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Movement of Scallops *Placopecten magellanicus* (Gmelin, 1791) (Mollusca:Pectinidae) on Georges Bank

by

G. D. Melvin, M. J. Dadswell and R. A. Chandler
Invertebrates and Marine Plants Division
Fisheries Research Branch
Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick E0G 2X0
Canada

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Abstract

During a 5-yr tagging program, 1977-1981, 20,086 scallops were released from 139 stations on Georges Bank (GB) and in Great South Channel (GSC). Of these, 1282 (6.4%) were returned representing 135 release sites. Tagged scallops were at large an average 310 d (R 2-1850) on GB and 243 d (R 11-783) in GSC. Mean individual distance between release and recapture was 8.4 km on GB and 5.7 km in GSC. Overall 52.5% of returns were within 5 km of release site, 77.1% within 10 km and 94.0% within 25 km.

Returns were partitioned into 12 grids for Georges Bank and data pooled for a single release site at the center of each grid. The angle of mean vectors for each grid indicated clockwise circular movement around the outer perimeter of Georges Bank in concert with the mean direction of current flow.

Résumé

Au cours d'une étude de marquage qui a duré 5 ans (1977-1981), 20 086 pétoncles ont été relâchés dans 139 stations situées dans le banc Georges (BG) et dans le Grand Chanel du Sud (GCS). De ce nombre, 1 282 (6,4 %) ont été recapturés; ils provenaient de 135 stations. Les pétoncles marqués ont été en liberté pendant une période moyenne de 310 jours (R 2-1850) dans le GB et de 243 jours (R 11-783) dans le GCS. La distance moyenne entre le point de libération et le point de recapture était de 8,4 km dans le GB et de 5,7 km dans le GCS. Dans l'ensemble, 52,5 % des pétoncles recapturés se trouvaient à moins de 5 km du point de libération, 77,1 % à moins de 10 km et 94,0 % à moins de 25 km.

Les pétoncles recapturés ont été répartis dans 12 grilles (BG) et les données ont été réunies pour un seul point de libération du centre de chaque grille. L'angle des vecteurs moyens de chaque grille indique un mouvement circulaire dans le sens des aiguilles d'une montre autour du périmètre externe du banc Georges, suivant la direction moyenne du courant.

Introduction

Swimming behavior in Pectinidae has been described as an avoidance response to disturbance or the presence of a predator and is well developed in the sea scallop, Placopecten magellanicus (Gmelin, 1791). Caddy (1968) demonstrated the swimming reactions of P. magellanicus in response to approaching divers and scallop drags. Thomas and Gruffydd (1971) and Peterson et al. (1982) described the specific response of Pecten maximus and Argopectin irradians invoked by various predators.

Scallops swim by jet propulsion (Stanley 1970; Gould 1971) and swimming speeds of ½-1 bl/sec are known (Moore and Trueman 1971; Gruffydd 1976). Of four scallop species studied, P. magellanicus was determined to be hydrodynamically the most suited for swimming (Thorbun and Gruffydd 1979). Escape movements of scallops are made at lower speeds and higher angles of attack than normal swimming (Moore and Trueman 1971) and the development of good hydrodynamic shape may be evolutionarily selected to facilitate movement by scallops for additional reasons.

Previous investigations of movement or migration of P. magellanicus were predominately descriptive. Baird (1954) examined the movement of scallops in the relatively shallow water of Penobscot Bay, Maine. From tag returns he concluded adult scallops demonstrate little, if any migratory behavior. Similar conclusions were drawn by Posgay (1982) for Georges Bank scallops. However, Posgay commented that although movement was localized, the direction of apparent movement corresponded well with known current patterns on Georges Bank.

Our study represents the first attempt to quantify movement of P. magellanicus in terms of distance and direction using vector analysis. A similar approach has been used to study directional movement of the bay scallop, Aequipectin irradians (Moore and Marshall 1967) and the western rock lobster, Panulirus cygnus (Phillips 1983).

Methods

Scallops were collected during the summer months (May-August) of 1977 through 1981 from Georges Bank and 1977-78 from the Great South Channel. Collections were made using a single 2.44 m offshore drag (New Bedford type lined with 3.8-cm mesh) towed for approximately 1 km on each set from the Canadian Research vessel "E.E. Prince". Each scallop was marked with one of three tag types (Peterson disk 1.4 cm dia., Floy spaghetti tag 7.6 cm long, or an Anchor tag 4.5 cm T-Bar), measured for shell height, notched, and retained in seawater until released at selected locations (Fig. 1). Release latitude and longitude were determined by Loran-A in 1977 and Loran-C from 1978 to 1981. A reward of two to four dollars, depending upon the year and the information provided with each tag, was offered to enhance returns.

All tag returns were reported by commercial fishermen. In many cases the information supplied was incomplete and accuracy of several recapture locations was doubtful. Approximately 50% of returns were tags with no information pertaining to location or date and could not be used in this study. In addition, several scallops were reported recaptured prior to their release or submitted in a batch with conflicting dates or locations. All the above returns were excluded from the analysis. However, in the event no objective grounds could be established for the removal of a return, it was included in the analysis.

For analytical purposes Georges Bank was divided into 12, 20-min grids. The angle of movement and distance traveled by each returned scallop was computed from its original release site to the point of recapture using standard trigonometric functions (Batschelet 1965); (Curry 1956). The data were then adjusted to represent movement about a single release point; the center of the grid. All latitudes and longitudes were rounded off to the nearest minute prior to analysis. Descriptive statistics and vector analysis were conducted on an HP 3000 computer using SPSS (Nie 1975) and author compiled FORTRAN programs.

Results

During the 5-yr tagging program 20,086 scallops were released from 139 stations on Georges Bank and the Great South Channel. Of these, 1282 (6.4%) were returned representing 135 release sites. Table 1 summarizes the number released and subsequently recaptured by year for each area. Release size of scallops ranged from 50 to 117 mm for Georges Bank and 83 to 96 mm for the Great Channel with means of 77.7 and 89.6 mm, respectively (Table 2).

Tagged scallops were at large for an average of 310 (Range 2 - 1850 d) on Georges Bank and 243 (Range 11 - 783 d) in the Great South Channel. Mean individual distance moved was 8.40 km for Georges Bank scallops and 5.72 km for the latter region representing yearly rates of 9.9 and 8.6 km. The mean days at large, distance traveled and rates of movement for each scallop size-class are presented in Table 3. Mean distance traveled demonstrated an inverse relationship with size for scallops greater than 60 mm; however, mean days at large were widely variable between the size intervals. Examination of mean rates of individual movement, which were positively skewed, generally demonstrated the converse, increasing rates to 90-99 mm. The mean rates are misleading and, when extrapolated, produce unrealistic distances with time. Median rates more appropriately describe the movement (Table 3). Maximum distance traveled on Georges Bank was 72.2 km in 675 d compared with 33.0 km in 92 d for the Great South Channel. Regression of distance with time (days) produced no significant correlation ($p < 0.05$). This was presumably confounded by the large number of returns with little movement. Removal of scallops traveling less than 5 km resulted in a significant ($p < 0.01$) relationship.

The relative frequency of individual distances moved on Georges Bank, in 5 km divisions were; 52.5% of returns recovered within 5 km of their release site, 77.1% within 10 km, and 94.0% within 25 km (Fig. 2). Scallops between 60 and 89 mm traveled the maximum distance (Fig. 4). Scallops above and below this range were relatively stationary. These findings may be related to the selectively of commercial fishing gear and restricted movement of larger scallops due to size.

The division of returns from Georges Bank into 12 grids and the pooling of data to a single release provided some cognizance for the variation in the direction of movement between grids. The angle of the mean vector and its associated length (Table 4) for each grid are graphically illustrated (Fig. 4). This figure depicts a clockwise movement around the outer parameter of the bank which follows the generalized current patterns described by Bigelow (1927) and Flagg et al. (1982). The direction of the mean vector is approximately southeast compared with a southwest vector for the Great South Channel. In addition, Rayleigh "Z", which tests the hypothesis of uniform distribution, indicates that direction of the mean vector differs significantly ($p < 0.05$) from 0 (Table 4) with a general concentration of movement for most northern and eastern grids. No significant direction was observed for grids A, B, C and F (Fig. 4).

The representation of only the mean vectors can be somewhat misleading (Fig. 5). There is a great deal of scatter in individual scallop movement about a single release site. Movement around a single point for each grid can be in all directions. Associated with each grid (Fig. 5) are the mean velocity and percent current occurrance for 8 directional bins determined from satellite-track drogues within 30 m of the surface (Flagg et al. 1982). Although these current patterns do not represent actual bottom currents, they do serve to demonstrate the variability and generalized movement of water on the bank.

Discussion

In this study the distance traveled by an individual scallop from release point to recapture location was widely varied and averaged only 8-10 km/yr. Apparently for scallops of the size tagged, movement was relatively localized with respect to Georges Bank as a whole. However, at the above rate an accumulated distance equivalent to the width of Georges Bank could be covered during the lifetime of this species.

On Georges Bank the distance moved by Placopecten was found to be size dependant. Mid-sized scallops (60-89 mm) displayed the widest dispersion of distance traveled. Smaller and larger scallops demonstrated localized movement. These observations agree with those available in the literature. Wiborg (1963) noted that mid-size Chlamys islandica swam more frequently than larger ones and laboratory studies by Gruffydd (1976) confirmed this observation. Caddy (1968) observed that P. magellanicus greater than 100 mm rarely swam. Our observations, however, may be confounded by two factors; gear selectivity (7.6-cm ring restriction on commercial drags) and scallop size. The majority of our smaller scallops, although probably relatively active swimmers, were collected for tagging by commercial drags lined with 3.8-cm mesh and as such were less susceptible to commercial capture at a later date. On the other hand, mid-size scallops were most certainly fully recruited to the fishery and vulnerable to capture over the entire bank. The observed limited distances of movement by larger scallops may well be a function of their inability or need to move (Gould 1971; Caddy 1968).

Although these data indicated Placopecten of the size tagged do not move significant distances in this region from a migratory sense, there is sufficient evidence to suggest that the apparent direction of observed movement was concentrated for one reason or another. Rayleigh's test of the distance vectors with each of the 20-min grids on Georges Bank indicated that 8 of the 12 divisions differed significantly from a uniform distribution away from the release site. This implies a concentration towards a preferred direction. Observed differences in the direction within and between grids on Georges Bank, the Great South Channel, and Browns Bank (Melvin, unpublished data) strongly suggests that some physical factor rather than directed movement may be responsible for these findings.

Underwater observations by Caddy (1968) (Figs. 9-10) provide convincing evidence that the escape direction of the scallop (P. magellanicus) to approaching divers was independent of current direction. The response appears to be evasive and perhaps a function of orientation within the current. There is, however, the indication that net movement might be related to the direction of water flow. Scallops swimming upstream have a tendency to move in an arc towards the prevailing current. Other researchers have used currents to explain the directedness of movement of the bay scallop, A. irrandians, Moore and Marshall (1967) and the progressive increase in age of C. islandica in the fjords of Norway (Gruffydd, 1976).

