STRAIN SYMPTOM PATTERNS OF SPRUCE BEETLE-ATTACKED SPRUCE

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ABSTRACT

Large-scale (1:2000) color-infrared aerial photographs of Engelmann spruce (Picea engelmannii Parry) were evaluated for strain symptoms of spruce beetle [Dendroctorus rufipennis (Kby.)] attack. Two patterns of damage (strain symptoms) were noted. The first related to the long term effect of the attack as the trees declined over a period of years. The second pattern related to the "green-attack" stage. The noted patterns indicated ways in which a forest manager could use visual photo interpretation techniques to evaluate beetle attacked trees.

INTRODUCTION

The early detection of bark beetle attacked trees in British Columbia's forest translates into dollars and jobs saved. In October, 1983, the estimated (premilling) value of timber at risk in the Prince Rupert Forest District (northwestern British Columbia) was set at approximately $1,674,400,000 (Paul Pashmik, Regional Protection Manager, B.C. Ministry of Forests - Pers. Comm.). Much of the timber at risk is high quality Engelmann spruce (Picea engelmannii Parry) under attack by the spruce beetle (Dendroctonus rufipennis (Kby.). To locate and identify new attacks, when the trees still maintain a full complement of green foliage, ground probes, have been the traditional approach. Ground crews are sent in to probe suspect areas, and to identify the new attacks by detecting the presence of brown boring dust around the base of trees. There are no pitch tubes. Ground probes are very expensive because of the man-power and time required to obtain results.

"The start of an outbreak is difficult to detect, because the foliage does not fade until a year after attack, and it turns pale green only before dropping" (Furniss and Carolin 1977). Suspect areas of new attack have, in part, been suggested based on the aerial sketch-mapping of old attacks where the trees have decidely faded or died. However, aerial sketchmapping cannot be used to diagnose new attacks. The purpose of this paper is to report on the results of a photo-interpretation study of newly infested spruce beetle attacked trees.

BACKGROUND

The spruce beetle follows either a one or two year cycle, (Furniss and Carolin 1977, Johnson and Lyon 1976). The basic pattern has the adult beetle emerging from its over-wintering

site in the late spring, and "attacking" new host trees by boring through the bark and into the cambial region between the xylen and phloem. The adults excavate galleries. Eggs are laid in the galleries, the pupae emerge and grow in the galleries. Their feeding activity can eventually girdle the tree. Depending on tree vigor and climatic conditions, the tree can in some instances produce enough gum and resin products to overwhelm the activity of the beetle or its larvae. If the resin products fill the galleries and stop the beetle activity, the beetle is termed to have been "pitched-out". If feeding is successful, adults emerge to eventually attack new host material, and the old host tree dies. Attack by small numbers of beetles in the first attack year may only partially affect the tree. Such trees are called "strip attack". The beetles may re-attack the same tree the next year or two before finally killing the tree. Strip attack is usually determined by removing the bark from around the circumference of the trunk and checking for the insect galleries.

Three conditions affect the rate of decline of the tree. First, the beetles must attack in sufficient numbers to affect the tree. One or two beetles attacking a tree probably won't kill the tree. Second, conditions must be such that the tree does not "pitch-out" the attacking beetles. Thirdly, the beetle does not act alone. Associated with the beetle is fungus which the beetle spreads to new host material. The associated fungus belongs to the genus Ceratocystis which is the same genus as the infamous Dutch elm disease [Ceratocystis ulmi (Buism) C. Moreau]. The burrowing adult beetle introduces the fungus into the tree. The spread of the fungus in the wood is indicated by a blue stain, and affects the tree through blockage of the translocates primarily in the xylen. When a tree "pitches-out" the beetle, the pitch supposedly also blocks the spread of the fungus, in which case the tree could survive. However, it is entirely possible that the tree may have pitched-out the beetle, but the tree succumbs to the effect of the fungus. Thus, with beetle attacked spruce, it is a complex association of insect and disease which is responsible for the decline and mortality of the tree. Consequently, the strain symptoms displayed by the tree are a product of the beetle-fungus association.

