Geologic and geomorphologic studies on distribution of
Simulium ochraceum (Diptera: Simuliidae)
larvae in Guatemala*

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Abstract: On-foot surveys were made for the purpose of mapping perennial streams infected with *Simulium ochraceum* in an endemic area of onchocerciasis in Guatemala. Of 246 perennial streams (144.4 km) found in 477 km², 119 (48.4%) or 27.8 km (19.3%) were found infested with *S. ochraceum*. *S. ochraceum* larvae were found mainly from older impermeable rocks such as Tertiary lahars and lavas, arkosic conglomerate and Cretaceous granite. Although recent volcanic rocks have very few perennial streams due to permeability, they are important as water reservoirs for the underlying impermeable rocks. Quarternary alluvium showed high stream density, but no *S. ochraceum* larva was found from these streams, due probably to small channel slope. The area with Tertiary lahars and lavas is the most important bed of *ochraceum*-breeding streams, which roughly coincides with the onchocerciasis endemic area. Of total 1469 channel segments in this area, only 203 (13.8%) had perennial streams, of which 108 (53.2%) were infested with *S. ochraceum*. With increment of the channel order, the ratio of channel segments with perennial streams increased, while, on the contrary, the ratio of perennial streams with *S. ochraceum* larvae decreased. No *S. ochraceum* larva was found in the fourth and fifth order channels. *S. ochraceum* larvae were found mainly in the uppermost part of the stream network, immediately below headsprings. The headsprings were found arranged nearly horizontally on the elevations 900 m, 1100 m and 1300-1460 m above sea level.

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INTRODUCTION

Simulium ochraceum is the principal vector of human onchocerciasis in Guatemala and Mexico, where larval control of *S. ochraceum* is very difficult because of its peculiar breeding preference on minute streamlets. Pessimistic views had been the main current on this subject (McMahon,

1967; Crosskey, 1973; Davies, 1974) until Nakamura *et al.* (1981) reported the first success in reducing fly density of *S. ochraceum* in Guatemala by the use of temephos as a larviciding agent. Their trial had an advantage in settling a small control area (3 km²) where breeding sites were well known. Such lucky situation, however, is not usual in Guatemala, and overlooking of breeding streams is the major problem of control operation. The control scheme of Nakamura *et al.* (1981) was not satisfactorily applied to the adjacent basin (Takaoka *et al.*, 1981).

The present study was carried out from 1977 to 1983 in a part of the pilot area of the Guatemala-Japan Cooperative Project on Onchocerciasis Research and Control in Guatemala. Main purpose of this study was to prepare detailed map for larviciding operation in the study area, based on geologic and geomorphologic knowledges, as well as to improve survey methodology applicable to other endemic foci in Guatemala.

MATERIALS AND METHODS

The topographic map "Amatitlán" and the geologic map "Amatitlán", both in 1:50,000 scale published by the Instituto Geográfico Nacional, Guatemala, were employed as the basic information of the study area. The geologic map describes 28 rock units in this area, most of which are Quaternary and Tertiary volcanic rocks (Table 1).

The drainage map was made from the topographic map by means of tracing V-indentations of the contour lines. The channel segments were classified into orders according to the definition by Horton (1945) and its modification by Strahler (1957): The finger-tip tributaries of the channel network are designated the first order. Where two channel segments of the *i*'th order join, a segment of the *i*+1'th order is formed. A channel undetectable in the topographic map is called the 0'th order. Orders with greater code number are called higher orders. The term "channel order" is adopted in this text instead of the original term "stream order" by Horton and Strahler, so that clear distinction will be made between "channel" in the geomorphologic term and "stream" in

