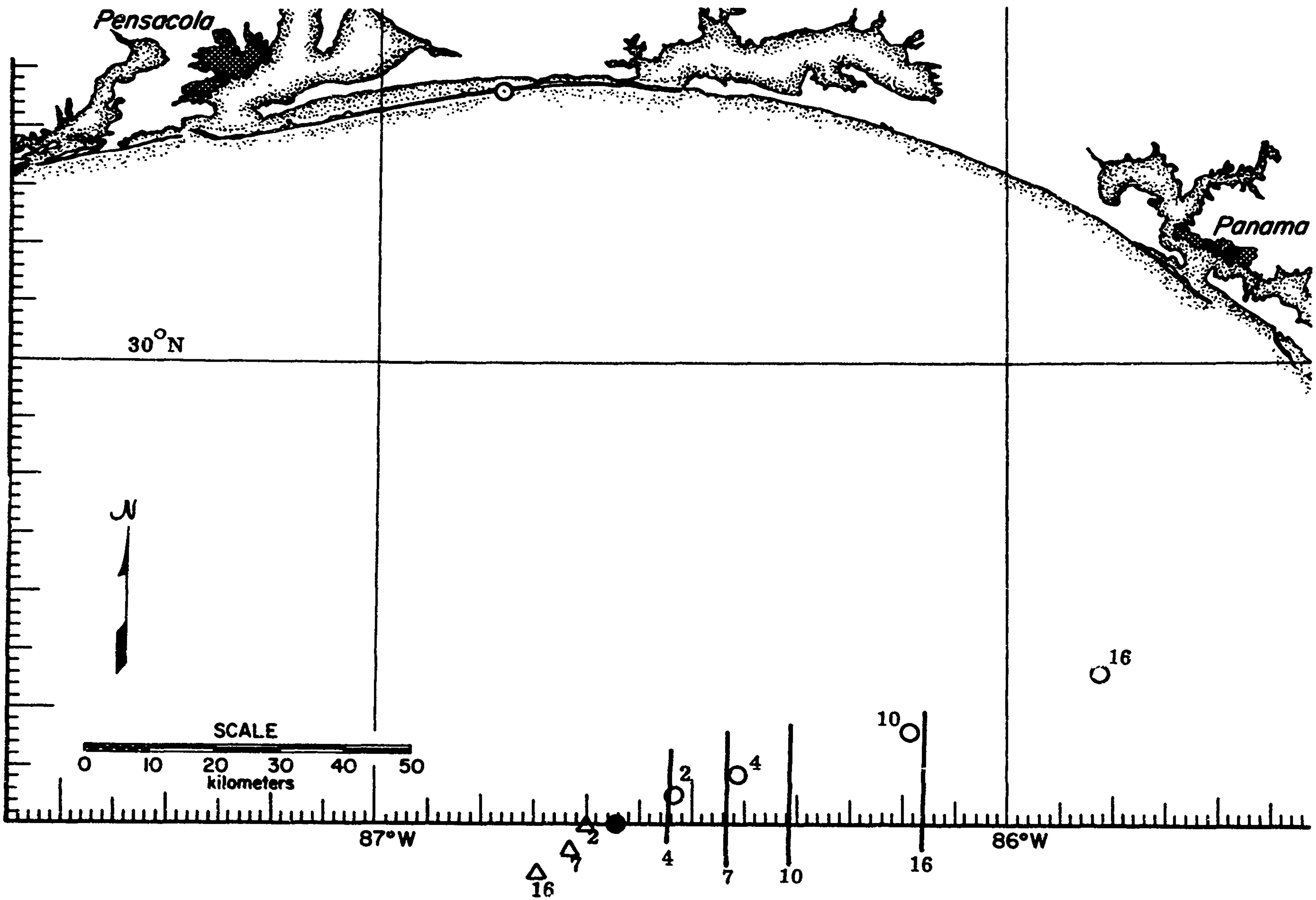


FIGURE 20 OLIVE IV CLOUD TRACKS

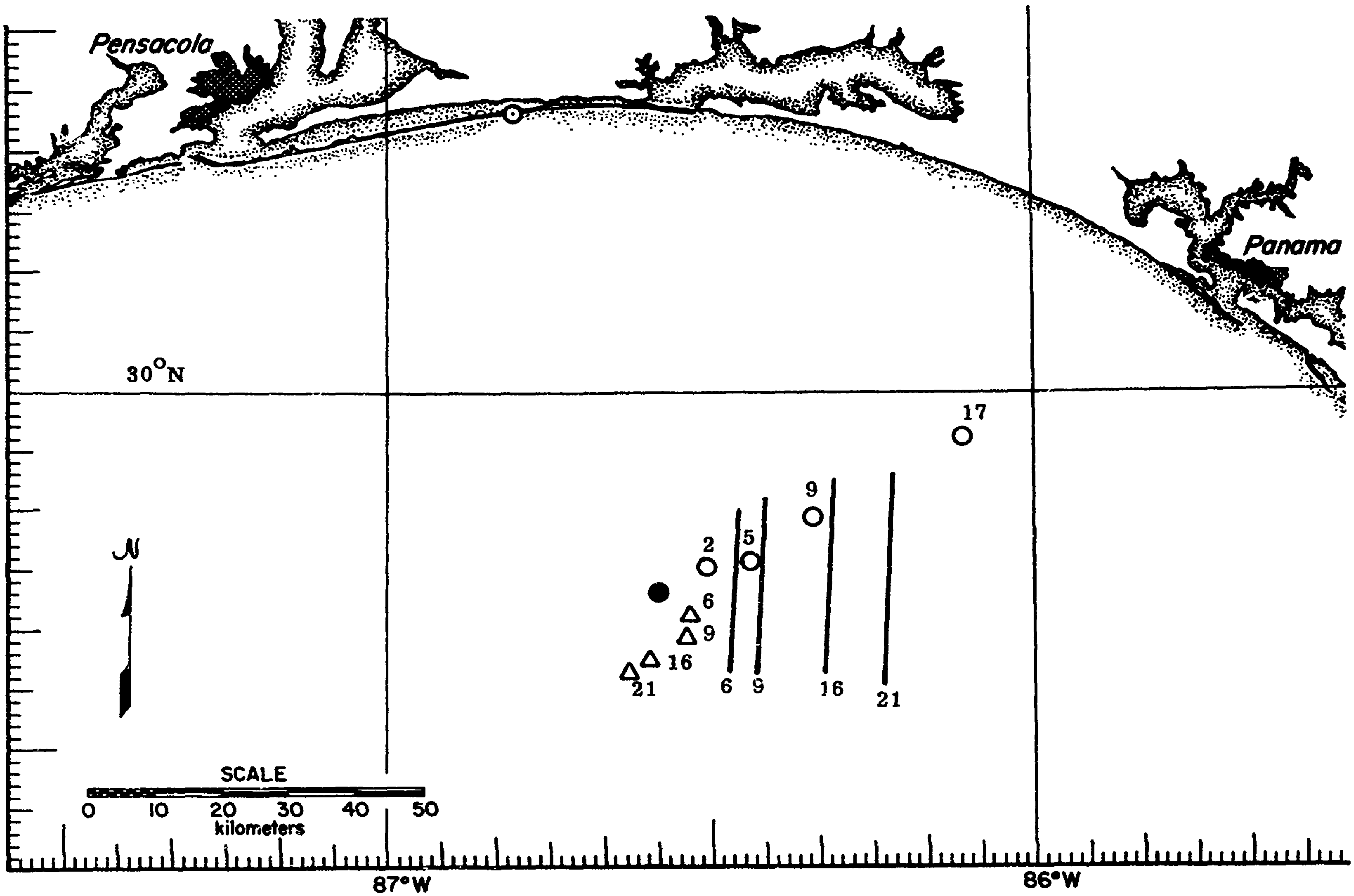


FIGURE 21   SPRUCE CLOUD TRACKS

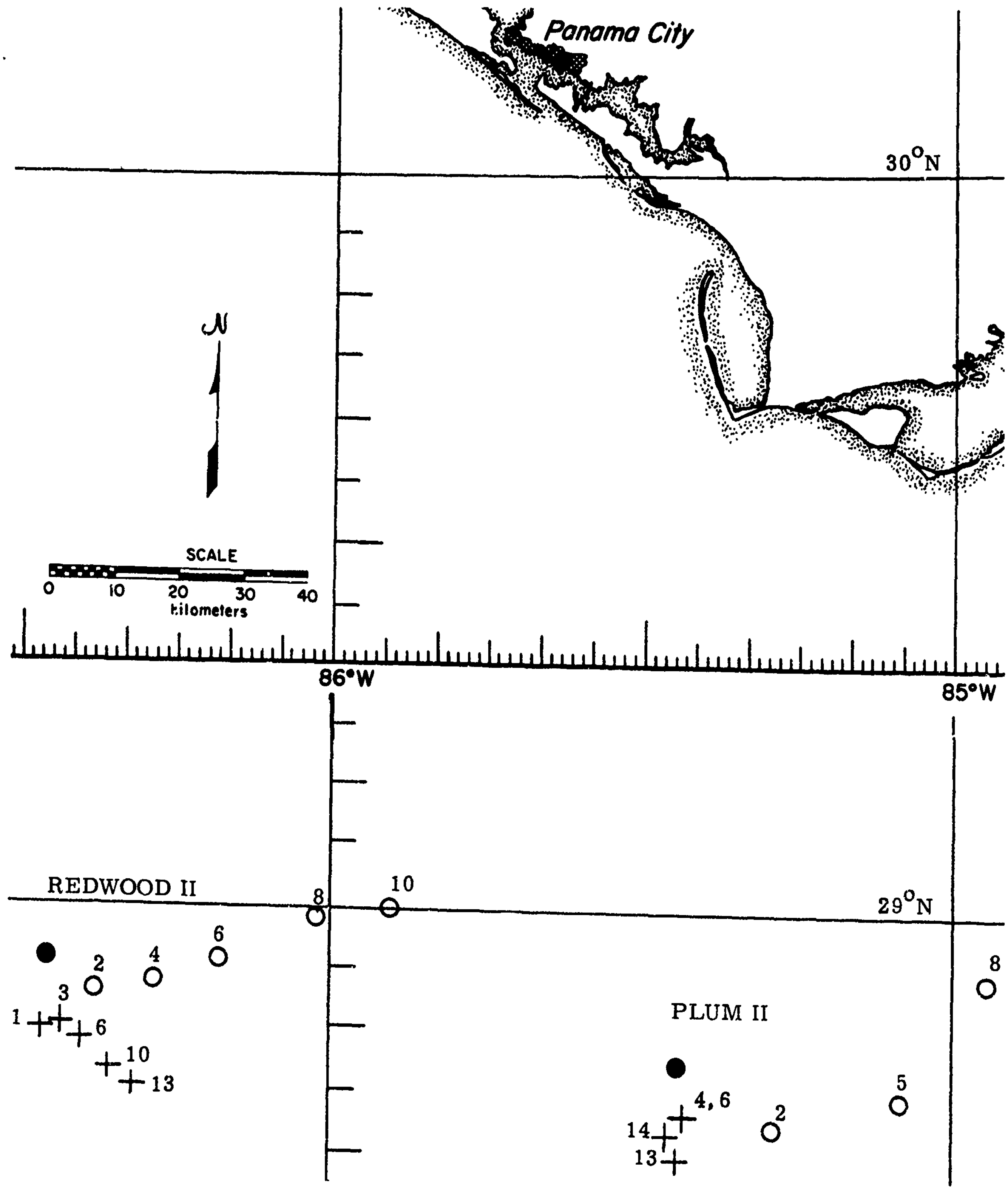


FIGURE 22 REDWOOD II and PLUM II CLOUD TRACKS

equal to the projection of foremost trailing edge striation on ground plot). Exceptions to this scheme are RedwoodI, in which the center of the ion cloud is plotted (cross), Olive I, in which the center of the trailing edge is plotted (solid diamond), and the Redwood II and Plum II puff releases, in which the center of the ion cloud is plotted (cross). Times shown at each plot point are in minutes after release.