According to Furniss and Carolin (1977) when a spruce is attacked successfully, the foliage fades (looses its greeness) and falls off. The tree does not go through a stage when the foliage turns a red-brown color (as do lodgepole pine [Pinus contorta Dougl.] attacked by mountain pine beetle [Dendroctonus ponderosae Hopk.]). After the spruce is attacked and dies, the foliage fades during the summer and/or through the following winter. The foliage first falls from the branch ends and the outer portions of the crown. Recently defoliated branches are dark, and depending on weather, after a year or so of defoliation, the branches dry out and some bark may be exfoliated, and then the branches become highly reflective at all wavelengths, and appear whitish. It is hypothesized that

these strain symptoms can be recognized as some of the damage types keyed by Murtha (1972). The hypothesis of this study was that successfully attacked spruce display a recognizable series of strain symptoms as the tree declines following the successful beetle - Ceratocystis attack and infection. Additionally it was also hypothesized that there are symptoms in the visually green foliage, which are recorded on color-infrared aerial photographs that are missed by the ground observer that separate a beetle attacked spruce from an un-attacked spruce.

METHODS

Ground Data

A study site was selected along the Indianpoint River, 100 km south-west of Prince George, British Columbia, in consultation with foresters and entomologists from the B.C. Ministry of Forests and Northwood Pulp and Paper Co. Ltd., on whose timber licence the stand was located. The stand and surrounding stands were slated for logging due to a heavy infestation of spruce beetle; however the Company agreed to reserve the selected site from logging. The stand was a mature stand of Engelmann spruce and subalpine fir [Abies lasiocarpa (Hook) Nutt] and had been subjected to beetle attack for several years [Wood and Van Sickle (1983); Sterner and Davidson (1983)]. Ground probes had indicated unattacked, newly attacked, old attacks, faded, defoliated and dead trees.

To assist the ground study phase, the site was photographed at 1:20,000 with color-infrared (2443) and normal color (2448) aerial photographs. The photographs were enlarged to a scale of 1:3000 and printed as black and white prints and these photographs were used as pictorial maps to establish tree location by the ground crew.

In June and July 1983, a ground crew examined 789 spruce trees on the site. Each tree was numbered, tagged, and the tree location was recorded on the enlarged 1982 photographic prints. For each tree the following field data were collected:

A. Attack Status

- Normal
- Unattacked
- 1983 Attack
- 1982 Attack
- 1982 Strip Attack
- Attack prior to 1982

B. Cone Crop

- None
- Light
- Heavy

C. D.B.H.

- 0-20 cm
- 20-20 cm
- 40+ cm

D. Site Position

- Upper (dry)
- Middle (moist)
- Low (wet)

E. Background Sky Illumination (when viewing tree)

Normal
Bright
Dark

F. Notes concerning crown condition

Foliage color
Foliage thinning
Full crown
Presence and number of old dead branches.

It was difficult for the field crew to determine strip attack since they wanted to avoid destructive sampling of the tree and thus avoid creating any possible unwanted stress in the trees. Sampling for strip attack would have resulted in girdling of the trees and thus causing unwanted stress in the tree.

The field crew also positioned flight line markers in order to assist in the aerial photography. The results of the ground work were not made known to the photo interpreter.

Aerial Photography

Large scale ± 1:2000, 70mm, color-infrared aerial photographs were flown of the test-site on August 18, 1983. The wing-tip system described by Williams (1978) was used. Two Vinten cameras equipped with 6" lenses with Wr. 12 + CC20M filters on each lens were used. A single intervolometer assured simultaneous exposure by both cameras. Thirty pairs of exposures were made of the test site. The film was developed to a positive transparency.

Photo Interpretation

The processed transparencies were mounted as matched pairs on viewing cards. A 2-power pocket stereoscope on a light table was used for interpretation. The 1982 black and white prints upon which the field crew recorded tree numbers were used to locate the ground-checked trees on the 1983 photographs. After the trees had been relocated the trees images were interpreted for strain symptoms according to the damage types described by Murtha (1972), (1978), and Murtha and McLean (1981) (Table 1). The damage types were used to describe the strain symptoms conceived to be associated with beetle attacked trees. If more than one symptom was obviously evident, each was recorded. In the analysis of the field data, these dual symptoms are presented as compound damage types.

Only after the trees had been interpreted were the field notes cross-checked to determine the beetle-attack status of each tree. It is re-emphasized here that the photo interpreter

had not been involved in the collection of field data, nor had visited the test site, or have any other a priori knowledge of the tree-attack status. Additionally, the field crew did not participate in the photo interpretation process.

RESULTS

Although the field crew collected data on 789 Engelmann spruce, only 624 trees were photo interpreted. Some of the spruce were shaded or over-topped by other trees and consequently their crowns were not clearly visible on the photographs. Some trees were missed by the aerial photography since they were located on the periphery of the study area.