The current structure of Georges Bank is complex and widely variable (Flagg et al. 1982). Overall the general movement of bottom water has been described as a clockwise gyre around the northwestern portion of the bank (Bumpus 1976; Bumpus and Lauzier 1965; Bigelow 1927). This is further complicated by the interaction of tidal and wind driven currents.

Unfortunately, no accurate measurements of bottom current direction or variability are available for the comparison of scallop and water movement. Flagg et al. (1982) have documented the mean velocity and percent occurrence of currents within 30 m of the surface for discrete area on Georges Bank from satellite-tracked drogues. The patterns they describe, although not directly related, are assumed to at least partially reflect the bottom currents of a specific area. Consequently, the appropriate patterns have been included with our figures of individual scallop movement to assist in the discussion of observed directed movement and the scatter about a release site. When examined, the figures show some interesting relationships. Not only does the mean vector of scallop movement for a specific grid lie close to the direction of the strongest and most dominant where statistically significant directed movement was observed, but also the variation in observed movement corresponds rather well with secondary currents. In addition, for areas where no significant direction was observed, the currents described by these authors were of approximate equal duration and speed - suggesting a relationship between direction of scallop movement and water flow. Anomalies occurred for grids with a small number of returns.

One possible explanation for the observed findings which must not be completely overlooked is that the mean vectors reflect a pattern of fishing. Fishermen have a tendency to follow traditional paths in search of their desired species. As such, the reported locations of returns may represent the general movement of the fleets fishing excursions.

Inherent with any quantative study which relies on reported data from uncontrolled sources is a certain degree of unknown error. We have attempted to remove as much of this type of error as possible from the data without biasing the results. We acknowledge that the results presented are subject to question owing to the many possible sources of error, especially the accuracy of reported recapture locations. However, the observed consistencies in mean direction of movement between grids, with generalized current patterns and the similarity of mean vectors with documented bottom currents on Georges Bank, Browns Bank and the Great South Channel, where current patterns are distinctly different, supports the general hypothesis of current-related movement of adult scallops. We conclude that, although scallop movement of the size examined was relatively localized, there is sufficient evidence to implicate the importance of velocity and direction of water flow on Georges Bank scallop movement.

Acknowledgments

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Literature Cited

Baird, F. T. Jr. 1954. Migration of the deep sea scallop (Pecten magellanicus). Bull. Dept. Sea and Shore. Fish. Fisheries circular No. 14: 8 p.

Batschelet, E. 1965. Statistical methods for the analysis of problems in animal orientation and certain biological rhythms. AIBS Monograph: 57 p.

Bigelow, H. B. 1927. Physical oceanography of the Gulf of Maine. Fish. Bull. U.S. Vol. 40(2): 511-1027.

Bumpus, D. F. 1976. Review of the Physical Oceanography of Georges Bank. ICNAF Res. Bull. Vol. 12: 119-134.

Bumpus, D. F., and Z. M. Lauzier. 1965. Surface circulation on the Continental Shelf of eastern North American between Newfoundland and Florida. Am. Georgraph. Soc. Atlas of the Marine Environment, Folio 7, 4 p., 8 pl., Appendix.

Caddy, J. F. 1968. Underwater observations on scallop (Placopecten magellanicus) behaviour and drag efficiency. J. Fish. Res. Board Can. Vol. 25(10): 2123-2141.

Curry, J. R. 1956. The analysis of two-dimensional orientation data. J. Geol. 64: 117-113.

Flagg, C. N., B. A. Magnell, D. Faye, J. J. Cura, S. E. McDowell, and R. I. Scarlet. 1982. Interpretation of the physical oceanogrpahy of Georges Bank. Final Report No. 1. EG & G Environmental Consultants, Walthone Mass. (prepared for U.S. Dept. of Interior Bureau of Land Management. Contract # AA851-CT1-39).

Gould, S. J. 1971. Muscular mechanics and Ontogeny of swimming in scallops. Palaeontology Vol. 14(1): 61-94.

Gruffydd, LL.D. 1976. Swimming in Chlamys islandica in relation to current speed and an investigation of hydrodynamic lift in this and other scallops. Norw. J. Zool. 24: 365-378.

Moore, J. K., and N. Marshall. 1967. An analysis of the movements of the bay scallop Aequipecten irradians in a shallow estuary. Proc. Nat. Shellf. Ass. Vol. 57: 77-82.

Moore J. D., and E. R. Trueman. 1971. Swimming of the scallop Chlamys opercularis (L.). J. exp. mar. Biol. Ecol. Vol. 6: 179-185.

Nie, N. H., C. H. Hill, J. C. Jenkins, K. Steinbrenner, and D. H. Bent. 1975. SPSS: Statistical Packages for the Social Sciences. McGraw-Hill, New York: 675 p.

Peterson, C. H., W. G. Ambrose, Jr., and J. H. Hunt. 1982. A field test of the swimming response of the bay scallop (Argopecten irradians) to changing biological factors. Bull. Mar. Sci. 32(4): 939-944.

Phillips, B. F. 1983. Migrations of pre-adult Western rock lobsters Panulirus cygnus, in western Australia. Mar. Biol. 76: 311-318.

Posgay, J. A. 1982. Movement of tagged sea scallops on Georges Bank. Mar. Fish. Rev. 43(4): 19-25.

Stanley, S. M. 1970. Relation of shell form to life habits of the Bivalvia (Mollusca). Geol. Soc. Amer. Nesnoir. 125: 1-296.

Thomas, G. E., and LL. D. Gruffydd. 1971. The types of escape reactions in the scallop Pecten maximus by selected sea-star species. Mar. Biol. 10: 87-97.

Thorburn, I. W., and LL. D. Gruffydd. 1979. Studies of the behaviour of the scallop Chlamys opercularis (L.) and its shell in flowing sea water. Mar. Biol. Ass. U.K. Vol. 59: 1003-1023.

Wiborg, K. F. 1963. Some observations on the Iceland scallop (Chlamys islandica) in Norwegian waters. Fiskeridirectorat skrifter Serie Havundersokelser 13(6): 38-53.

Table 1. Summary of scallops marked and recaptured for Georges Bank and the Great South Channel from 1977 - 1981.

Location	Year	Number release stations	Number scallops released	Number of station recaptures	Number of scallops recaptured	Percent recaptured
Great South Channel	1977	4	542	4	22	4.1
	1978	2	302	2	10	3.3
Georges Bank	1977	24	3185	24	130	4.1
	1978	17	3272	17	88	2.7
	1979	22	3990	22	242	6.1
	1980	41	4447	41	493	11.1
	1981	29	4348	25	297	6.8
TOTAL		139	20086	135	1282	6.4

Table 2. Summary of scallop return data. Mean values have associate standard deviations.

	Georges Bank	Great South Channel
Number released	19242	844
Number recaptured	1250	32
Number without recapture date	485	15
Number with incomplete data	83	1
Number with complete data	682	16
Mean release size (mm)	77.7 ± 8.6	89.6 ± 4.4
Mean recapture size (mm)	88.9 ± 11.3	101.9 ± 12.6
Mean days at large	310.0 ± 268	244 ± 257
Mean distance moved (km)	8.40 ± 9.77	7.72 ± 7.75
Mean rate of movement (km/day)	0.03 ± 0.10	0.02 ± 0.07
Angle of mean vector	217.41° ± 39.9	101.5° ± 17.1

Table 3. Summary of Georges Bank scallop movement statistics for each height interval. Values in brackets are standard errors.

Size (mm)	Number	Mean days at large	Mean distance (km)	Mean rate (km/d)	Median rate (km/d)
59	11	373.5 (87.6)	6.5 (1.4)	0.05 (0.02)	0.02
60-69	96	382.7 (25.6)	9.3 (1.0)	0.06 (0.02)	0.02
70-80	291	323.5 (13.5)	8.7 (0.5)	0.05 (0.01)	0.02
80-89	231	257.9 (18.8)	8.0 (0.7)	0.14 (0.19)	0.03
90-99	41	263.5 (41.0)	8.0 (1.7)	0.22 (0.84)	0.04
100-110	11	547.3 (176.7)	4.8 (0.7)	0.07 (0.41)	0.01

Table 4. Mean individual distance, distance of mean vector, angle of mean vector, and Rayleigh's Z for each 20 min grid on Georges Bank (A-L) and the Great South Channel (M).

Grid	N	Mean individual dist. (km)	Dist. mean vector (km)	Angle mean vector	Rayleigh Z	
A	4	6.32	2.79	6.8	1.73	NS
B	2	37.04	35.54	54.9	0.40	NS
C	7	7.93	0.58	90.0	0.03	NS
D	6	3.52	2.17	166.7	2.99	*
E	46	13.35	6.38	307.6	8.09	**
F	16	8.99	3.21	281.9	0.96	NS
G	357	7.68	2.00	206.4	21.29	**
H	5	7.49	3.74	233.5	2.42	*
I	77	8.03	3.15	225.0	8.59	**
J	102	7.67	4.30	233.4	8.53	**
K	46	10.75	5.15	245.8	8.18	**
L	14	8.60	6.68	187.7	7.4	**
TOTAL	682	8.40	2.40	217.4	40.8	**
M	16	5.72	2.22	101.5	1.26	NS