In general, the measurements of the tracking data records were carried out to 15 to 20 minutes for most releases. The error associated with the plot of a given point is considered to be approximately of the order of the size of the symbol chosen to plot the point, i.e., a few kilometers. A further indication of the triangulation accuracy is the fact that solid lines representing the extent of the trailing edge should in effect be a projection of local geomagnetic field lines on the earth's surface, and as such should be essentially parallel to one another for all events. Some minor variance is observed.

The neutral and ion cloud track data has been further reduced in tabular form to provide a semi-quantitative value of the cloud velocity and geographic heading vector for 5-minute intervals for the six primary and two visible secondary (puff) releases. The primary cloud data is presented in Tables III through V for the neutral center, ion trailing edge, and ion cloud leading edge respectively, and in Table VI for the neutral cloud center and ion cloud center for the puff releases.

The altitudes of the neutral and ion clouds derived from the triangulation process described above are shown in Figures 23 through 28. In most cases, the features plotted are the center of the neutral cloud (circle), the leading edge of the ion cloud (triangle), and the center of the trailing edge (square). Exceptions are Plum II and Redwood I in which the center of the ion cloud is plotted as a square.

TABLE III

SECEDE II CLOUD MOTION - NEUTRAL CENTER

MEAN VELOCITY (SPEED, AZIMUTH)

EVENT	APPROXIMATE TIME PERIOD			
	0-5 MIN.	5-10 MIN.	10-15 MIN.	15-20 MIN.
NUTMEG I (150 km)	56 m/s (103°)	52 m/s (106°)	66 m/s (126°)	63 m/s (133°)
PLUM I (185 km)	125 m/s (99°)	105 m/s (59°)	69 m/s (72°)	
REDWOOD I (250 km)	86 m/s (104°)			
OLIVE I (185 km)	71 m/s (90°)	75 m/s (81°)	81 m/s (81°)	56 m/s (90°)
OLIVE IV (180 km)	50 m/s (68°)	79 m/s (71°)	84 m/s (75°)	78 m/s (76°)
SPRUCE (185 km)	48 m/s (71°)	50 m/s (60°)	48 m/s (67°)	50 m/s (66°)

TABLE IV

SECEDE II CLOUD MOTION - ION TRAILING EDGE

MEAN VELOCITY (SPEED, AZIMUTH)

EVENT	APPROXIMATE TIME PERIOD			
	0-5 MIN.	5-10 MIN.	10-15 MIN.	15-20 MIN.
NUTMEG I (150 km)			47 m/s (131^{o})	45 m/s (118^{o})
PLUM I (185 km)	71 m/s (98^{o})	66 m/s (83^{o})	70 m/s (81^{o})	
REDWOOD I* (250 km)	28 m/s (136^{o})	13 m/s (75^{o})	16 m/s (139^{o})	23 m/s (125^{o})
OLIVE I (185 km)		48 m/s (89^{o})	62 m/s (84^{o})	62 m/s (112^{o})
OLIVE IV (180 km)	26 m/s (60^{o})	47 m/s (89^{o})	57 m/s (90^{o})	58 m/s (80^{o})
SPRUCE (185 km)	35 m/s (79^{o})	23 m/s (78^{o})	25 m/s (55^{o})	

* VELOCITY OF ION CLOUD CENTER

TABLE V

SECEDE II CLOUD MOTION - ION LEADING EDGE

MEAN VELOCITY (SPEED, AZIMUTH)

EVENT	APPROXIMATE TIME PERIOD			
	0-5 MIN.	5-10 MIN.	10-15 MIN.	15-20 MIN.
NUTMEG I (150 km)	13 m/s (178°)	12 m/s (256°)	14 m/s (112°)	24 m/s (235°)
PLUM I (185 km)	17 m/s (70°)	21 m/s (91°)		
OLIVE I (185 km)	28 m/s (3°)	18 m/s (246°)	39 m/s (241°)	45 m/s (204°)
OLIVE IV (180 km)	18 m/s (266°)	18 m/s (219°)	14 m/s (217°)	12 m/s (288°)
SPRUCE (185 km)	23 m/s (179°)	13 m/s (168°)	9 m/s (260°)	

TABLE VI

SECEDE II CLOUD MOTION - NEUTRAL CENTER

MEAN VELOCITY (SPEED, AZIMUTH)

EVENT	APPROXIMATE TIME PERIOD			
	0-5 MIN.	5-10 MIN.	10-15 MIN.	15-20 MIN.
PLUM II (185 km)	119 m/s (98°)	106 m/s (53°)		
REDWOOD II (185 km)	75 m/s (90°)	119 m/s (74°)		

SECEDE II CLOUD MOTION - ION CENTER

EVENT	APPROXIMATE TIME PERIOD			
	0-5 MIN.	5-10 MIN.	10-15 MIN.	15-20 MIN.
PLUM II (185 km)		17 m/s (180°)		
REDWOOD II (185 km)	22 m/s (104°)	25 m/s (130°)	35 m/s (130°)	