The results of the collection of the ground data and photo interpretation of the 624 trees are presented in Tables 2 and 3. Many of the trees had been attacked in at least two or more years. Of the 242 spruce attacked in 1983, 171 were new attacks and the remaining 71 were re-attacks or strip attacks in 1982. Obviously, intensity of beetle attack, and degree of Ceratocystis infection influenced the tree strain symptoms evident in the tree crown. By mid-August, and after the of aerial photography, the field crew reported that all the trees had "pitched-out" the attacking beetles. The implications of this result were that the trees would survive the 1983 beetle attack, especially the 171 trees which were newly attacked in 1983. Thus, the number of repeat attacks, the new attacks, and the pitching-out only serve to make tree "health" categories even more difficult to define.

Tables 2 and 3 show 36 trees which were interpreted as normal, but the ground data indicated at least one beetle attack on each tree. How many attacks and what level of intensity of attack are required to kill a tree? Cross referencing of the field data with the interpretation data indicated that 35 trees interpreted as VM (variegated magenta) were attacked only in 1983, but the other remaining 1983-VM tree was attacked (strip attacked) in 1982. Thus the omission errors perhaps could be calculated as (36-35)/240 or 0.4%.

The damage types conceived to be associated with spruce bark beetle are described in Table 1, and the numbers associated with each damage type are given in Table 2. The damage types are illustrated in Figure 1 (the figure caption gives the photo interpretation category and the attack status as determined by the ground survey). The percentage figures in Table 2 relate the tree number in each damage type-attack category to the total trees in each row. Since many trees were attacked in more than one year, the row percentages do not equal 100 percent. Recognition of the normal, unattacked tree is accomplished by comparison of all trees in a photo frame. Murtha and McLean (1981) described darker (III0a) and lighter (III0b) magenta-hued categories in the interpretation of so-called "healthy" Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco].

[Evaluation of other species has also indicated both the (darker) III0a and (lighter) III0b categories as well as a normal or average magenta pattern.] During the interpretation of the spruce beetle attacked spruce, it was noted that not only only did some trees show a darker or lighter magenta pattern, but these same trees, and the average magenta-hued pattern trees had a decidely variegated or mottled pattern. All these trees were subsequently designated by the letters "VM" in Table 2.

Later analysis indicated that 174/240 or 72.5% of these trees were unattacked by the spruce beetle. Visually the tree crown of the VM trees appears to have a range of tones and colors. The initial appearance is magenta on the color-infrared photos, with the branch tips being a pink magenta, and the inner branch a dark magenta. The dark magenta should not be confused with shadows in the tree crown, since the shadows are decidedly much more cyan. Some of the VM trees had a generally darker (III0a) or lighter (III0b) hue to the crown, and also showed the VM pattern. These 32 trees were assigned a compound classification and included in the 174 total. Thirty of these trees, however were field recorded as attacked and subsequently included in the ommission error classification, even though 27 of the 30 were attacked only in 1983 and these trees too were recorded as "pitched-out" by the field crew. The remaining 3 trees were attacked in previous years as well; added to the one VM 1983 strip-attack tree mentioned above, it is possible that the ommission error adds to only 4 trees in 240 (1.6%), or considering the entire population, 4 trees in 624 (0.6% or 6 trees in 1000) were missed by the photo interpretation.

Conversely, the other damage categories included 70 trees as attacked but the field data suggested they were not attacked. Since these trees displayed strain symptoms they were definitely under some form of stress perhaps by a site factor or disease. These are commission errors, and amount to 11.2% of all trees photo interpreted. The commission and ommission errors indicate possible population mistakes and indicate that every single tree was not correctly classified through photo interpretation. However, the overall photo interpretation tally indicated that 384 of 624 trees had been attacked. The field tally also indicated that 384 trees, albeit not the same 384 trees as the photo tally, had been attacked. Since foresters involved in management of mature spruce stands need to know more about stand condition than single tree condition, it should be realized here that 2 days of photo interpretation gave the same stand attack status in terms of numbers of trees as did 6 weeks of intensive field work.

DISCUSSION AND CONCLUSIONS

The 1982 Forest Insect and Disease Survey (FIDS) report (Wood and van Sickle 1983) for British Columbia categorizes spruce beetle attack into the five following classes:

1) healthy;

2) current: (attack presumed successful in the year of the survey, but the tree foliage is still green);

3) red: (the foliage has turned red brown - a situation common for pine, but very rare for spruce beetle attack. Attack has usually been 2 years prior to the survey;

4) grey: (the trees were successfully attacked at least 2 years prior to the year of the survey), and

5) partial or strip attack: (determined during the ground probe by removing some of the bark from the tree trunk. Strip attack is usually not considered successful, the trees display visually green foliage, and are frequently re-attacked the following year).