* Significant at 0.05 level
** Significant at 0.01 level
NS Non-significant

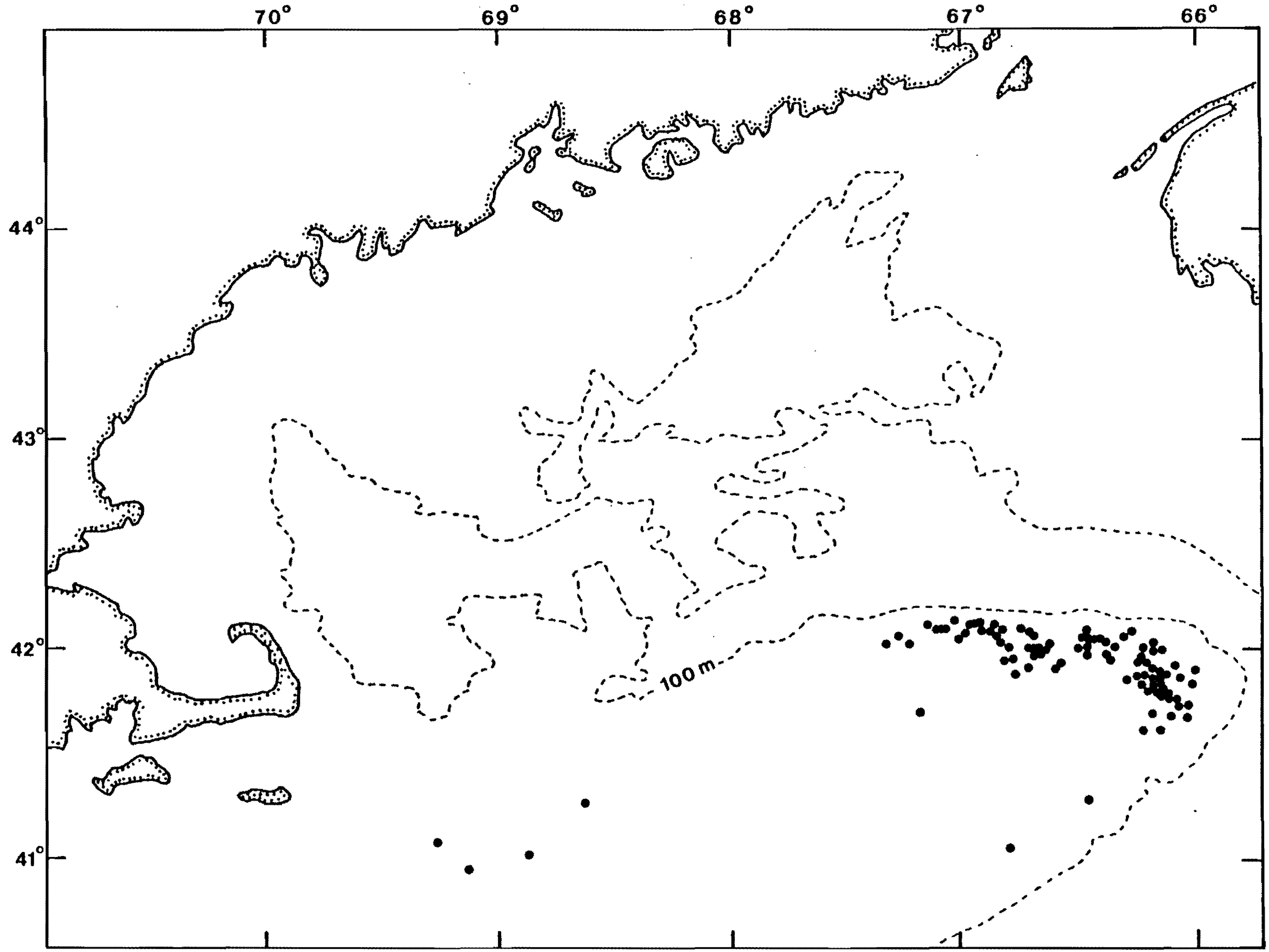


Figure 1. Scallop release sites on Georges Bank and the Great South Channel.

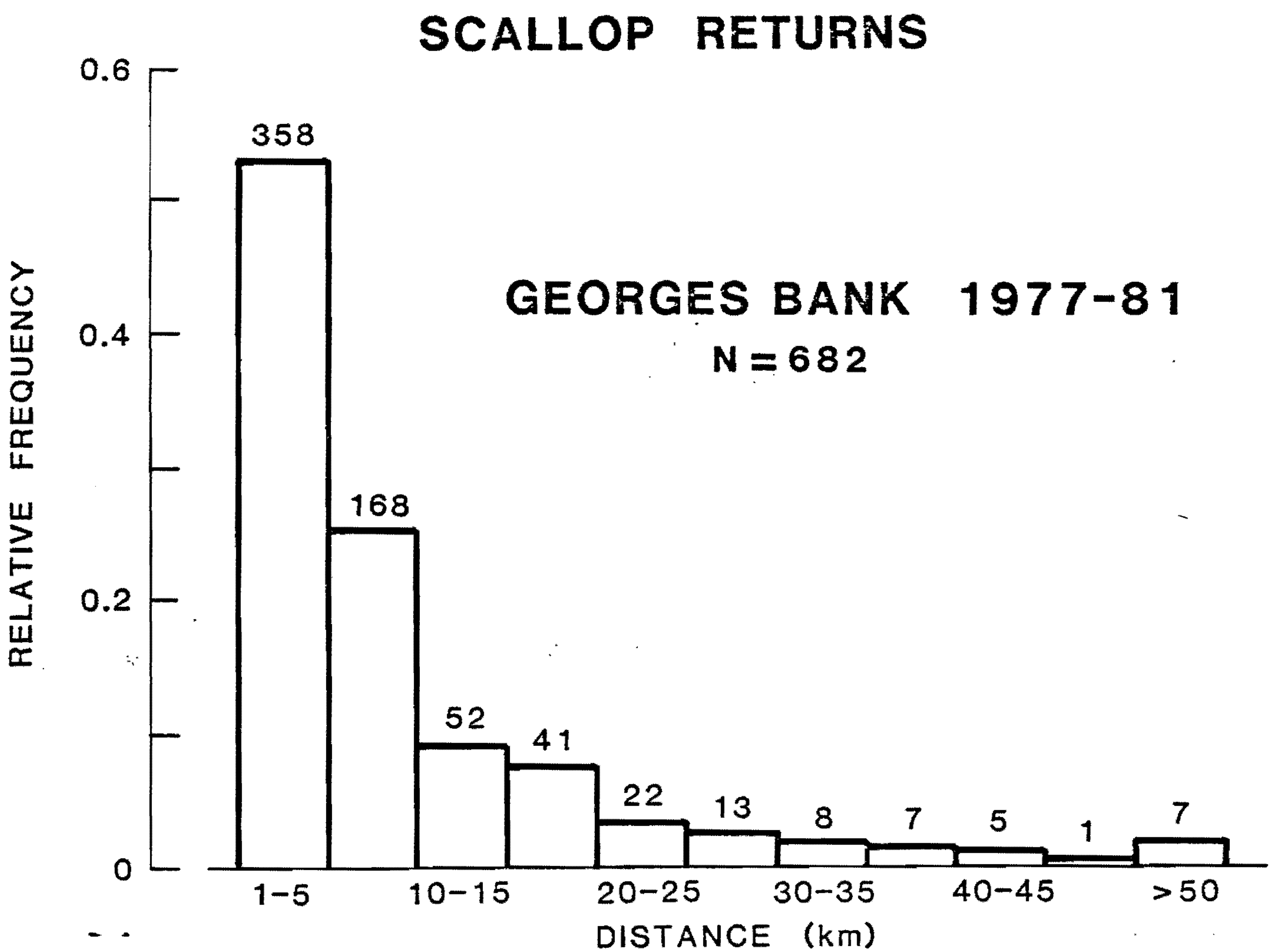


Figure 2. Frequency distribution of distance in 5 km divisions for Georges Bank scallop returns.

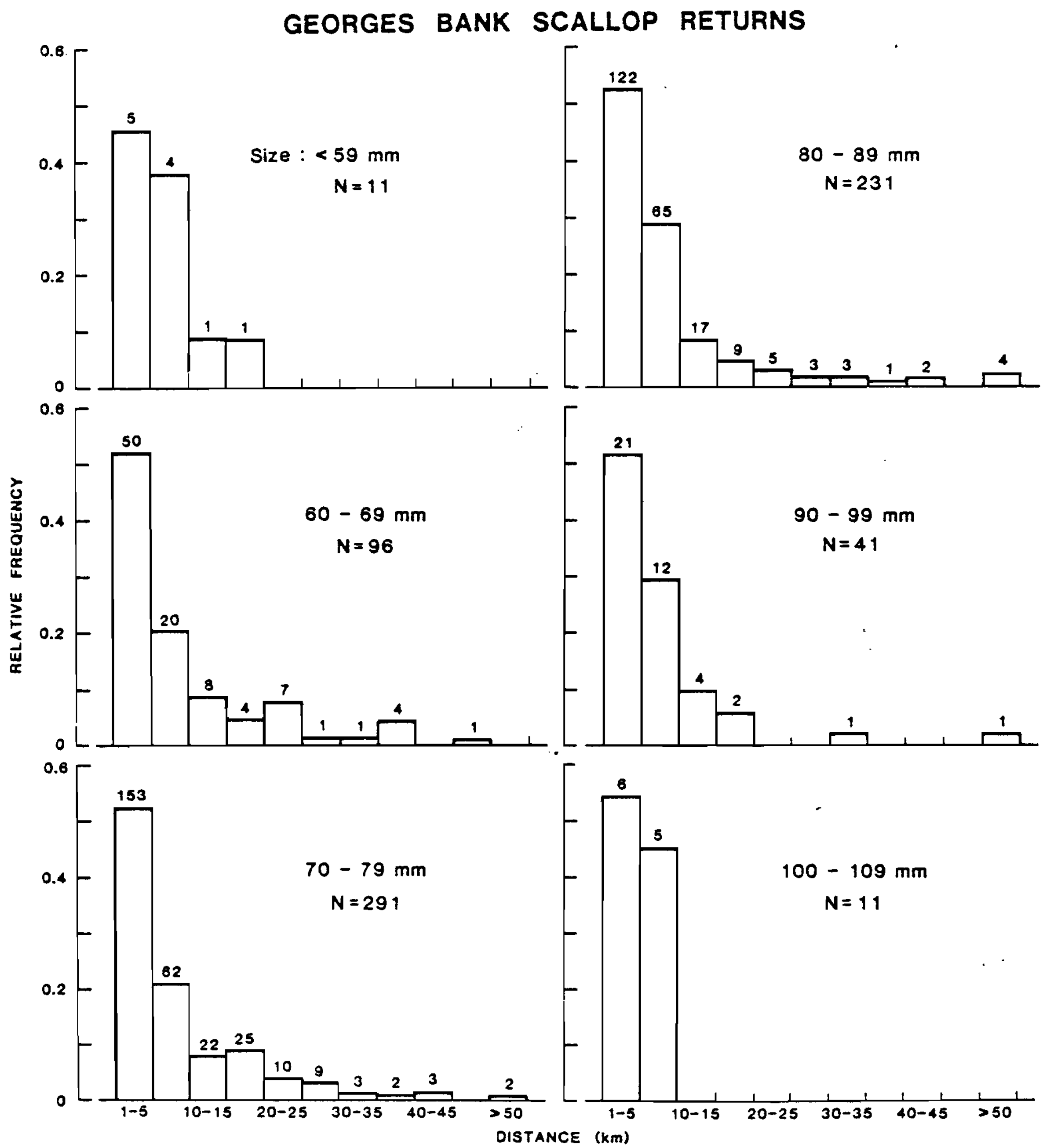


Figure 3. Relative frequency of distances moved for Georges Bank scallops by shell height.