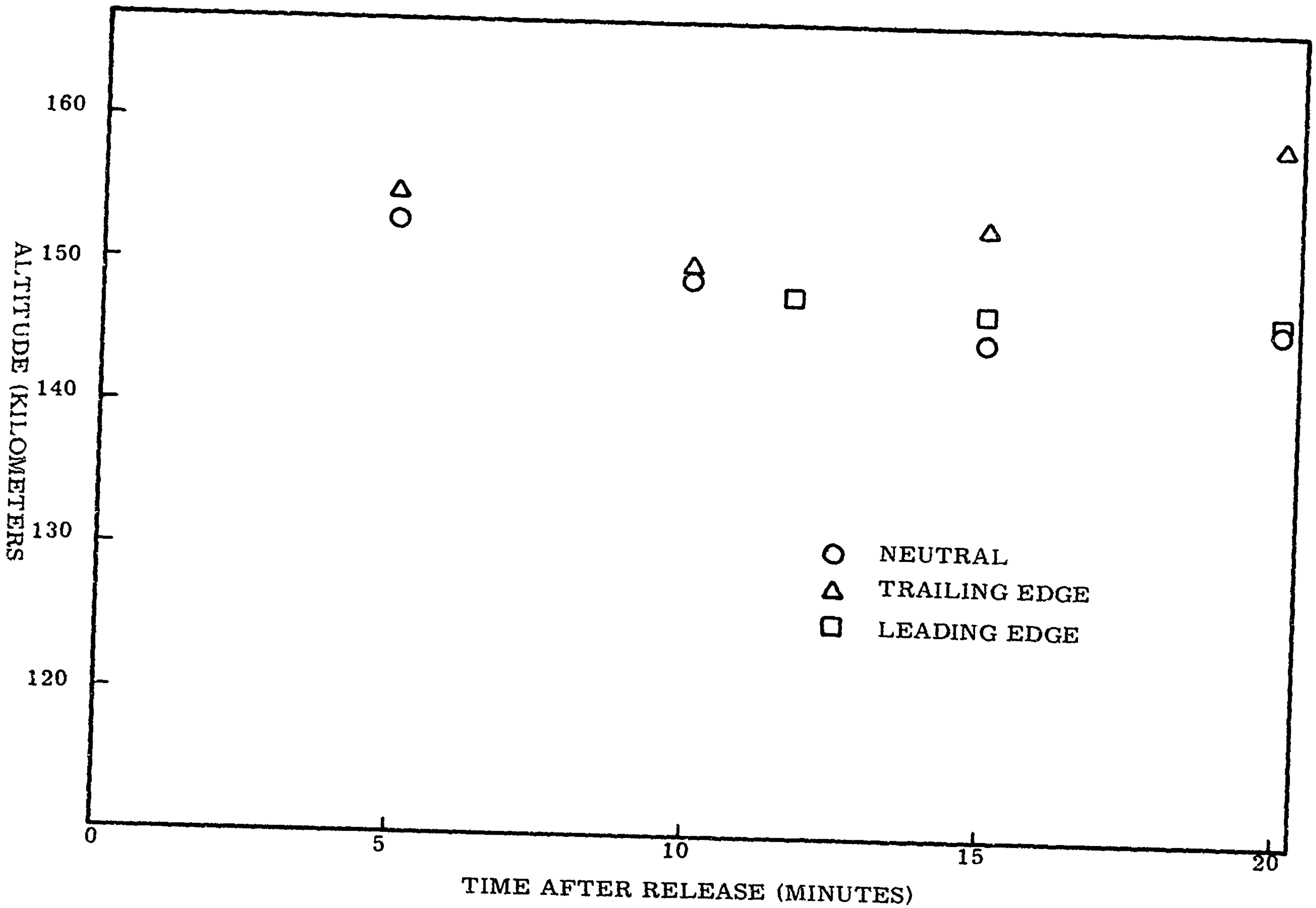


FIGURE 23 NUTMEG CLOUD ALTITUDE

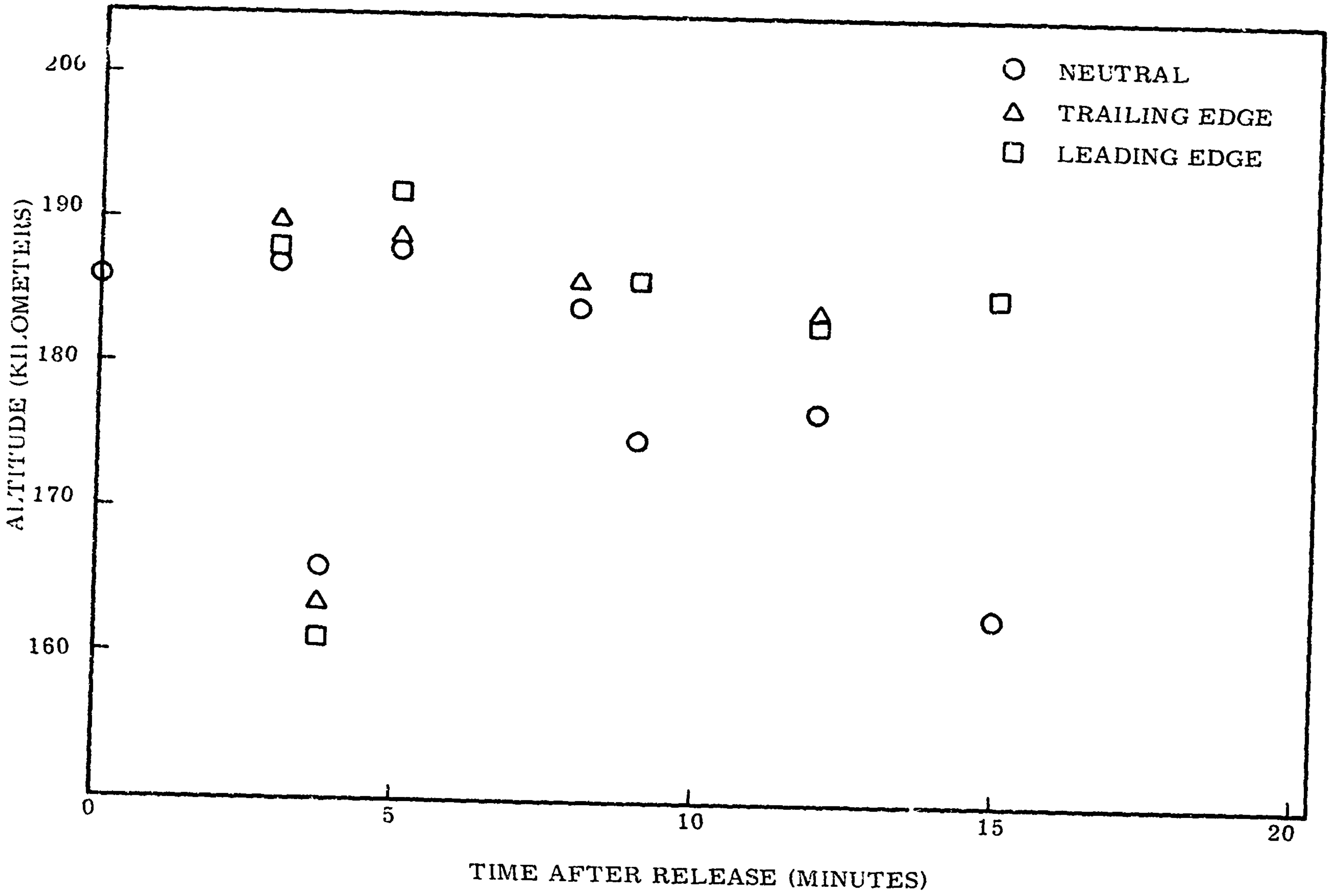


FIGURE 24 PLUM I CLOUD ALTITUDE

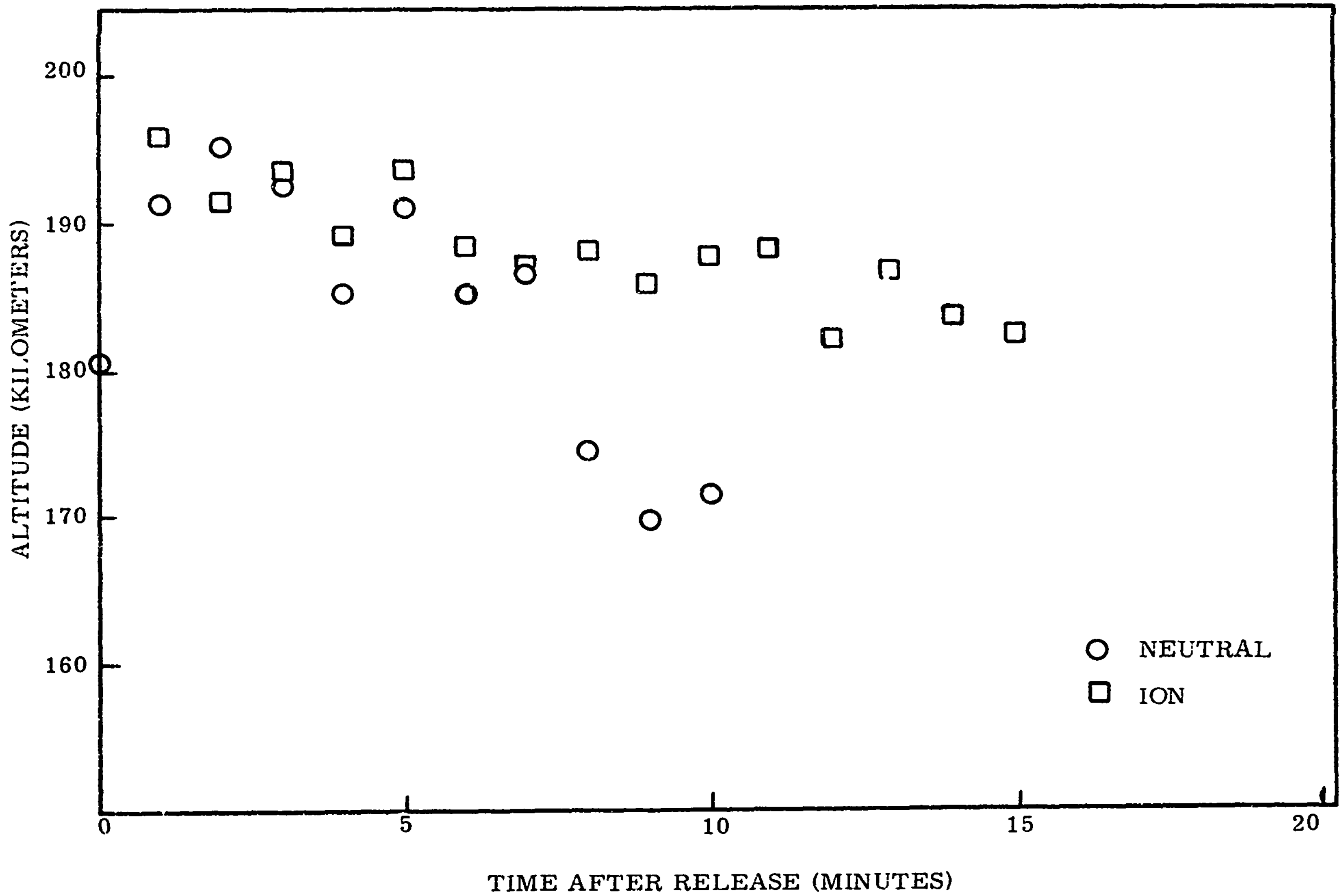


FIGURE 25 OLIVE I CLOUD ALTITUDE

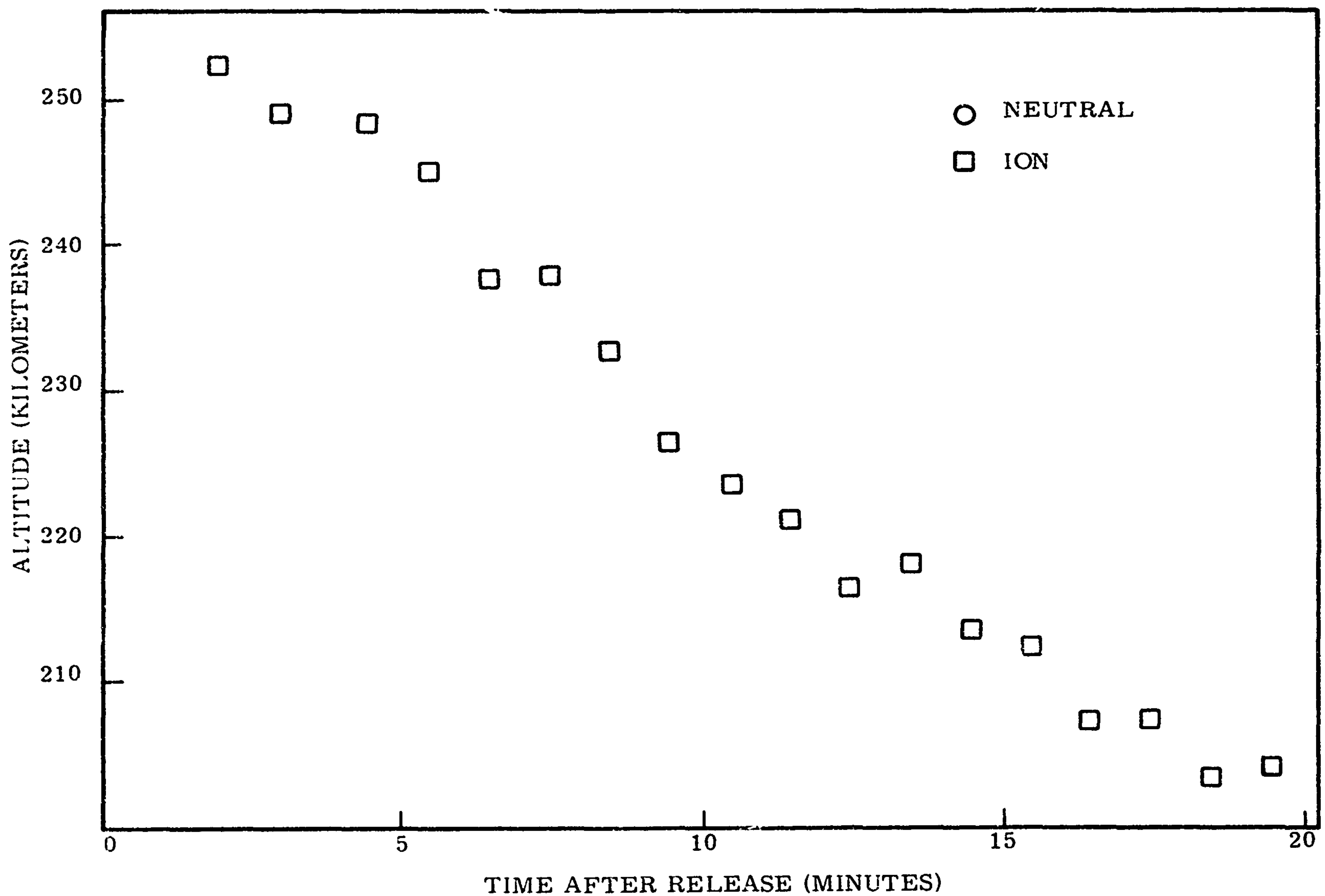


FIGURE 26 REDWOOD I CLOUD ALTITUDE

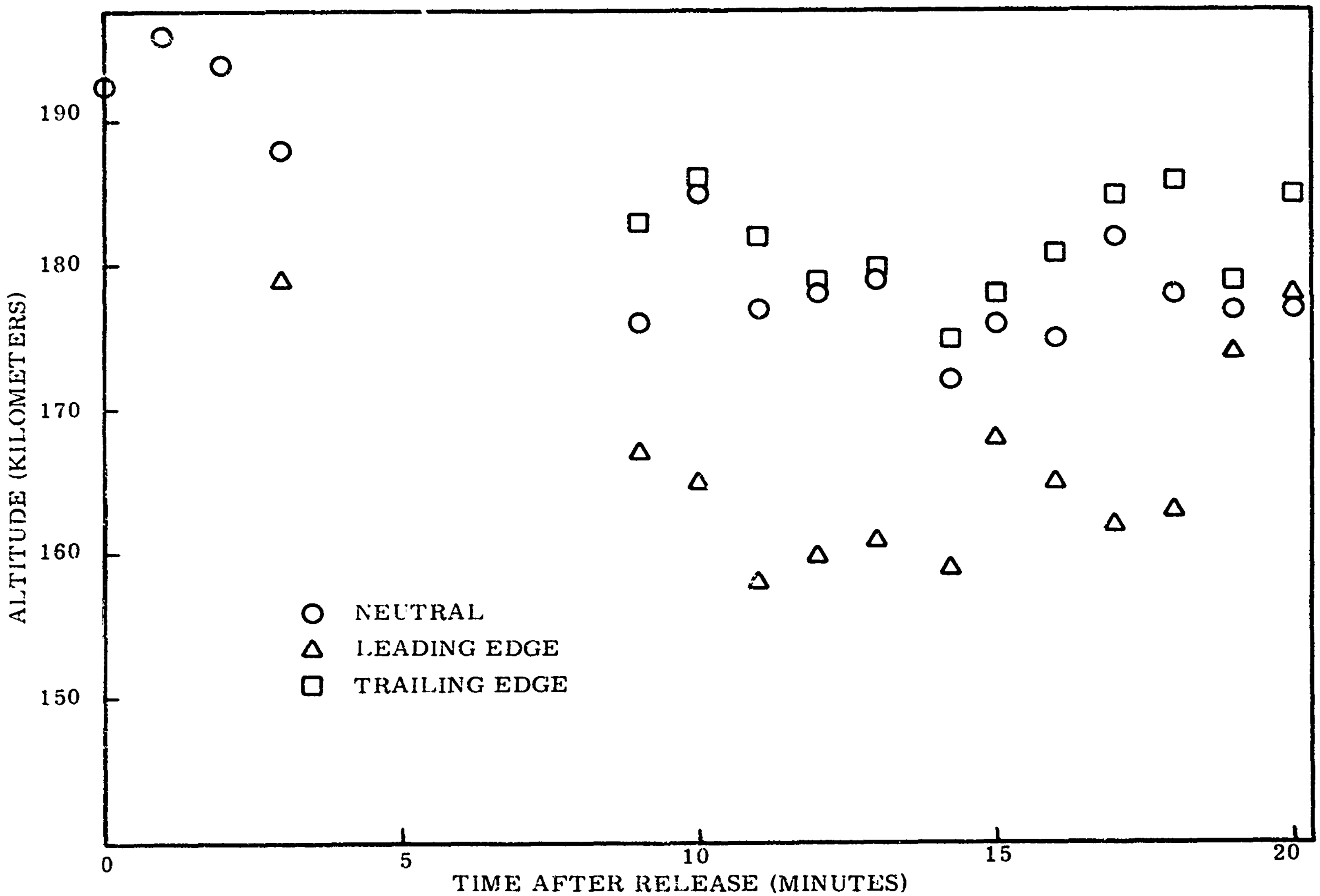


FIGURE 27 SPRUCE CLOUD ALTITUDE

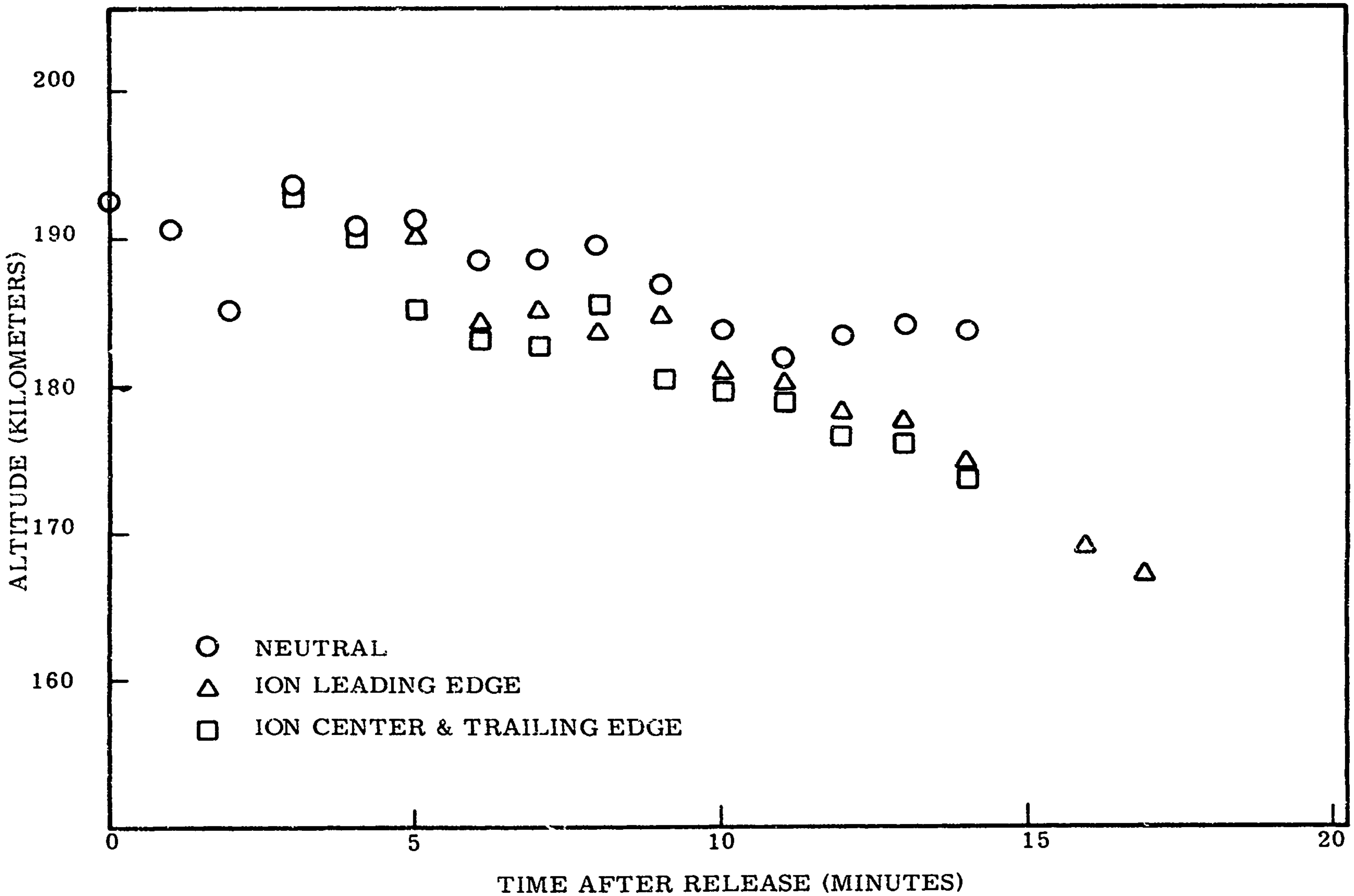


FIGURE 28 PLUM II CLOUD ALTITUDE

IV STRIATION MORPHOLOGY

The phenomenology surrounding the precursor conditions, morphological development, and fine structure characteristics of the striated structure occurring in a barium ion cloud above 150 km is one of the main regions of interest in the Secede program. By virtue of the location of the primary optical sites with respect to the release point, extensive high quality data was obtained on the phenomenological development of the Secede II ion cloud striations.

The reduction and analysis of Secede II striation data has centered about the following parameters:

1. Striation onset times
2. Motion of trailing (striated) edge of ion cloud [Section III]
3. Morphological development of an individual striation
4. Fine structure dimensions
5. Striation number history
6. Spatial frequency dimensions and striation widths of a whole ion cloud