The red and grey categories have been mapped by aerial sketch-mapping, but the other categories required data from ground probes. It is suggested here, that based on the results of this study, it is possible to obtain spruce beetle attack data which is less costly and just as useful in making forest management decisions by using photo interpretation techniques and large-scale, color infrared photos. Table 2 presented the commonly seen damage type categories used in the study. Table 4 presents a redefinition of the basic units that should be used in the photo interpretation of spruce beetle attack in spruce stands. Note that in the damage type categories, types IIIOa and IIIOb have been associated with unattacked trees even though they may represent some other form of stress. Categories IIIOa-T and IIIOb-H are beetle attack categories (see Table 4 for descriptions) and are never found in conjunction with the VM unattack category, but are frequently found associated with the IID defoliation category. Visually the foliage would be described as green or light green. Figure 1 illustrates the damage types.

Thus it appears that there are two distinctive pattern of beetle attack which can be interpreted from the large-scale (1:2000) color-infrared air photos. The first pattern relates to the long-term effect as the trees decline over several years. These patterns are not new and have been used in the analysis of beetle attack for many years. The scenario is as follows:

> "About a year after attack the foliage fades (Damage Type IIIOb-H) since it turns a pale green before dropping (IID). While the tree is partially defoliated, some foliage remains (IIIOb-H/IID). After the foliage drops, the dead tree appears grey (IB)."

These damage type associations can be used with smaller scales (1:15,000) and over-view photography.

"First-year attacks can be detected only by the presence of brown boring dust around the base of trees"

[Furniss and Carolin (1977)]. The second scenario relates to the "green-attack" phase (attached trees with green foliage) and is as follows:

Unattacked trees show a variegated magenta (VM) pattern on color infrared photos. Strip attack in the current year probably shows as the IIIOa-T pattern (See Table 4 for descriptions), whereas current-year successful attack shows as IIIOb-H. One year old successful attack shows as IIIOb-H or IIIOb-H/IID. Attack more than one year old can appear as IIIOb-H/IID or IID (as described above). There are overlapping categories and in the study area, it is obvious from the ground attack data that more than one year of attack was required to kill the trees.

The critical categories the forest manager should look far to assess "current-attack", while the foliage is still visually green are IIIOa-T and IIIOb-H.

ACKNOWLEDGEMENTS

The author would like to thank Mr. Allan Banner and field assistant for the collection of the field data; Mr. Tom Maher, Northwood Pulp and Paper Co. for his cooperation, and a grant to the author by the B.C. Science Council for funding of the field work on the aerial photography.

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Table 1. Preliminary description of damage types* used as a guide to categorize spruce strain symptoms as seen on large-scale (1:2000), color-infrared aerial photographs, during the photo interpretation study of spruce beetle attacked spruce.

Damage Type	Description
1A	Tree dead, bark exfoliated, exposed wood bleached whitish through weathering. An old dead tree.
1B	Tree totally defoliated, limbs and branches maintain bark, and are dark toned; tree is recently dead (one or two years).
IID	A thin-crowned, partially defoliated tree, loss of foliage is primarily from the outer portion of the branches, because current foliage has been lost. Inner branches are not visible.
IIE	A thin-crowned tree, premature loss of older foliage, current foliage present, inner branches are visible. [This symptom is related more to chronic stress, than to the results of beetle attack].
IIIB	The foliage has yellowed and appears mauve on color-infrared photos.
IIIG	Entire crown shows dead, red-brown foliage (not common for spruce beetle attacked spruce).
IIIOa	The foliage is a darker magenta hue than normal trees, (noted by comparison within the same photo frame).
IIIOb	The foliage is a lighter magenta hue than normal trees, (and is noted by comparison within the same photo frame).

* There are numerous damage types described by Murtha (1972, 1978) and by Murtha and McLean (1981) but the ones listed were hypothesized to relate to strain symptoms caused by trees stressed by the spruce beetle- Cerotocystis complex.