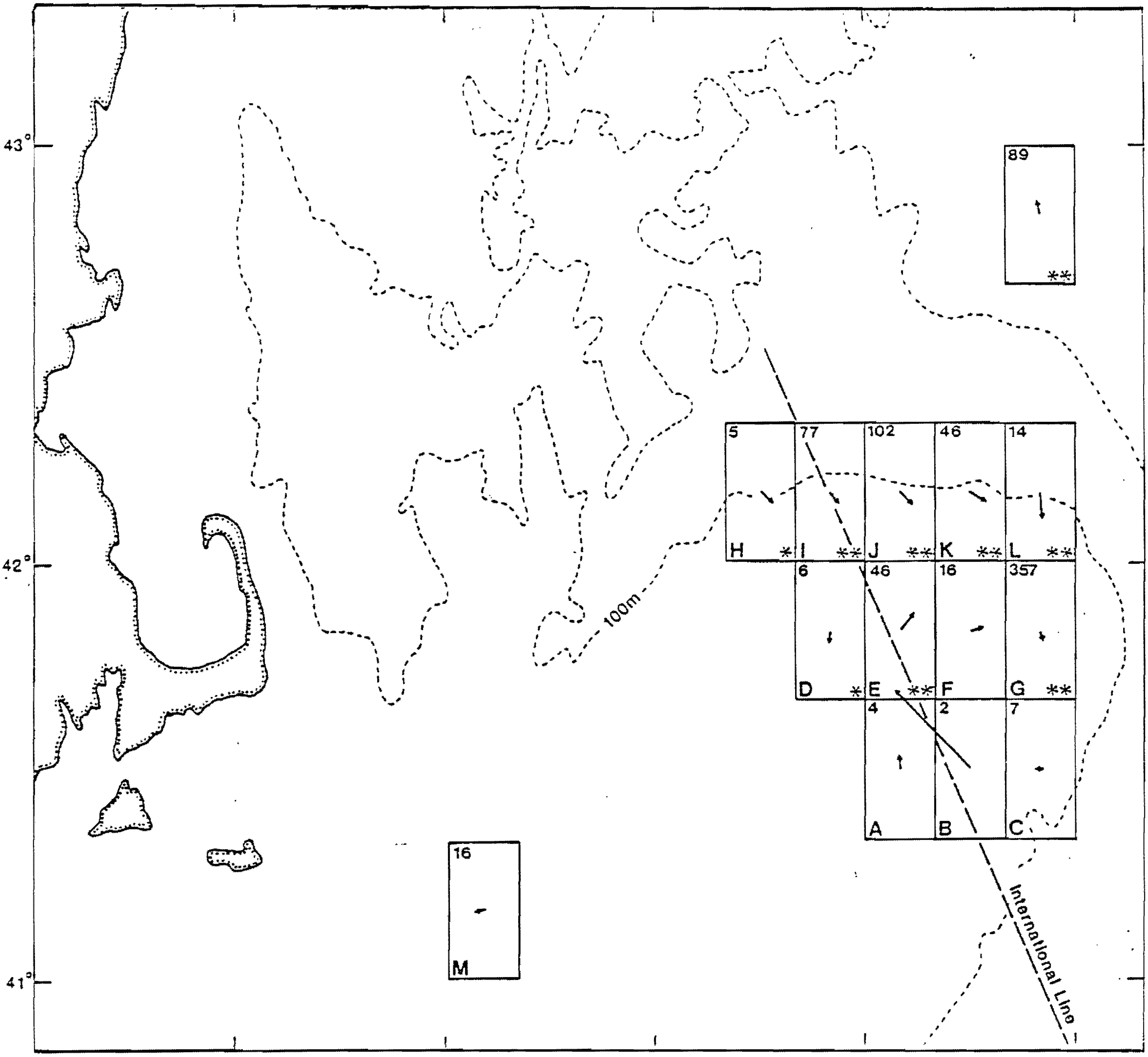


Fig. 4. Mean directonal vector for each 20 min grid on Georges Bank, the Great South Channel, and Browns Bank. Values in the upper left-hand corner represents the number of returns for each grid. Asterisks refer to significance level of Rayleigh's "Z" as per Table 3. Length of the mean vectors are scaled to mean distance traveled.

Figure 5 (A-M). Individual scallop movement and mean vector for each grid. The insert represents the approximate velocity and percent occurrance of currents for 8 directional bins reproduced from Flagg et al. (1982). Length of the mean vectors are scaled to mean distance traveled.

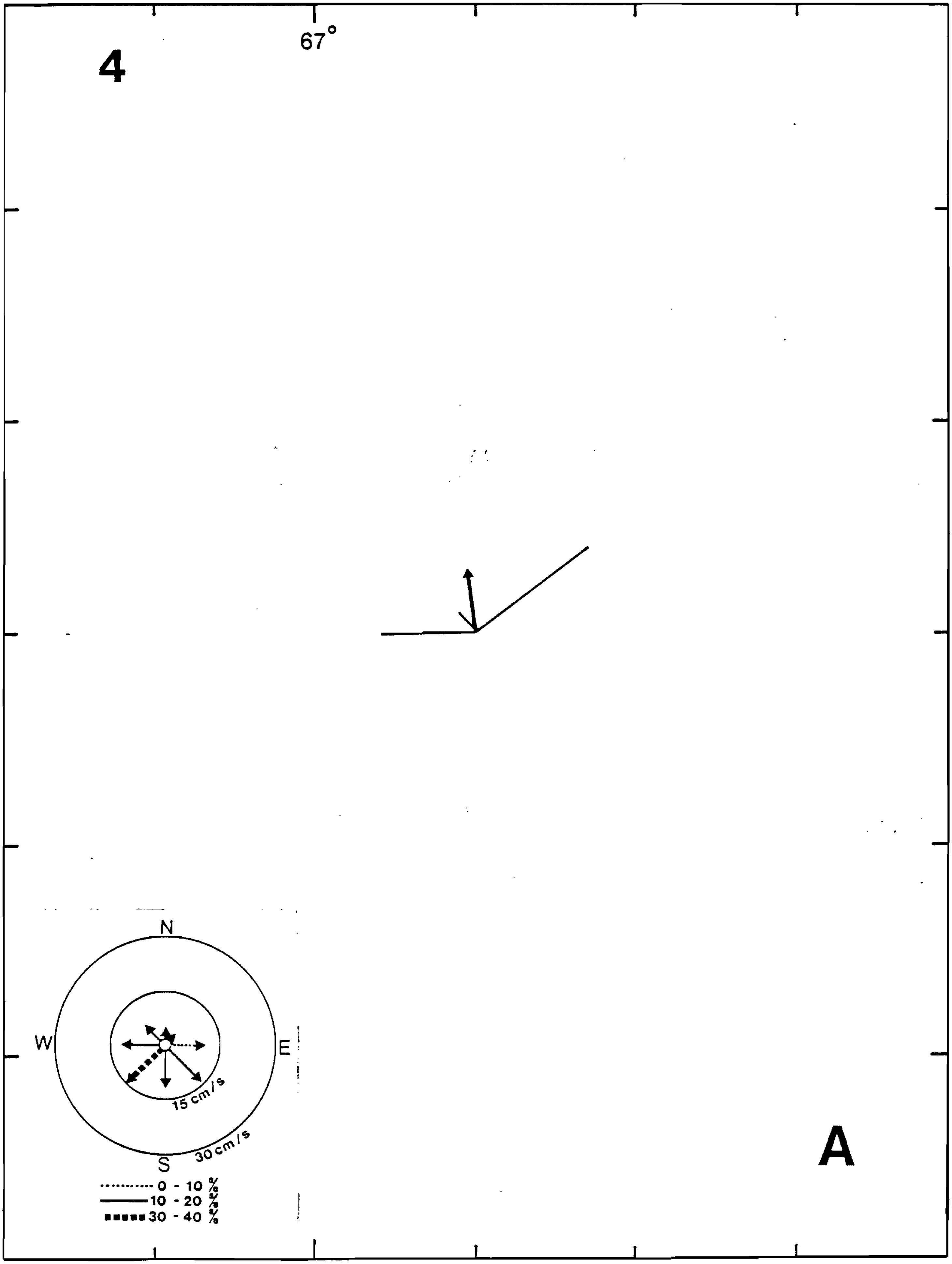
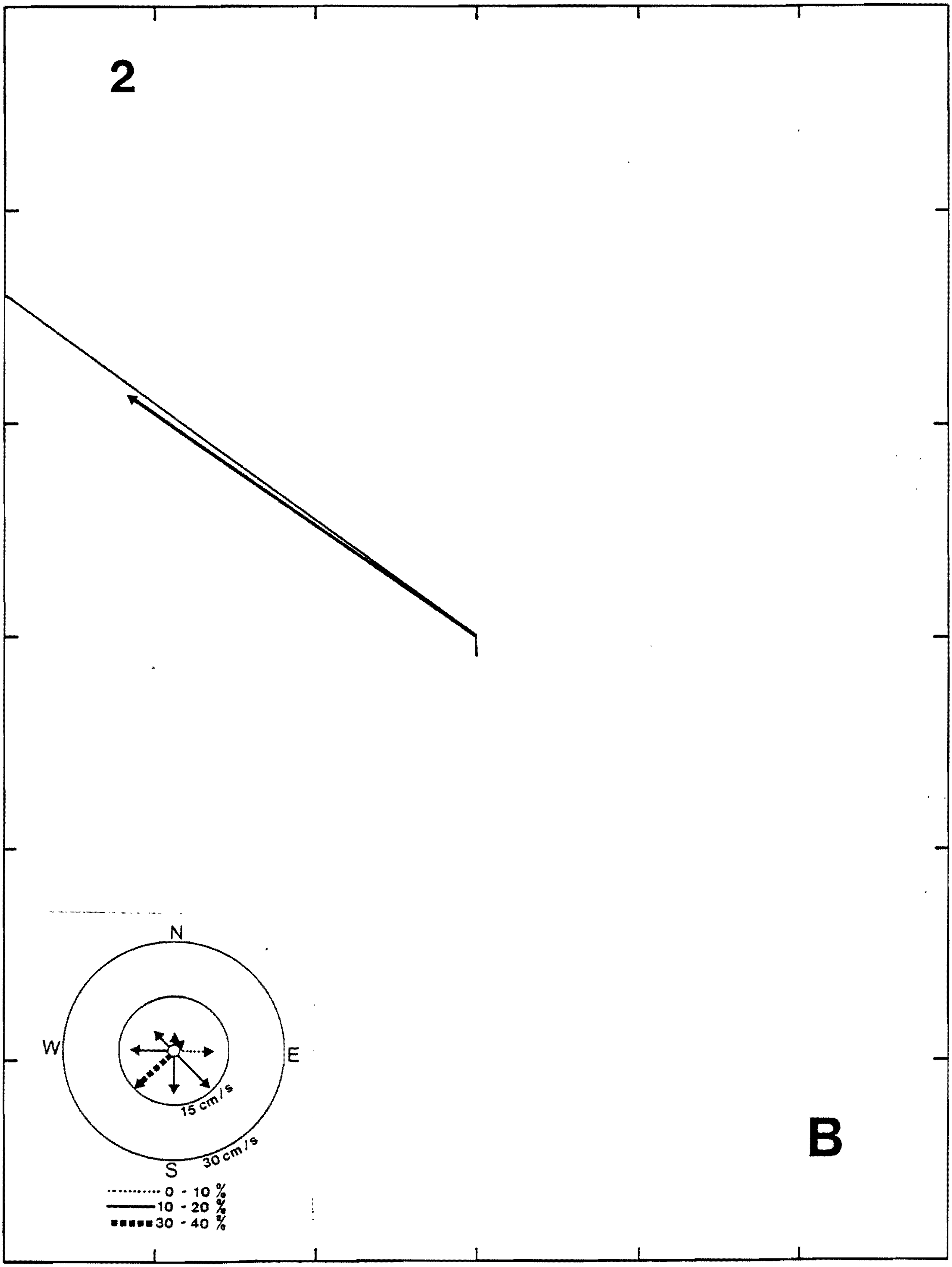