Table VII presents the striation onset times for the six primary Secede II releases as determined from photographic records from several optical site locations. It is immediately evident that striations are not observed at the same time from different sites, as might be expected. What does stand out, however, is the fact that when the C-6 site was viewing the ion cloud up the field lines during the formation of striations, the formation was always observed earlier than at the other sites.

The striation formation morphology data obtained during Secede II has proven to be of exceptional quality and, therefore, interest to theorists concerned with striation phenomenology. A sequence of high reso-

TABLE VII

SECEDE II ION CLOUD STRIATION ONSET TIMES

EVENT	C-6 SITE	TYNDALL AFB	BARIN FIELD	MOBILE VAN
NUTMEG I	02m --	02m 36s	04m 30s	07m --
PLUM I	06m 11s	04m 40s	07m --	06m 53s
REDWOOD I	15m 41s	17m 58s	18m 23s	15m 43s
OLIVE I	19m 40s	20m 58s	19m --	19m 29s
OLIVE IV	05m 53s	07m 36s	05m 36s	(clouds)
SPRUCE	10m 03s	12m 53s	12m 00s	11m 06s

lution photographs of the evolution of some striations in the Redwood I ion cloud is presented in Figure 29. These data frames are from C-6 site records viewing the striation development up the geomagnetic field lines. This four-part sequential series covers a period of 4-1/2 minutes. Figure 30 shows a similar high resolution sequence of the Spruce ion cloud from C-6, but over a time period of less than twenty seconds. Close inspection of the data in Figures 29 and 30 will reveal much about the spatial evolution of striations.