	Damage Type[2]	ATTACK STATUS[1] UN No.	%	1983 No.	%	1982 No.	%	Prior to 1982 No.	%	Om-Att[3] No.	%	Com-UN[4] No.	%	Total Trees[5] No.	%
UNATTACK	VM[6]	142	79.8	-	-	-	-	-	-	36	20.2	-	-	178	28.5
	VM/IIIOa	13	46.4	-	-	-	-	-	-	15	53.6	-	-	28	4.5
	VM/IIIOb	19	55.9	-	-	-	-	-	-	15	44.1	-	-	34	5.4
ATTACK	IIIOa-T	-	-	27	57.4	1	2.1	2	4.3	-	-	18	38.3	47	7.5
	IIIOb-H	-	-	64	56.6	18	15.9	7	6.2	-	-	39	34.5	113	18.1
	IIIOa-T/IID	-	-	7	46.6	7	46.6	1	6.6	-	-	1	6.6	15	2.4
	IIIOb-H/IID	-	-	67	48.5	73	52.9	65	47.1	-	-	8	5.8	138	22.1
	IID	-	-	9	30.0	11	36.6	13	43.3	-	-	4	13.3	30	4.8
	IB	-	-	3	7.3	9	21.9	40	97.6	-	-	-	-	41	6.6
	Totals	174		177		119		128		66		70		624	---
	%	27.8		28.4		19.0		20.5		10.5		11.2		100	---

1 Attack status: the field data indicated many trees had been attacked in more than one year. Summed numbers and percentages in rows do not total 100%. Summed percentages in column do not total 100%.

2 See Table 4 for the revised description of basic damage types. Compound damage types are combinations of the basic type.

3 "Om-Att" = omission errors: These are trees which appear normal on the photographs but ground data indicate at least one beetle attack.

4 "Com-UN" = commission errors: These are trees that displayed symptoms common to attacked trees, but the ground data indicate no attack was noticed.

5 Total Trees is the recorded number of trees examined in each damage type category.

6 VM = Variegated Magenta: No symptoms of damage see text for explanation.

Table 3. Summary of photo interpretation results vs ground reference data.

I. Ground Data

a) Total ground-checked trees located on air photos = 624

b) Total trees attacked by spruce beetle = 384 (61.5%)

c) Total trees attacked in 1983 = 284 (38.8%)

d) Total trees attacked in 1982 = 124 (19.9%)

e) Total trees attacked prior to 1982 = 129 (20.7%)

f) Total trees unattacked = (624-384) = 240 (38.5%)

g) Total trees attacked for the first time in 1983 = 171

II. Photo Interpretation Data (Table 2) vs field data

a) Total trees (VM categories) interpreted as unattacked [178 + 28 + 34]/240 = (72.5%)

b) Total trees interpreted as attacked (Table 2) = 47 + 113 + 15 + 138 + 30 + 41 = 384

c) Ommission Errors

1) Attacked trees interpreted as normal (VM) only but field notes indicate attack
36/240 = 15% or 36/624 = 5.8%

2) Attacked trees interpreted as normal (VM) but showing darker or lighter magenta pattern
30/240 = 12.5% or 30/624 = 4.8%

3) Total Ommission Error (all VM categories)
66/240 = 27.5% or 66/624 = 10.5%

d) Commission Errors

Unattacked trees called attacked
70/624 = 11.2%

e) Attacked trees interpreted as attacked vs field total
47 + 113 + 15 + 138 + 30 + 41 = 384/384 = 100%.
(However the ommission and commission errors indicate that it was not the same trees in all cases).

Table 4. Revised description of damage types to use during photo interpretation of color-infrared, large-scale, aerial photographs for spruce bark beetle attack assessment.

Interpretation Category	Description
VM	"Variegated magenta"; these are unattacked trees. The crown and branches have a mottled, variegated appearance, usually with light-pink magenta branch ends and darker magenta toward the tree trunk. Some very light straw hues may be present. The overall crown hue may be lighter or darker than other trees, but note the mottling. Do not confuse contained crown shadows as part of the mottling.
VM/IIIOa	These are "VM" trees as described above however the magenta hue is somewhat darker than normal. [This is a similar pattern as that described by Murtha and McLean (1981) for Douglas-fir.]
VM/IIIOb	These are "VM" trees as described above however the magenta hue is light magenta to somewhat pink. [This too is a similar pattern as that described by Murtha andMcLean (1981) for Douglas-fir.]