Figure 5A



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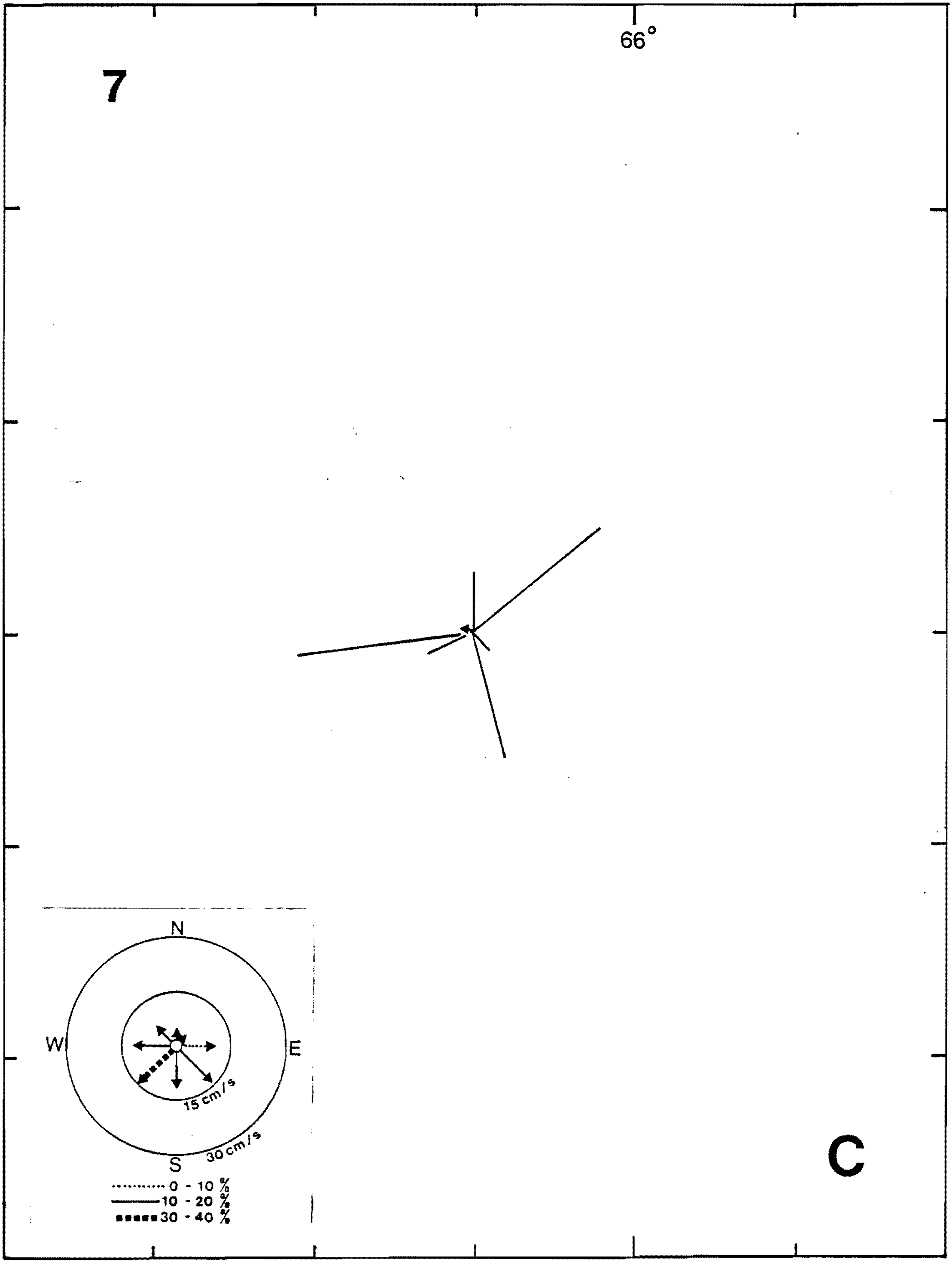

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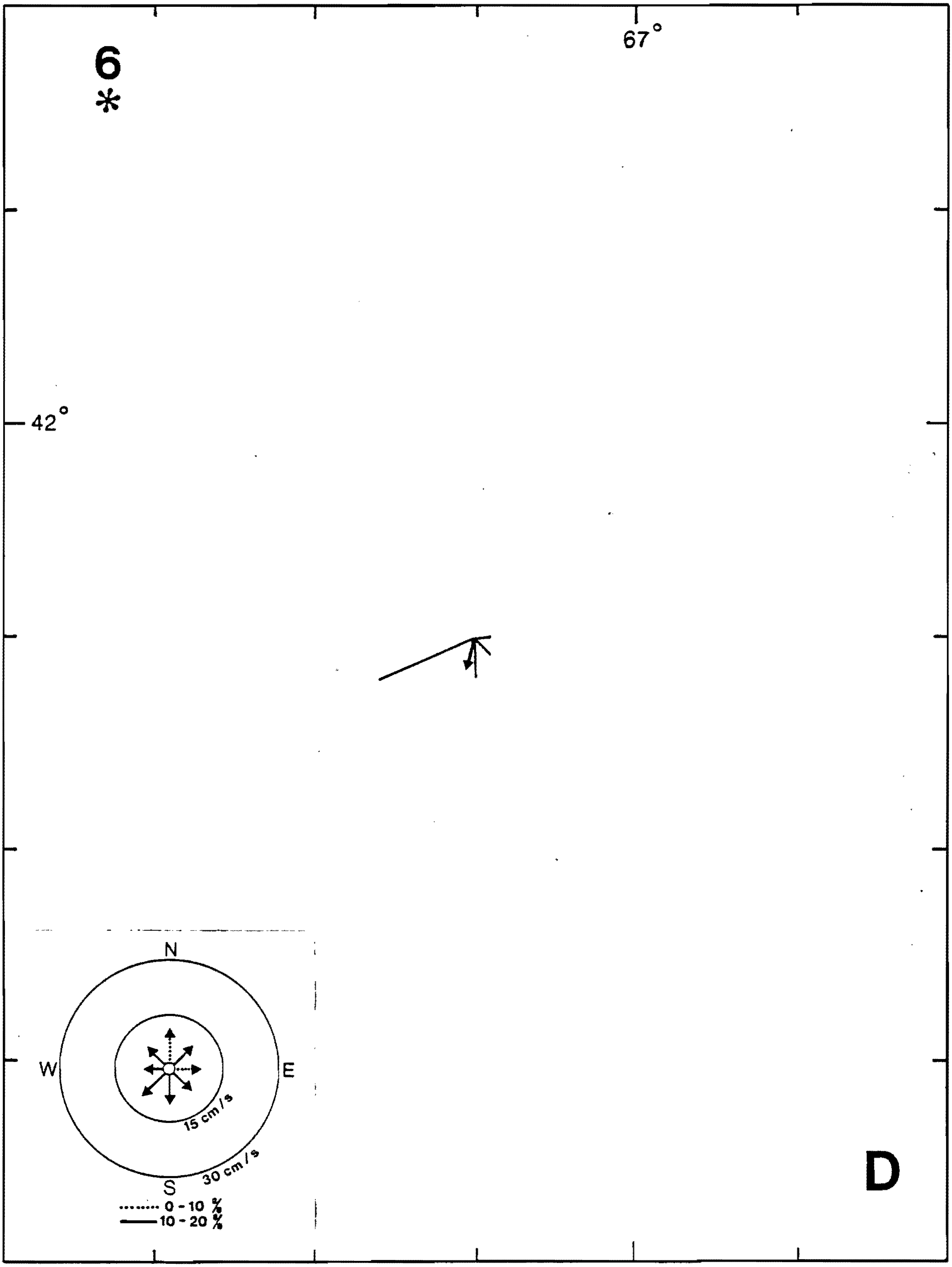

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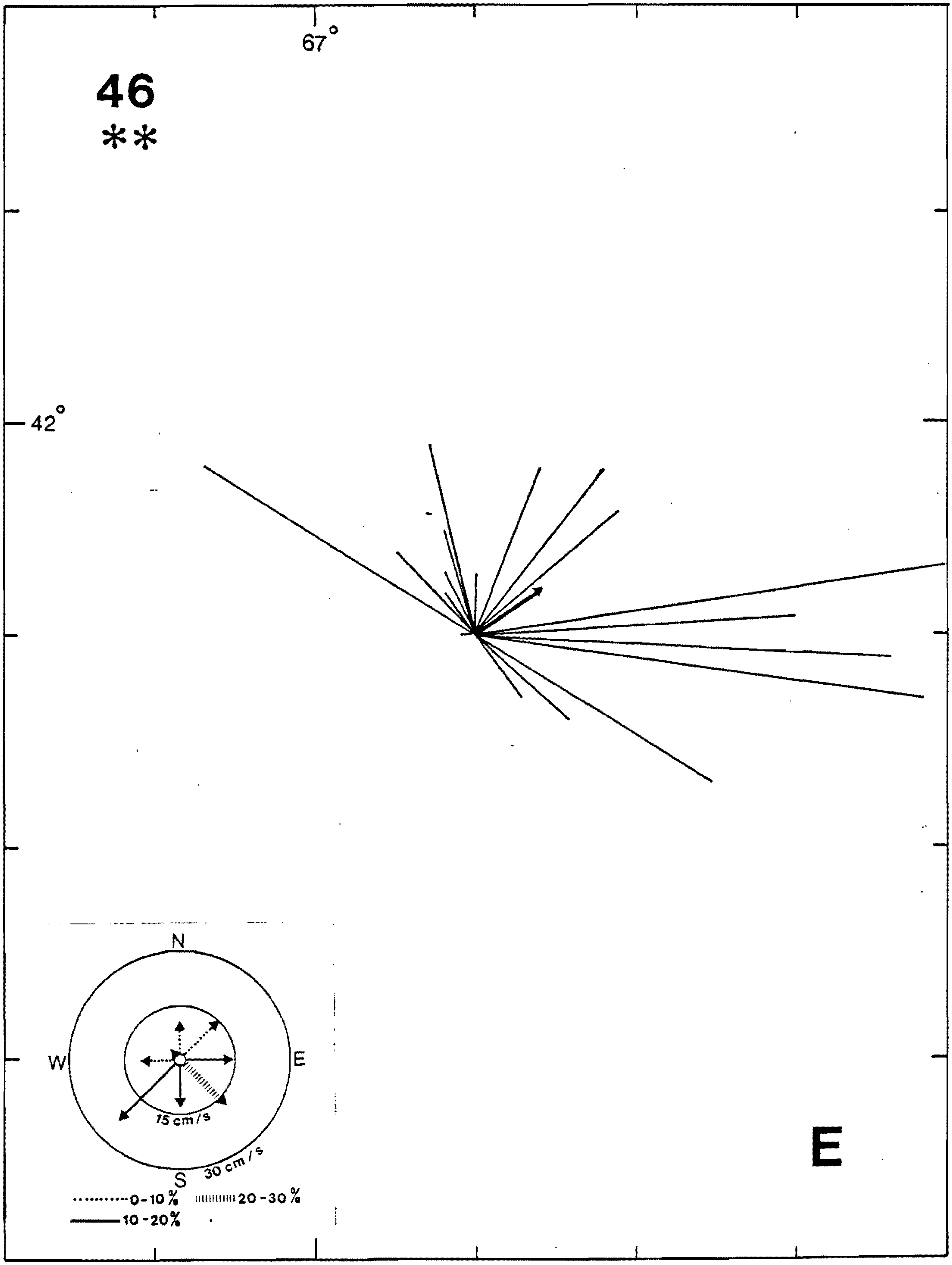