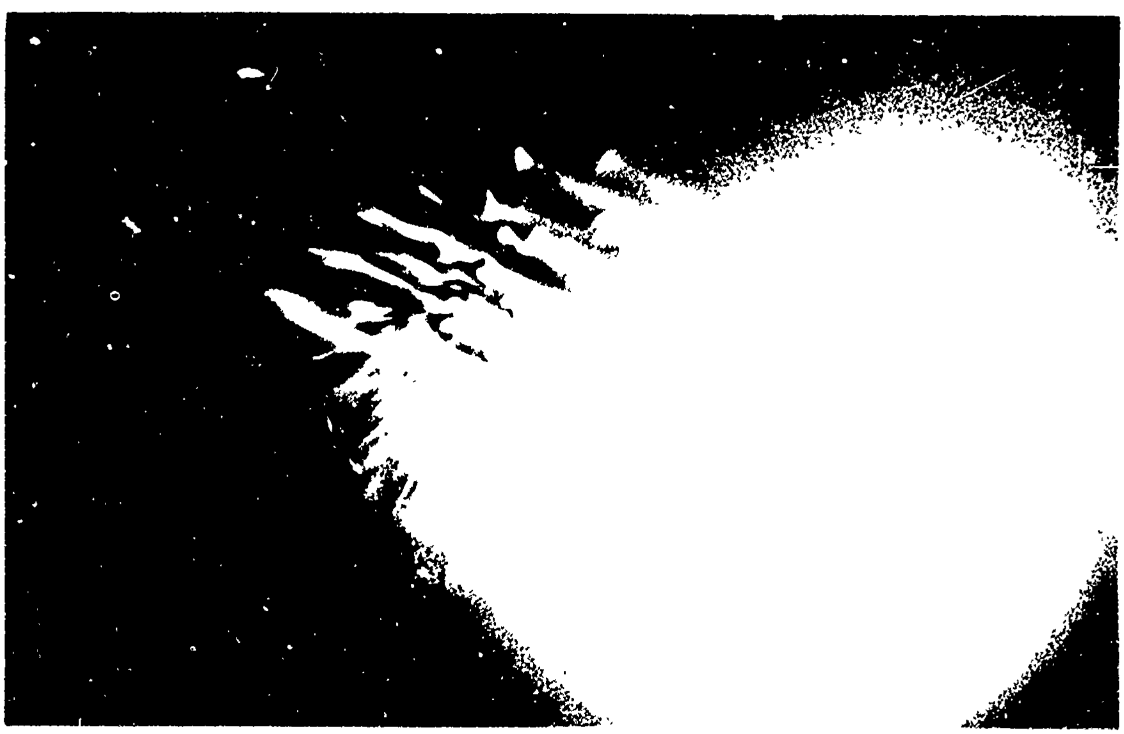
Figure 31 shows a comparison of two high resolution records of Plum I and Olive IV ion clouds as seen from Tyndall AFB, Florida. The resemblance of the two events is striking.

As indicated above, the number of striations as a function of time was measured for several events where the data warranted such an analysis. In Figures 32, 33 and 34, the striation number history has been compiled for the Plum I, Olive IV and Spruce events respectively. The number of striations was determined from each of the primary optical sites for comparison. There are major differences as would be anticipated depending upon the perspective of the optical instrumentation. The decline in the slope of the curves may represent a number of influential factors but is probably due in the Olive IV data to the setting of the sun at cloud altitude.

Figures 35 and 36 are presented to show the kind of fine structure dimensions observed in the large ion clouds looking up the magnetic field lines. As can be seen in Figure 36, structural dimensions as low as 20 meters were observed. Throughout many of the records, striation dimensions of 100-200 meters were common for long periods of time.

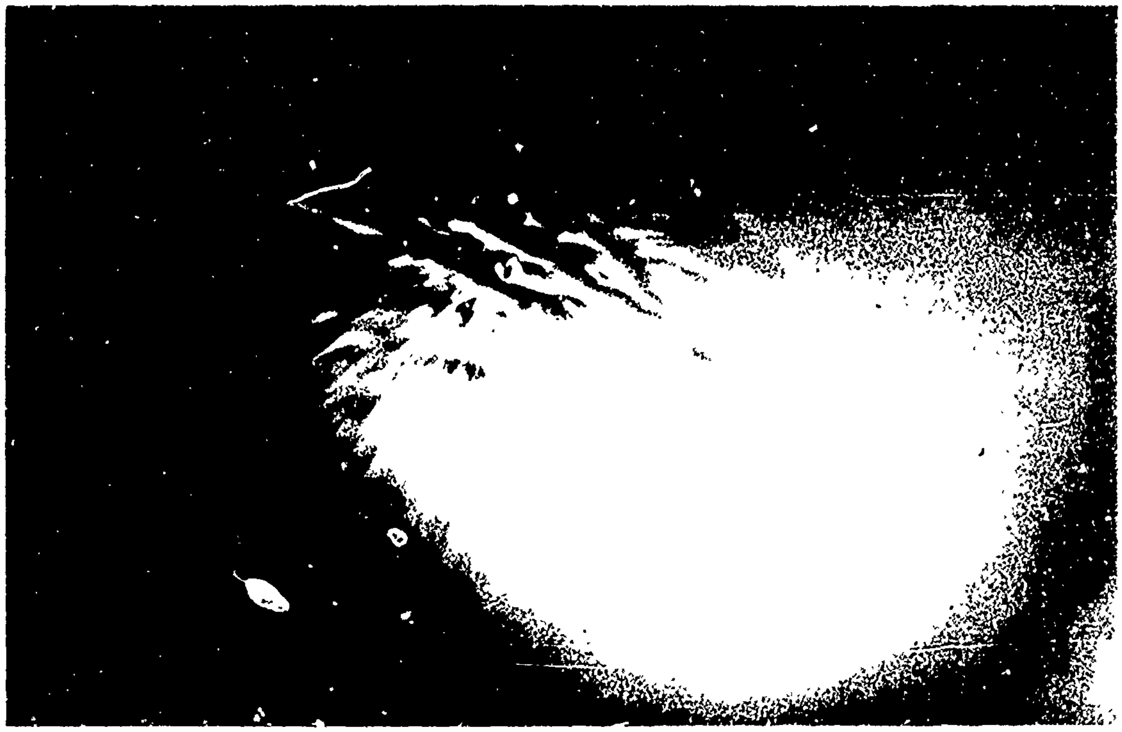
An attempt was made to measure the mean width and separation of the matured striations as viewed from the Tyndall AFB optical site.

(a) R + 21 min



(b) R + 23-1/2 min

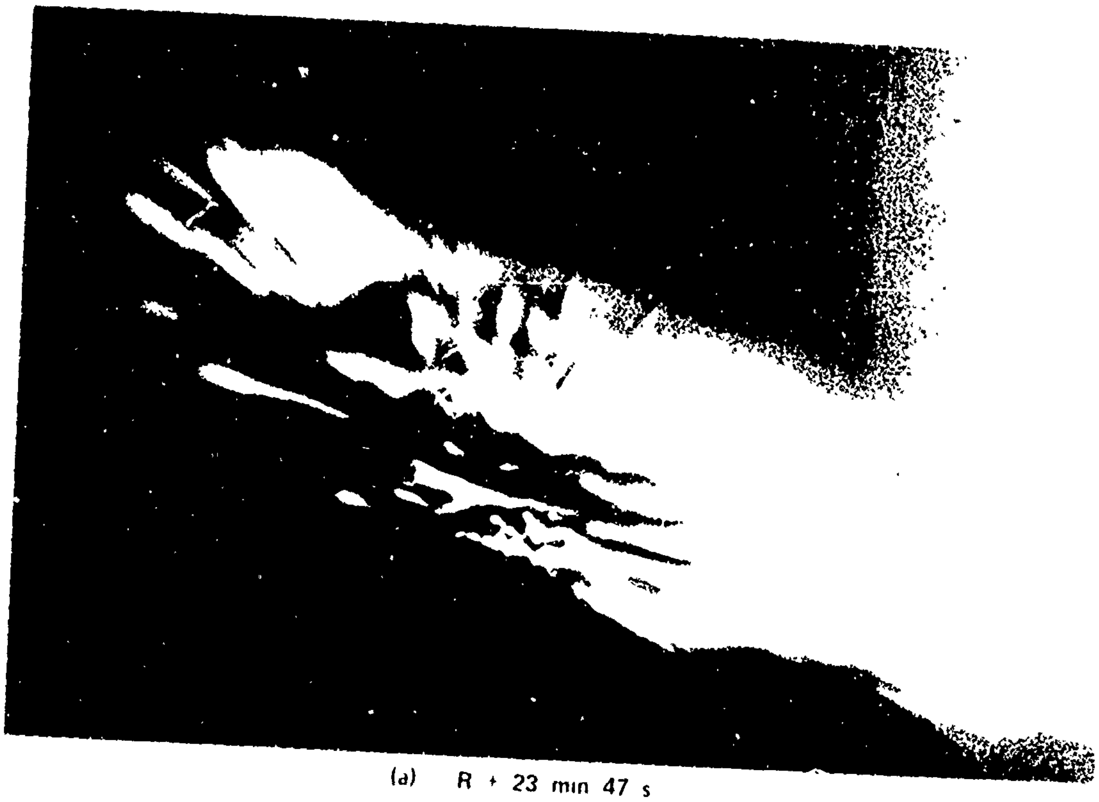
FIGURE 29 REDWOOD HIGH RESOLUTION PHOTOGRAPHS



(c) R + 24-1/2 min

(d) R + 25-1/2 min

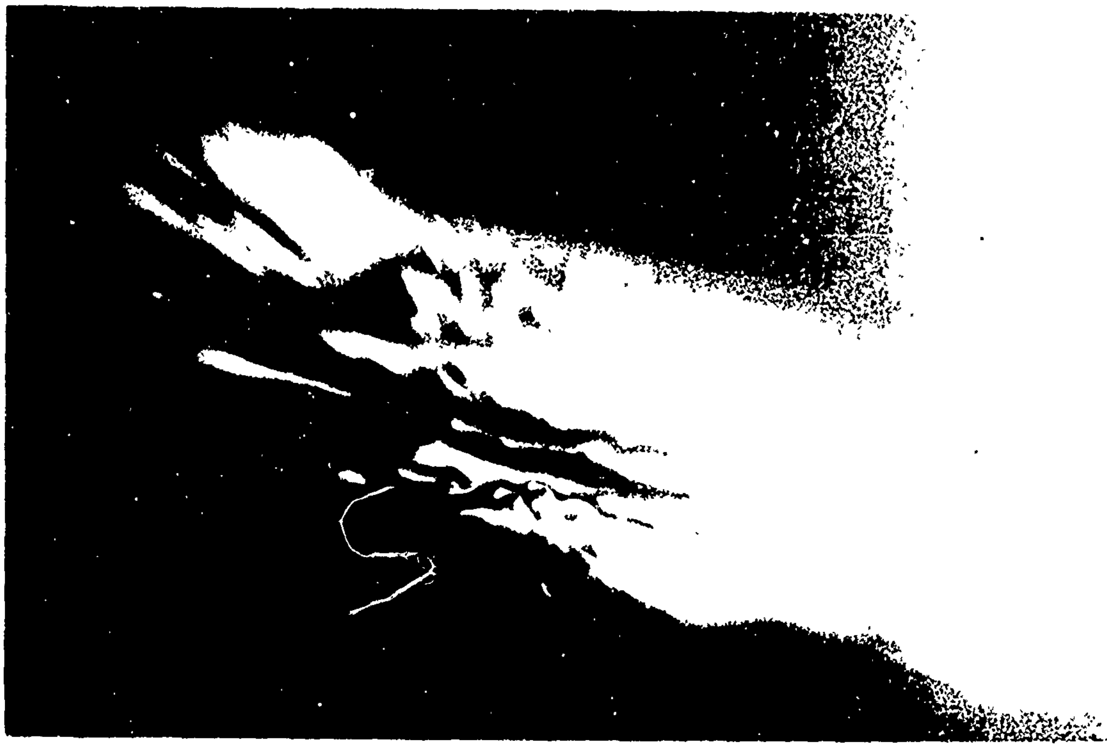
FIGURE [illegible] (Concluded)