The following types are spruce beetle attack categories:

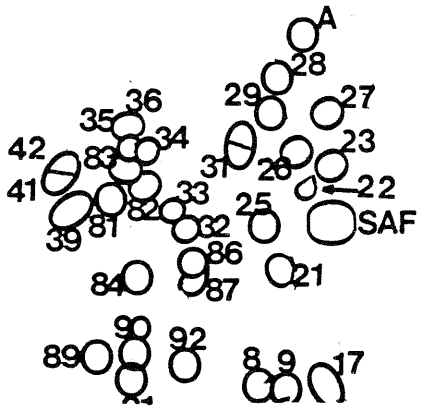
IIIOa-T	The foliage is decidedly darker magenta to tan-magenta than normal, mottling is not evident. Each branch has a similar hue and tone. Contained crown shadows will be present. Beetle attack probably occurred in current year; or there was strip attack in the previous year.
IIIOb-H	The foliage is decidedly lighter than normal. The foliage may be so light that it appears whitish, or off-white, and the crown and branches appear to have a Halo appearance. Mottling is not evident. These trees would be called "faders" since the foliage is dead and has blanched. Beetle attack is severe for current year, or the attack occurred in previous years.
IID	The crown has lost dead foliage from branch tips, usually light toned foliage remains. Various degrees of defoliation may be evident but the inner branches will be obscurred because of the residual foliage. This is the early part of the grey-phase classification of beetle attacked trees. Beetle attack is most likely two years old.
IB	The crown is defoliated, the twigs and branches are dark toned. The tree is recently dead. Old beetle attack.

Figure 1. Large scale (1:2000), 70mm, color-infrared contact prints of part of the study area showing one of the flight line markers and examples of the beetle attacked spruce. [Photo No. 308:116, Aug. 18/83 by Selkirk Remote Sens. Ltd., Vancouver, B.C.]

Tree No.	Photo Interpretation Damage Type	Ground Data
17,22,29,81,90,92	VM	Unattacked
9	VM/IIIOa	"
23	VM/IIIOb	"
84	VM (heavy Cones)	"
85	IIIOa [Commission Error]	"
25	IIIOb [Commission Error]	"
26,27	IIIOb-H	'83 attack
28,32,34	IIIOb	"
31	IIIOb (mauve)	"
83	IIIOb (pink)	"
42	IIIOa	"
30,36	VM/IIIOb [Omission Error)	"
33	VM [Omission Error] very light	'83 attack
35	IIIOb/IID	'82 attack
86	IIIOa (IIE)	'83,'82 strip attack
87	IIIOa/IID (Cone crop)	'83,'82 strip attack
91	IIIOa/IID	'82 attack
21	IB	Prior '82 attack
39	IIIOb/IID	'83,'82, Prior '82 attack
41	IIIOb/IID	Prior '82 attack
82	IIIOb/IID	'83,'82 strip attack
89	IID	'82 attack
Other Categories		
8	IIIOb/IIE	Root Rot (Fomes pinicola)

A = Aspen

SAF = Abies lasiocarpa - subalpine fir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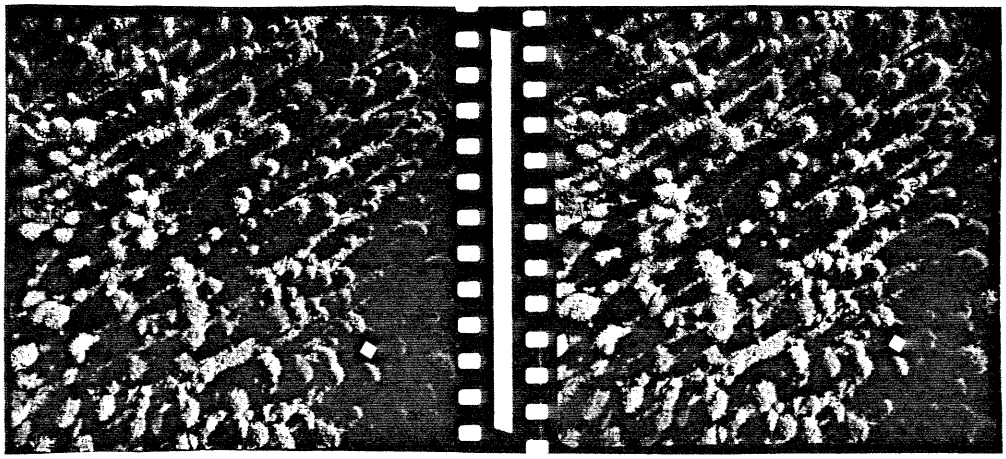

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83	IIIOb (pink)	"
42	IIIOa	"
30,36	VM/IIIOb [Omission Error)	"
33	VM [Omission Error] very light	'83 attack
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86	IIIOa (IIE)	'83,'82 strip attack
87	IIIOa/IID (Cone crop)	'83,'82 strip attack
91	IIIOa/IID	'82 attack
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