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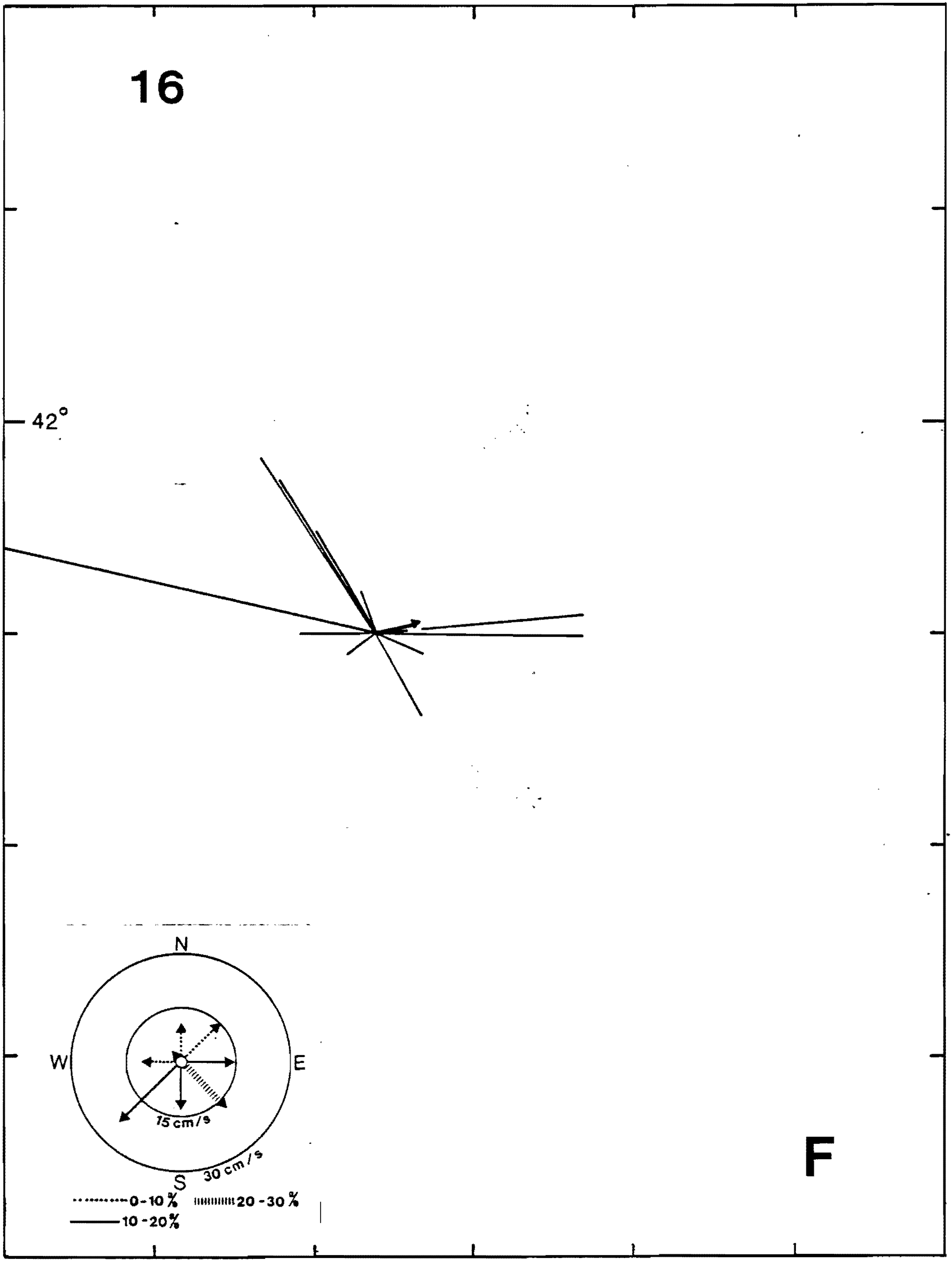

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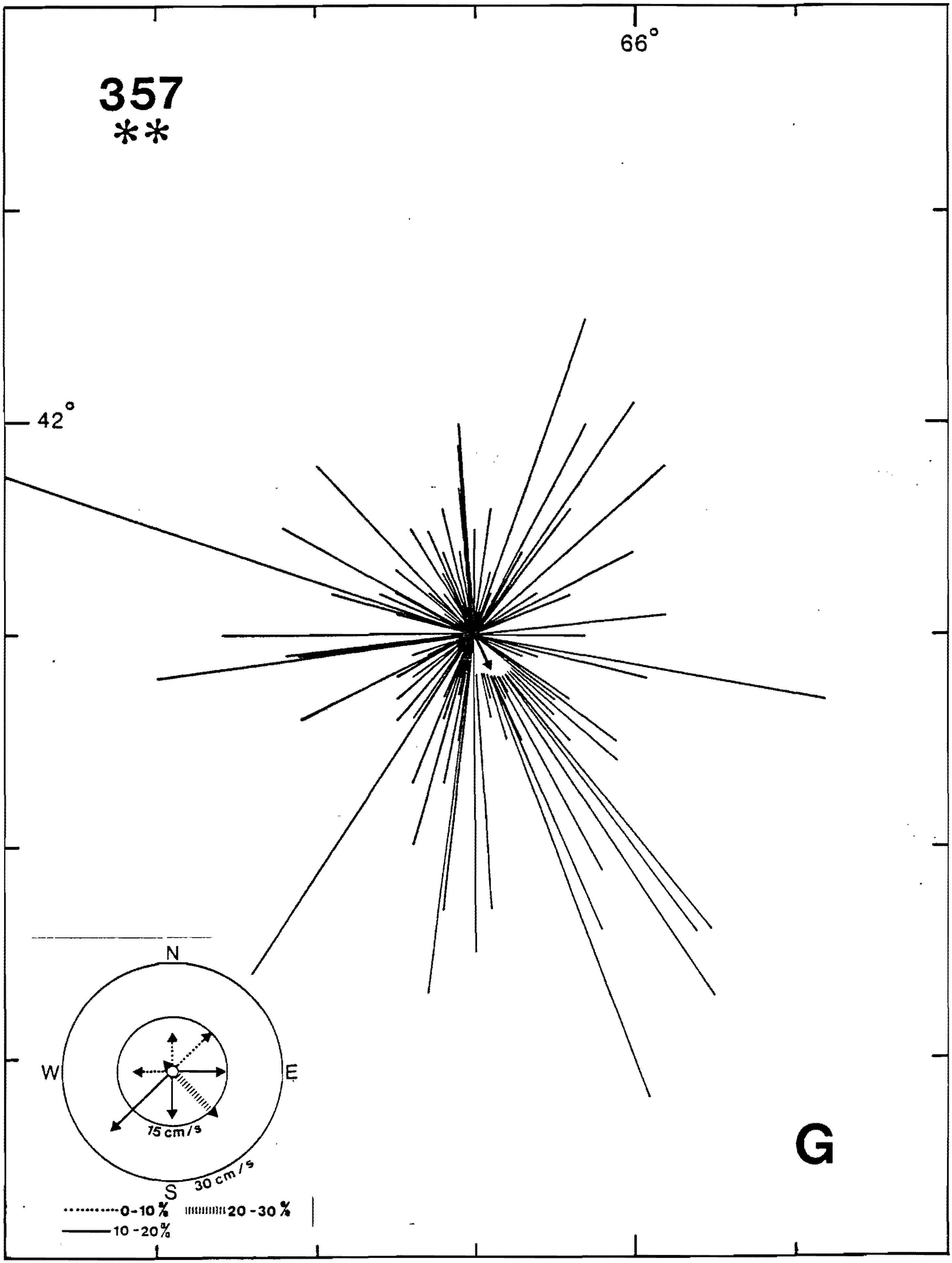