(a) R + 23 min 47 s

(b) R + 23 min 51 s

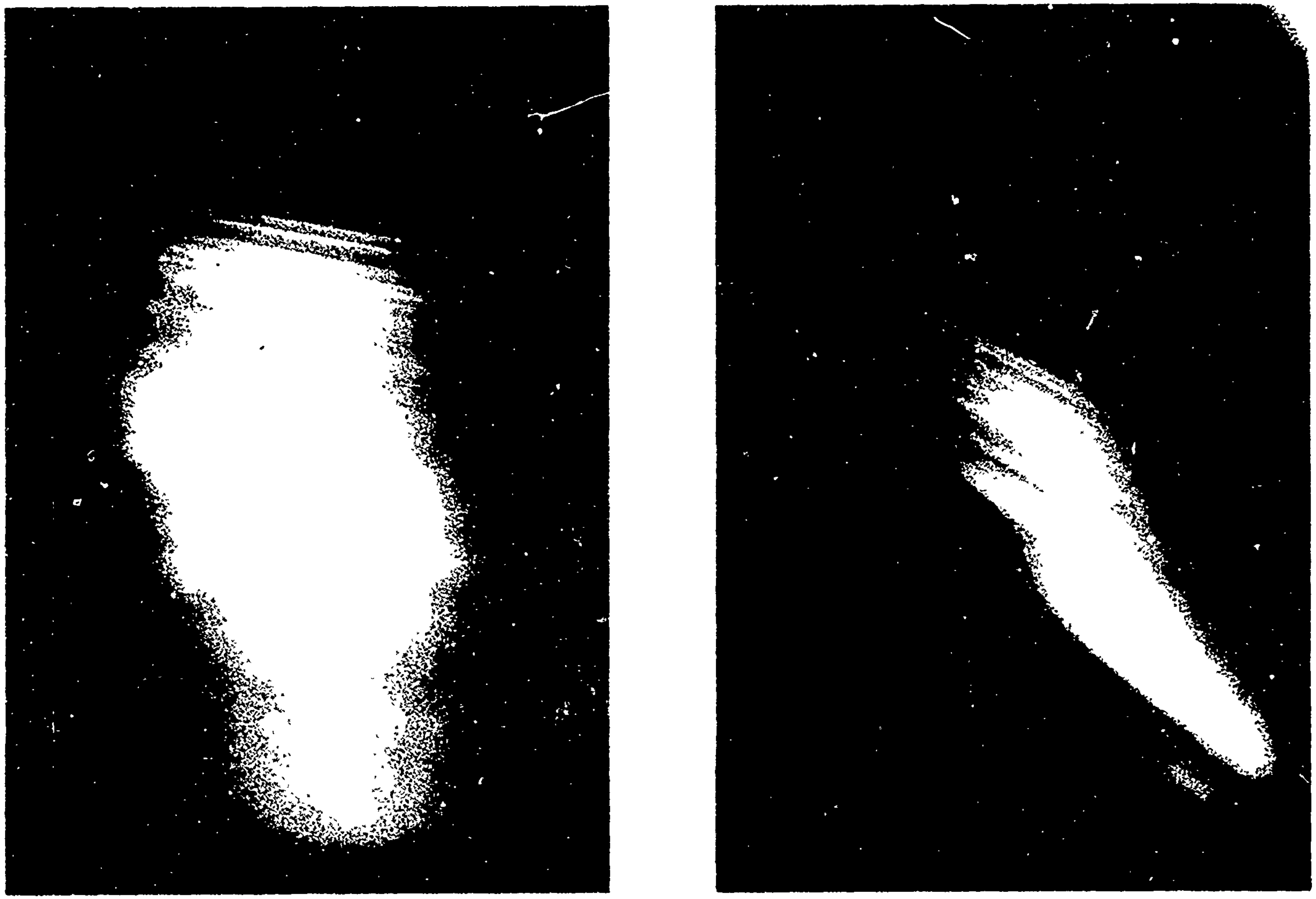
FIGURE 30 — SPRUCE HIGH RESOLUTION PHOTOGRAPHS



(c) R + 24 min

(d) R + 24 min 05 s

FIGURE 30. (Concluded)