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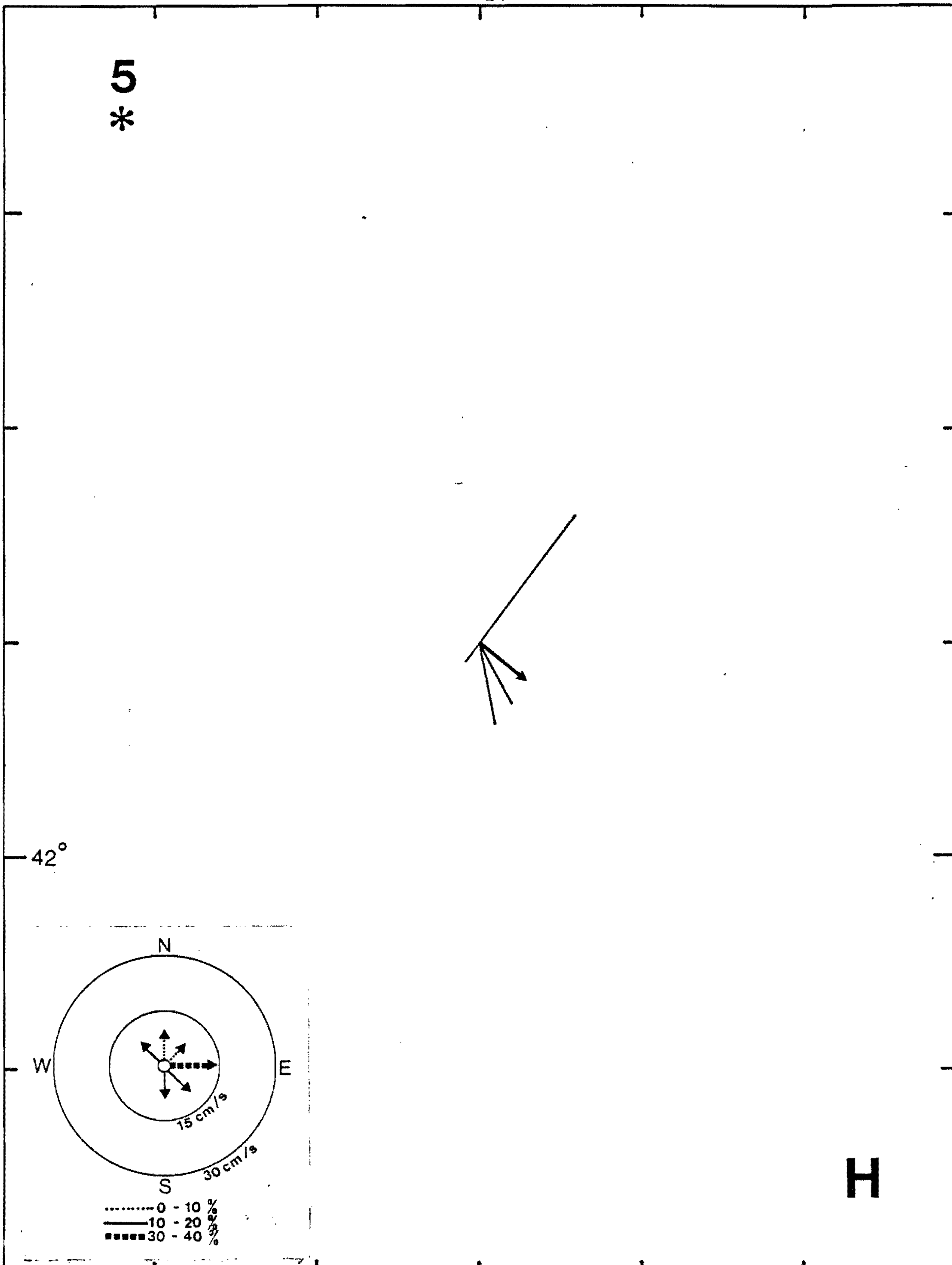

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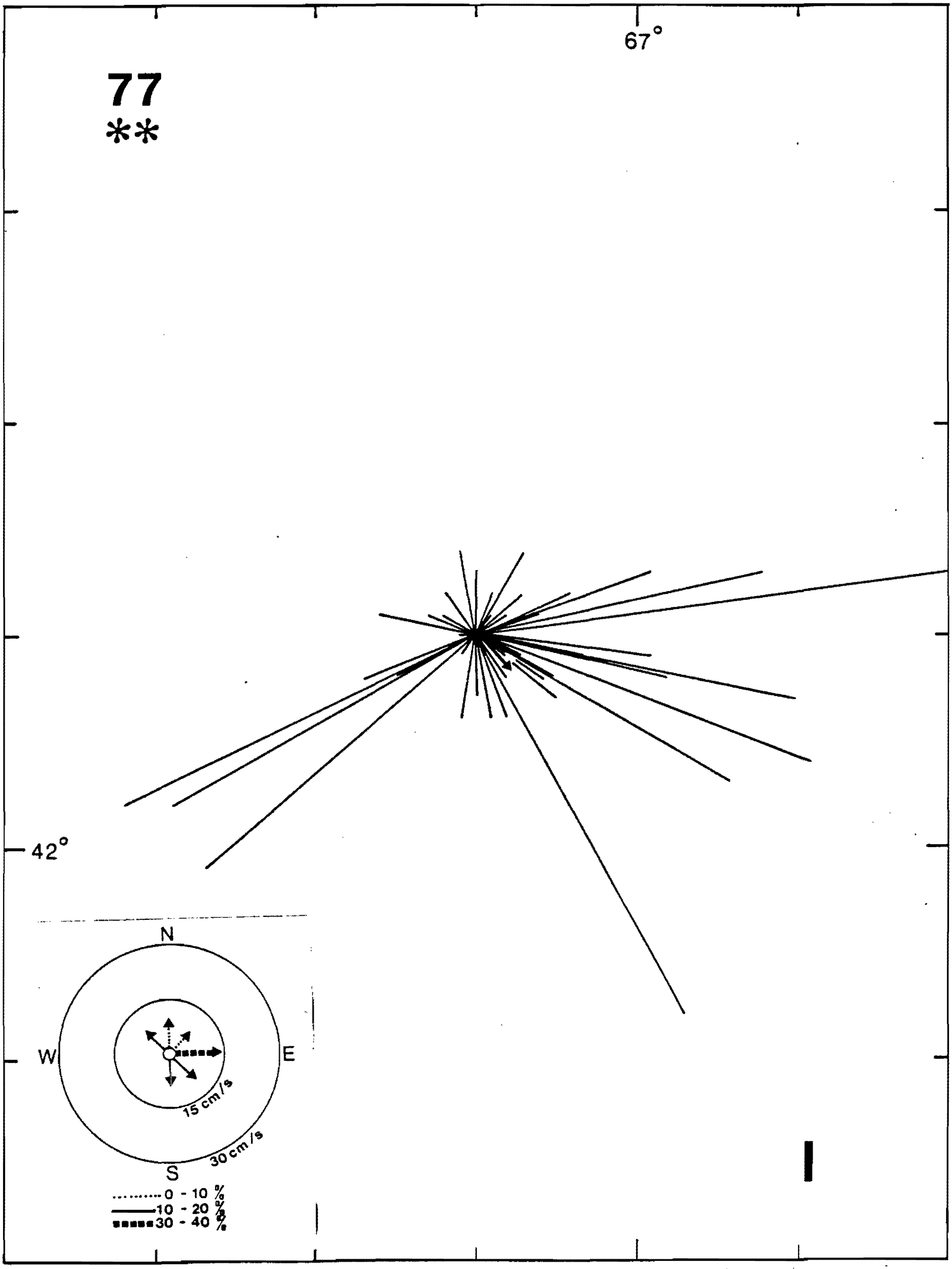
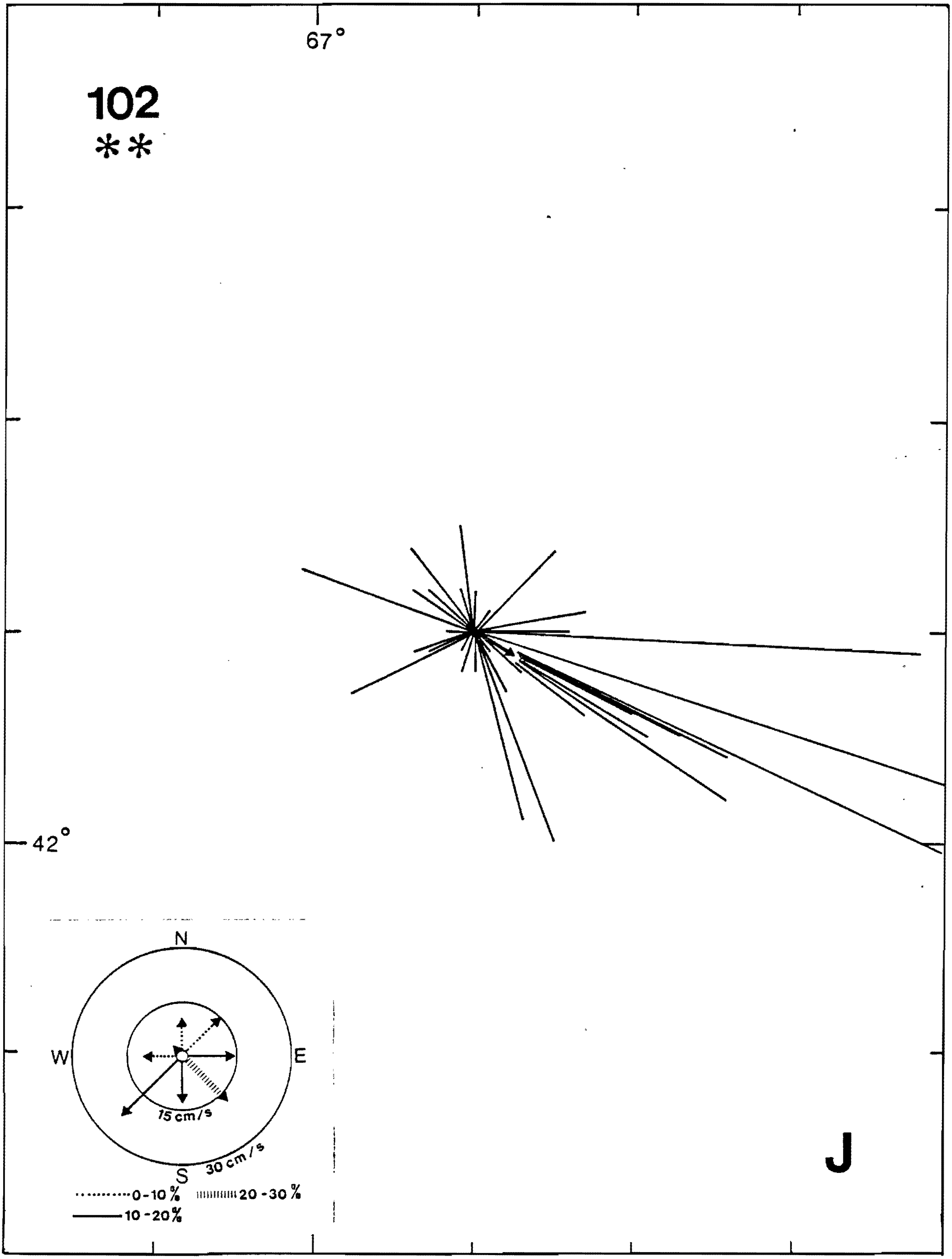


Figure 5I.



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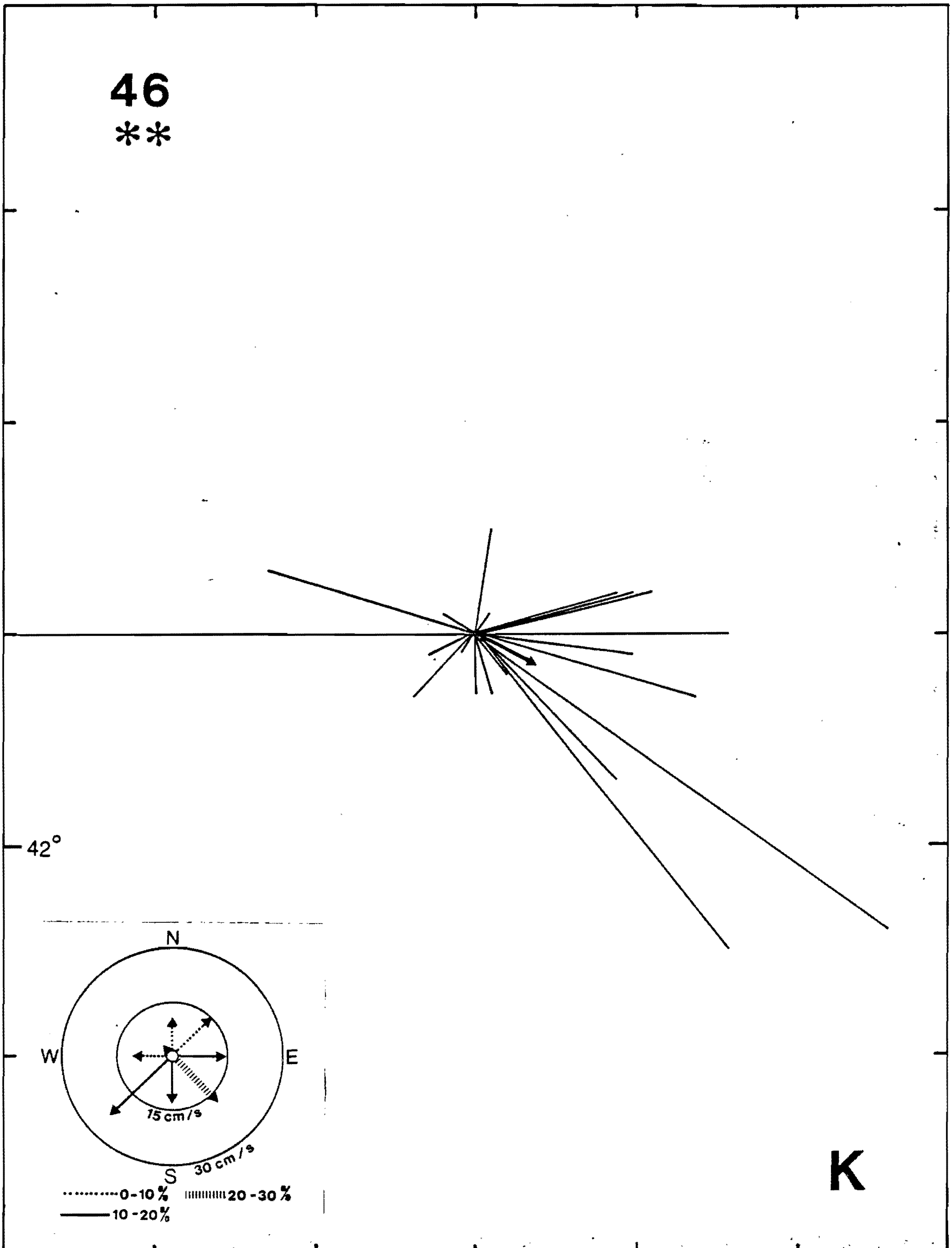

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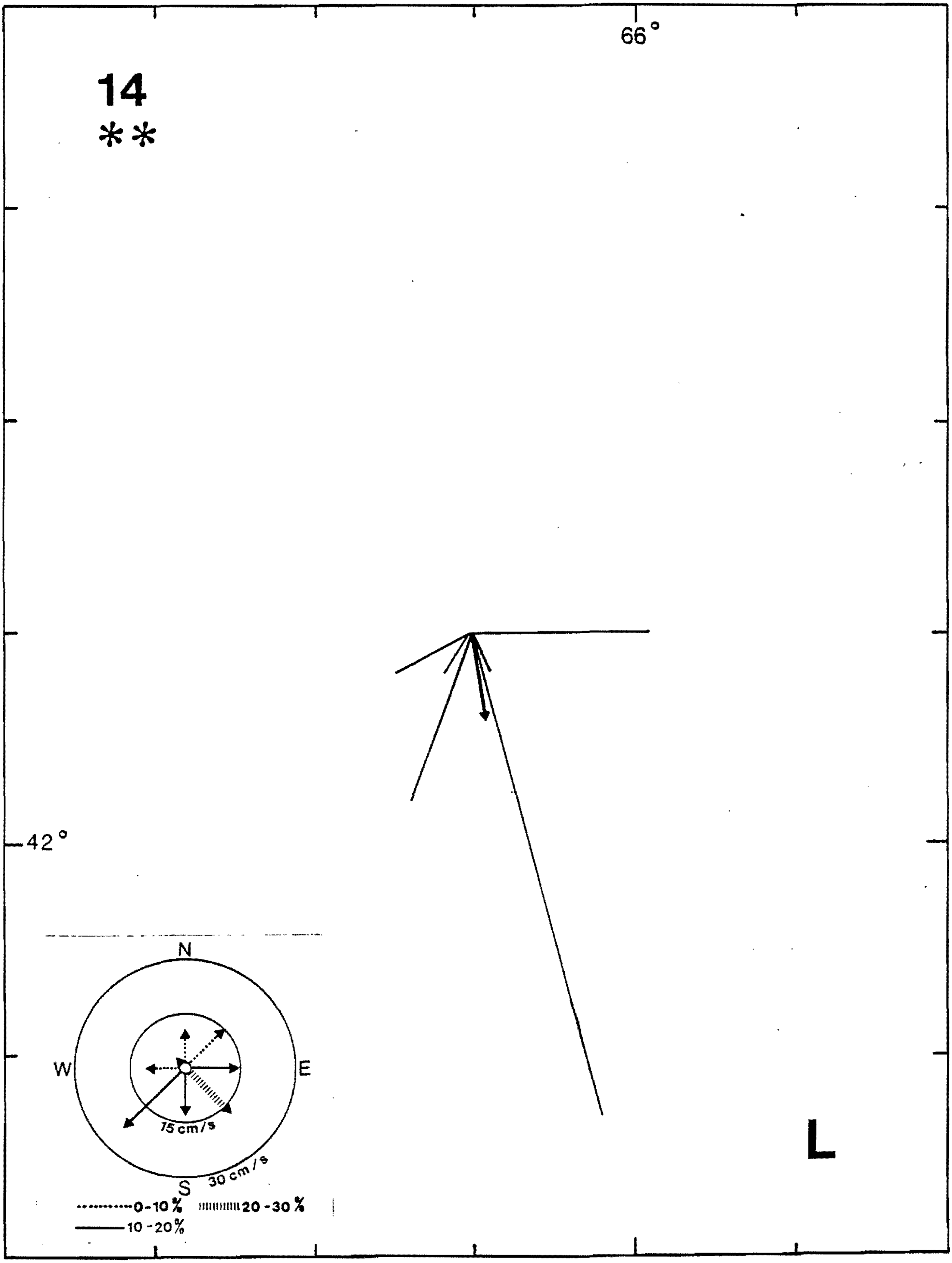

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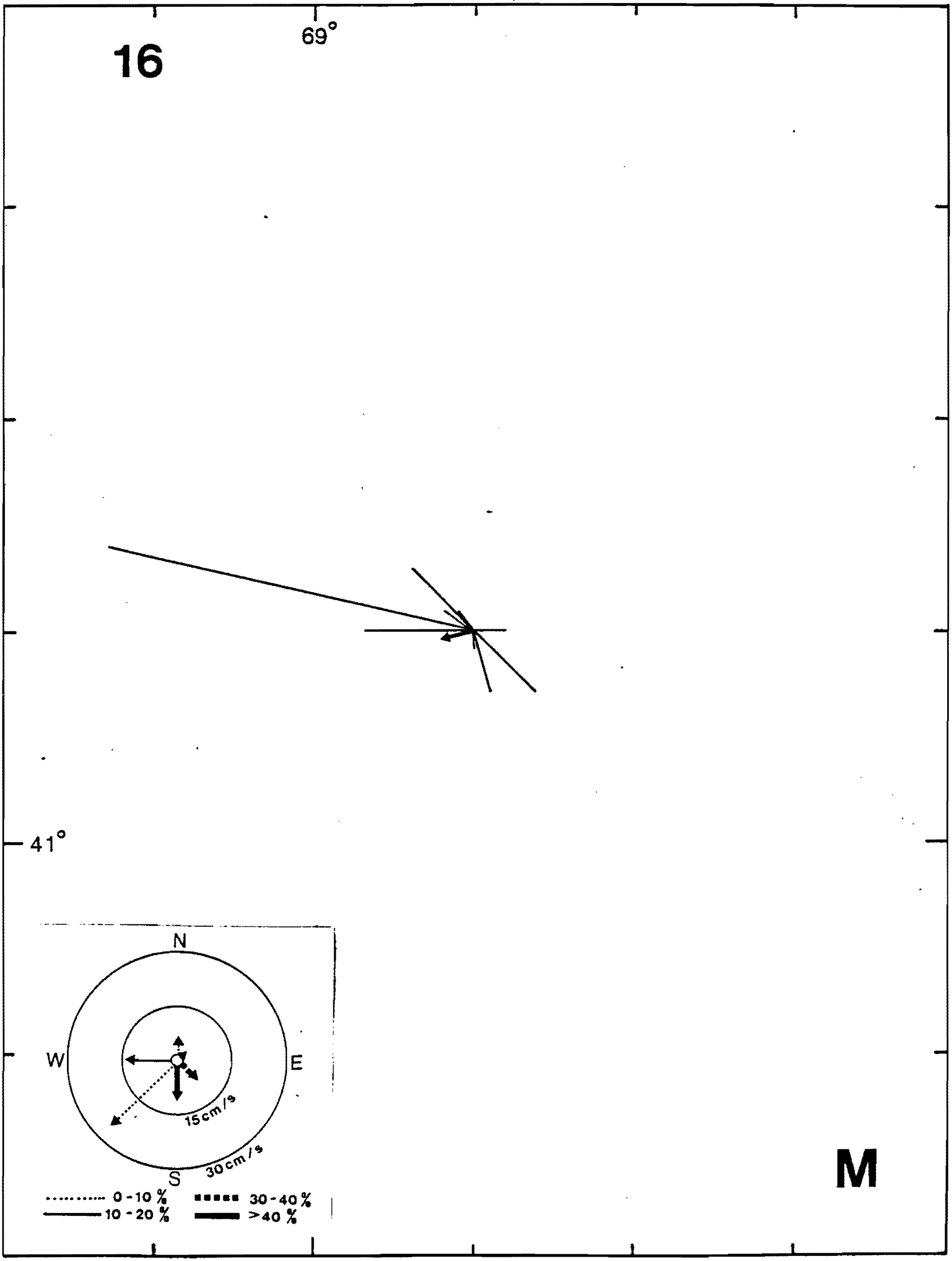

Figure 5M.