(a) PLUM I, R 15 min 19 s

(b) OLIVE IV, R + 13 min 57 s

FIGURE 31 HIGH RESOLUTION PHOTOGRAPHS FROM TYNDALL OPTICAL SITE

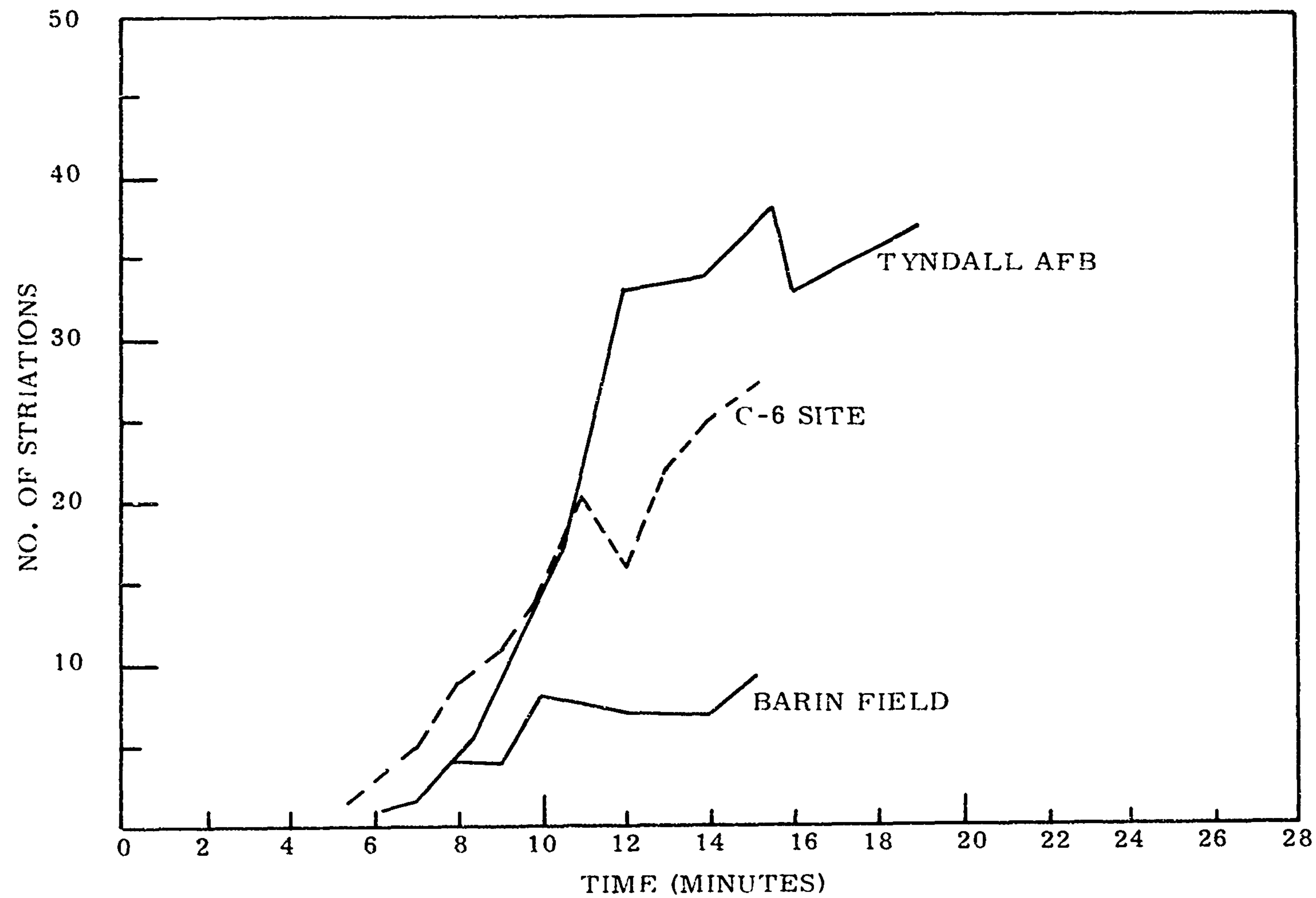


FIGURE 32 PLUM I STRIATION HISTORY

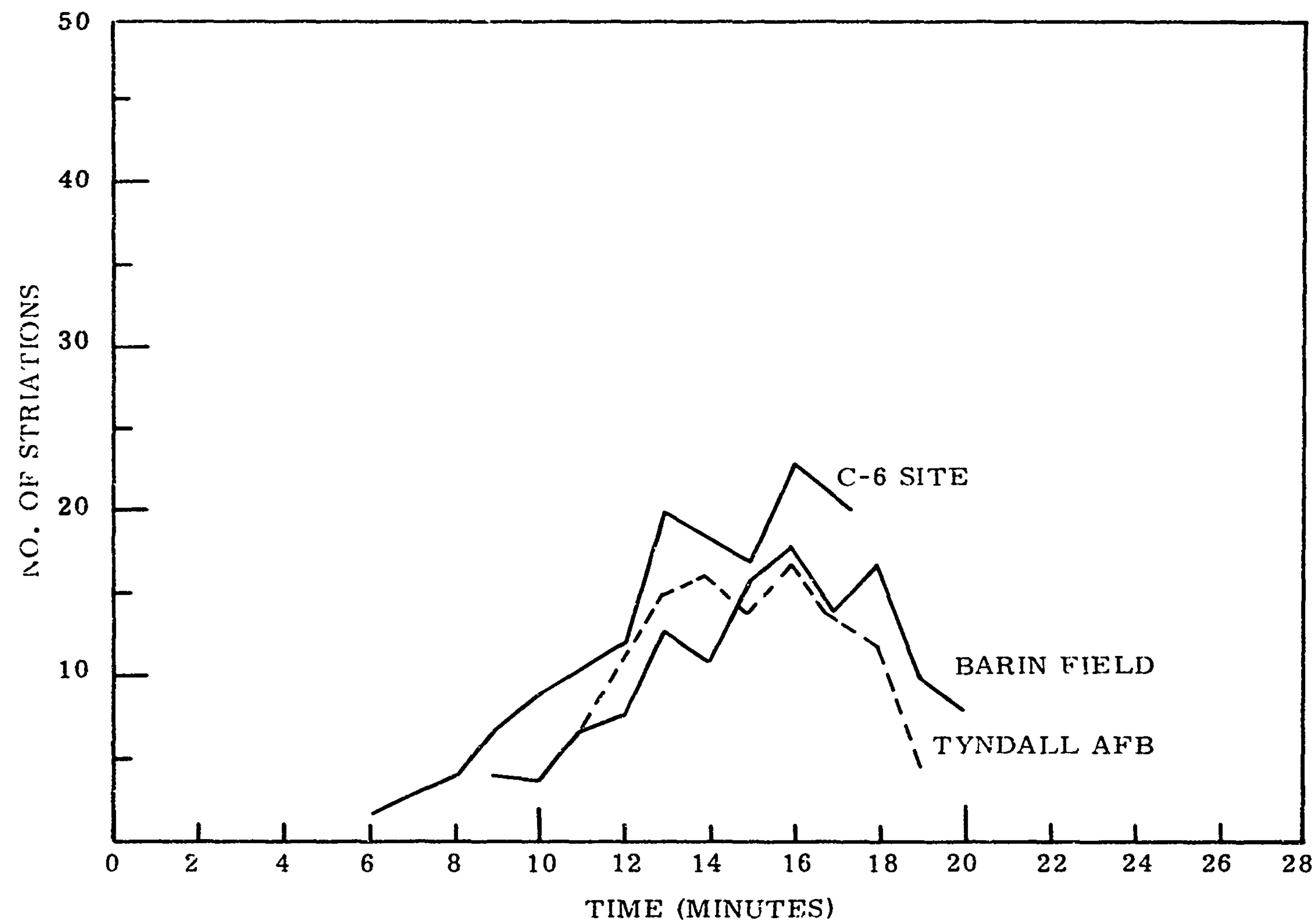


FIGURE 33 OLIVE IV STRIATION HISTORY

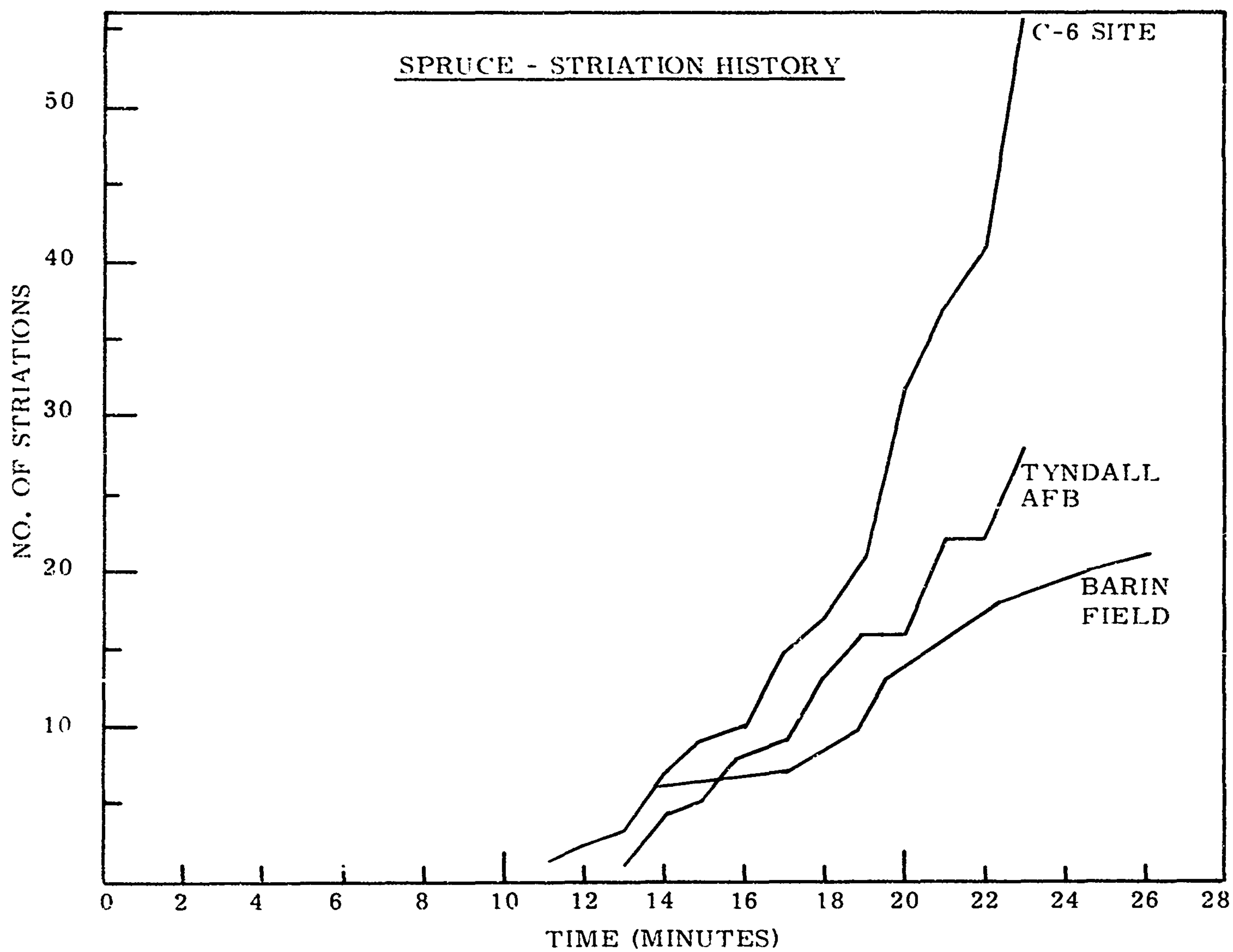


FIGURE 34 SPRUCE STRIATION HISTORY

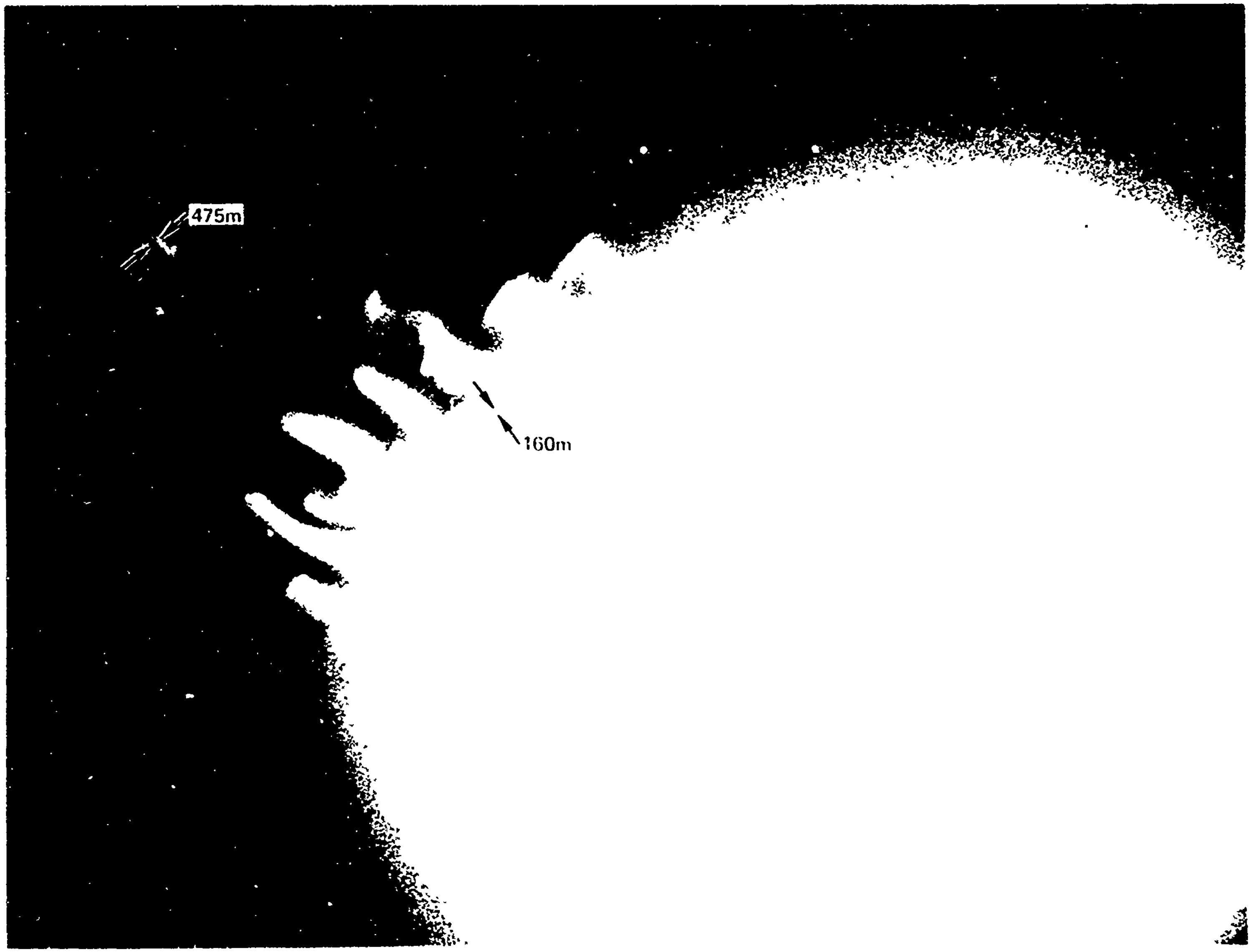


FIGURE 35 REDWOOD I FINE-STRUCTURE DIMENSIONS, C-6 SITE, R+22 MIN

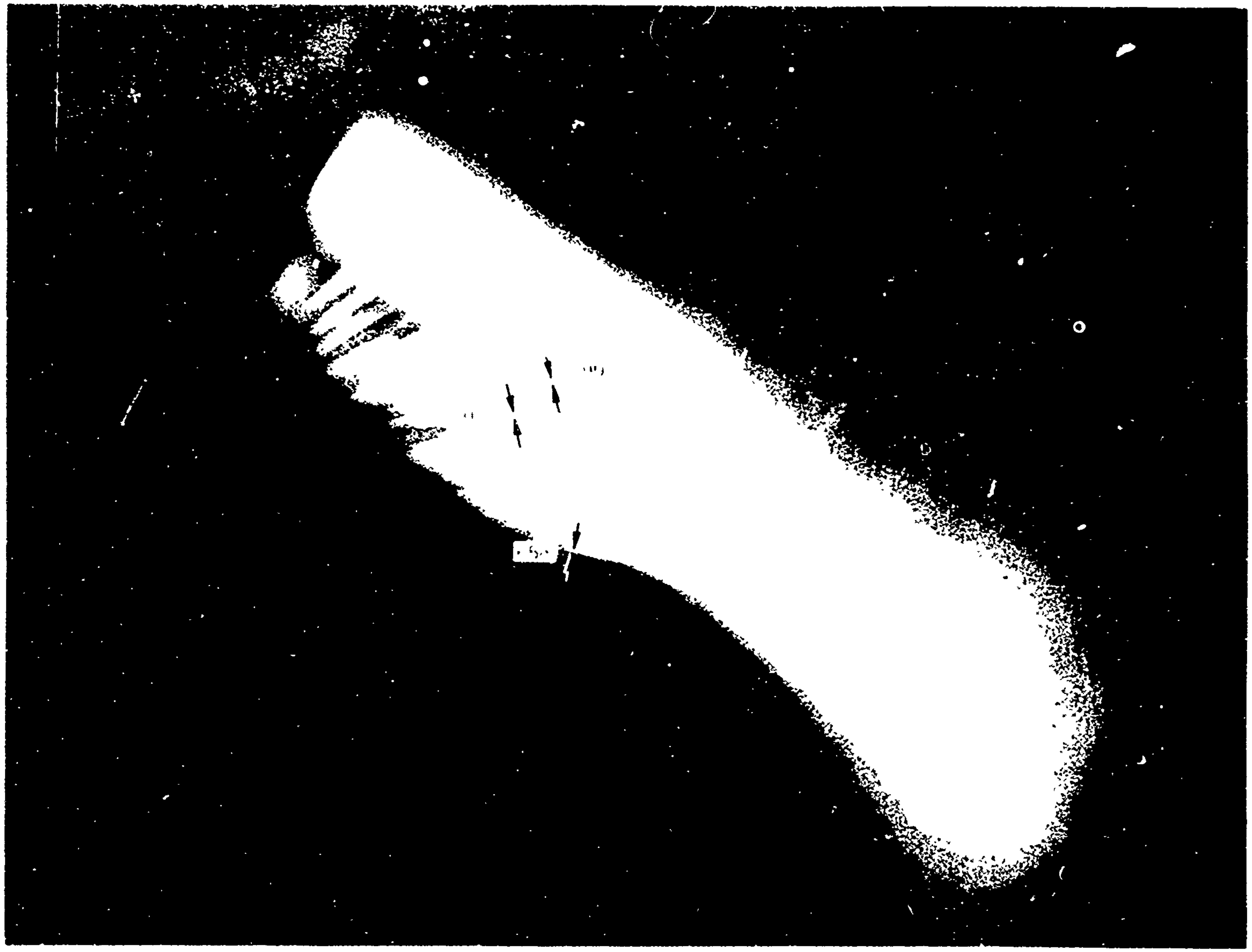


FIGURE [illegible] - FRACTURE DIMENSIONS, C-6 STEEL, R 1 MAX

A summary of the results of this analysis is presented in Table VIII for the Plum I and Spruce events. It is interesting to note that in each case multiples of the mean separation appeared more or less consistently and a qualitative indication of this is given in Table VIII.

TABLE VIII

STRIATION CHARACTERISTICS

EVENT	TIME (MINUTES)	MEAN WIDTH (KM)	MEAN SEPARATION (KM)	MULTIPLES OF MEAN SEPARATION PRESENT
PLUM I	12	0.4	0.4	1, 2, 3
PLUM I	15	0.35	0.35	1, 2, 4, 5
SPRUCE	15	0.53	0.8	1, 2
SPRUCE	20	0.53	0.38	1, 3, 6
SPRUCE	25	0.32	0.31	1, 2, 3

V RADIOMETRIC MEASUREMENTS

The complement of optical instrumentation at each of the primary optical sites included a narrow band interference filter camera for observation of a selected barium ion line - either 4554 A^{o} or 4934 A^{o}. These filters were used in conjunction with f/0.75 or f/0.87 optics and a very high sensitivity black and white film emulsion. On occasion, the filter was removed from the lens and a "white" light exposure was made for reference during the 0-20 minute portion of a given record. After about 20 minutes it was common to remove the interference filter to gather all possible light from the ion cloud. In most instances photographic records were obtained until 30 minutes or more after release.

The peak radiance time history of the Plum I, Olive I, and Spruce events was determined from about R + one minute to about R + 28 minutes for one of the two wavelengths mentioned. The measurements were made by first generating a two-dimensional isodensity contour of the desired image, converting this to radiance, and then determining the peak apparent radiance of the image by inspection. The apparent radiance was then converted to an absolute value by factoring in the transmission of the optical components and an estimated value of atmospheric transmission at the applicable wavelength.

Figure 37 is a summary of absolute peak radiance values for the three events chosen for analysis. The data points are connected by a straight line to aid the reader, but by no means should be interpreted as the functional relation. This data was obtained from C-6 site records in each instance.

A comparison of radiometric data including integrated radiance (optical power) from different sites is presented in Table IX. Although

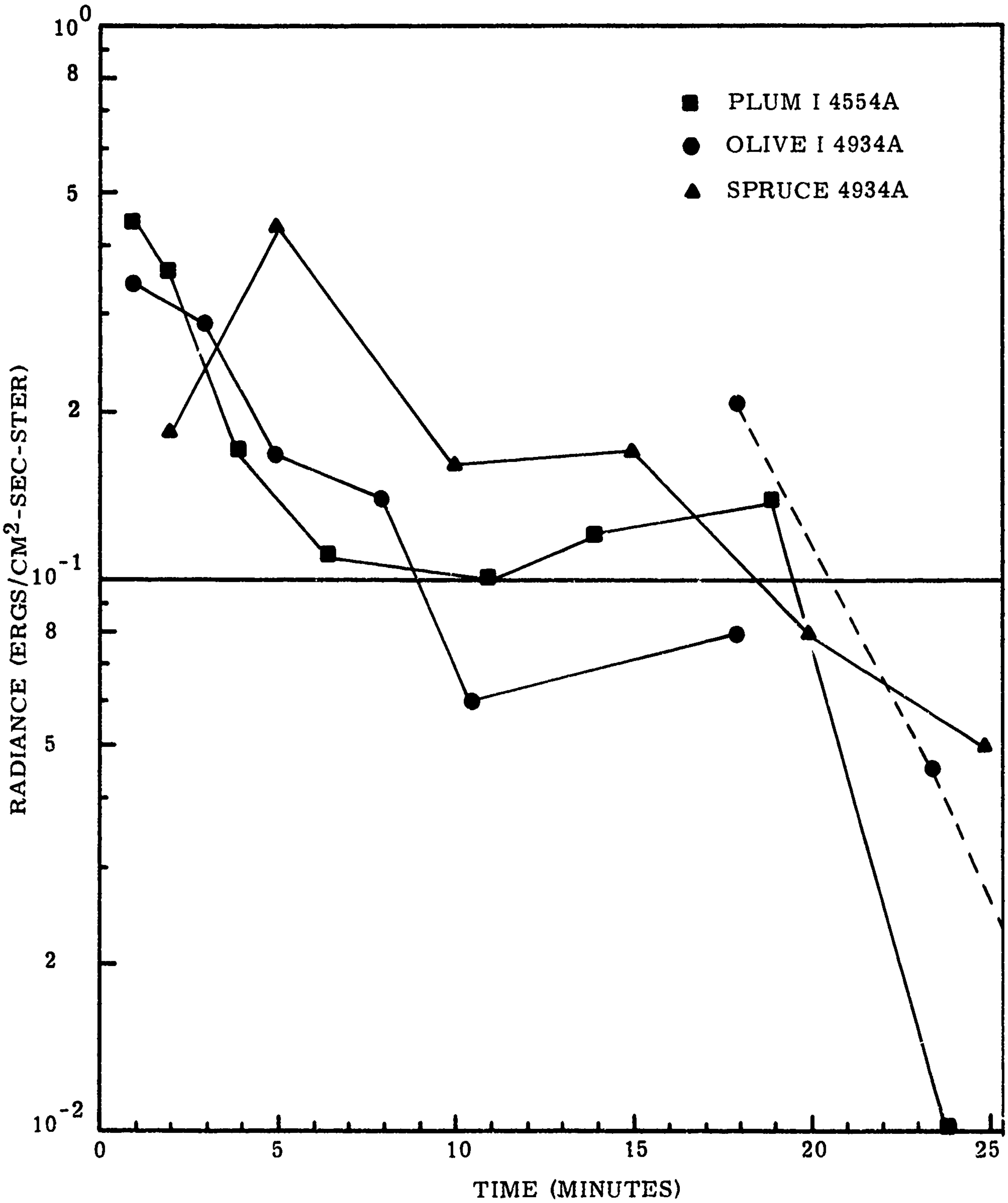


FIGURE 37 PEAK RADIANCE HISTORY OF PLUM I, OLIVE I, AND SPRUCE

TABLE IX

COMPARISON OF RADIOMETRIC DATA FROM DIFFERENT SITES

EVENT (TIME)	STATION	WAVELENGTH	PEAK RADIANCE ($ERGS/CM^2$-SEC-STER)	POWER (ERGS/SEC)
PLUM I	C-6	4554Å	.36	3.4×10^{12}
(2 MIN)	TYNDALL	4934Å	.13	3.8
	BARIN	4554Å	.27	6.1
OLIVE I	C-6	WHITE	.21	30.2
(18 MIN)	C-6	4934Å	.08	5.5
	TYNDALL	4554Å	.08	18.9
	BARIN	4554Å	.10	7.4
SPRUCE	C-6	4934Å	.16	6.2
(10 MIN)	TYNDALL	4554Å	.11	8.7

it is difficult to draw conclusions from data of this extent, it is interesting to note that the integrated radiance, which incorporates the area of the image being measured, will vary extensively due to the foreshortening of the image size from certain perspectives for an optically thick radiator.

VI CONCLUSIONS

The 1971 Secede II high altitude release series were, from an optics point of view, the most successful and informative to date. This success stems from a combination of the variety in barium yield and altitude (incorporating secondary puff releases), the sophistication and deployment of the optical instrumentation, and the fact that the releases were positioned such that the striation development could be viewed up the field lines with high resolution instrumentation.

Much information was derived from the Secede II program from an operational viewpoint. Because of the wide geographical coverage provided by the primary photographic stations, for example, the track and altitude of the primary ion and neutral cloud features (as well as the puff releases in general) were able to be plotted as the features developed in time over an extensive region. Moreover, the fact that a number of the releases were made at relatively low solar depression angles was found to be readily accommodated optically by the use of color film emulsion. Whereas the brightness contrast at these early times was minimal due to the high ambient sky background, the spectral contrast was in fact more than adequate to determine the growth and early morphological changes of the primary ion clouds. Thus, future test series need not be delayed to achieve early optical coverage if it is desired to maximize the late time observations for a given event.

In general it can be stated that the successful deployment and operation of real time TV tracking systems, high resolution, cloud track and cine and time lapse photographic systems, with respect to the wide variety of release yield, altitude, and time of day was such as to permit the extrapolation of this experience to subsequent high altitude tests. It can be expected, therefore, that a given set of optical coverage requirements can be achieved with maximum efficiency in future operations.