Table 1 List of rock units in the study area A.¹⁾

Symbol	Rock unit	Landform
Quaternary		
Qb	Basalt	Composite cones
Qad	Andesite and dacite	Domes
Qr-d	Rhyodacite and dacite	Domes and flows
Qcc	Basalt	Cinder cones
Qva	Andesite and lahars	Composite cones
Qp	Dacite and rhyodacite	Pumice plateau
Qac	Andesite	Ancestral volcano
Qa	Alluvium	Plains
Tertiary		
Ta	Andesite	Fault scarps
Ti-a	Lahars and lavas	Rugged mountains
Ti	Andesite	Intrusions
Tc	Arkosic conglomerates	Fault scarps
Cretaceous		
Kg	Biotite granite	Fault scarps

¹⁾ Geologic symbols and legends were cited from the geologic map "Amatitlán", 1:50,000, Instituto Geográfico Nacional, Guatemala, with modifications. Qb in this table includes Mb1, Mb2, Mb3, Mb, Mc, Mch, Hb1, Hb2, Hb3, Hb, Hp-c, Qpcf, Qpc, Qb and Qic, which are thus distinguished in the original map according to the time of eruption. Qva in this table includes parasitic cones (Qpa) in the original map.

the hydrologic term.

The initial field surveys were made in a rectangular area belonging to the Departments of Escuintla and Guatemala, Republic of Guatemala (the study area A in Fig. 1, 14°20'–14°30' N., 90°30'–90°45' W., ca. 500 km²). Streams shown in the topographic map were traced to discover their tributaries. Detailed field surveys were made in the southwestern quarter (the study area B in Fig. 1, 14°20'–14°25' N., 90°37'–90°45' W., ca. 77 km²), where all the channel segments were meticulously visited. Blackfly larvae were collected for 10 minutes at every stream segment, and specimens were preserved in 70% ethanol solution for later identification

in laboratory.

RESULTS

Geologic aspects of distribution of S. ochraceum larvae in the study area A

After detailed on-foot surveys, 246 perennial streams with total length of 144.4 km were found from the study area A. Of these streams, 119 (48.4%) with total length of 27.8 km (19.3%) were infested with *S. ochraceum* larvae. Figure 1 shows the distribution of perennial streams, both with and without *S. ochraceum* larvae, with reference to geology. The *ochraceum*-breeding streams were found only in three rather small regions: (1) Ti-a area and adjacent part of Qp on the southwestern quarter of the study area (ca. 77 km²), (2) Tc and adjacent part of Ta on the northeastern corner (1 km²), and (3) Kg and adjacent part of Ta about 5 km south of the former (2 km²).

Table 2 shows the number, length and density of perennial streams and *ochraceum*-breeding streams on different rock units. *S. ochraceum* larvae were found from only

five rock units (Qp, Ta, Ti-a, Tc and Kg) of total 13 in the area. Of these five, Qp and Ta hold *ochraceum*-breeding streams exclusively above the contacts with underlying Ti-a, Tc or Kg.

The density of *ochraceum*-breeding streams was highest in Kg (2.80 km⁻¹), followed by Tc (0.58) and Ti-a (0.22). As to the total length of the *ochraceum*-breeding streams, Ti-a alone contributed as much as 75.9% of whole area, though its area is only 20.2%. Furthermore, Ti-a together with adjacent part of Qp covered 87.4% of the whole *ochraceum*-breeding streams.

Ti-a, Tc and Kg, the three principal *ochraceum*-breeding rock units, are characterized as impermeable older rocks. They can maintain even small amount of running water. On the other hand, permeable volcanic rocks showed low density of perennial streams. Although the recent volcanic cones (Qb, Qcc, Qva and Qac) occupy as much as 33.1% of the whole study area, only two streams were found there due to high permeability. Among the rest of permeable rock units, Qp and Ta have perennial streams

Fig. 1 A geologic map of the study area A, showing the distribution of perennial streams both with and without *S. ochraceum* larvae. (Partly reproduced from the geologic map "Amatitlán" with permission of the Instituto Geográfico Militar, Ejército de Guatemala.) Geologic symbols are explained in Table 1.

Table 2 Number, length and density of perennial streams and *ochraceum*-breeding perennial streams on different rock units in the study area A.

Rock unit ¹⁾	Permea- bility ²⁾	Area		Perennial stream				<i>ochraceum</i> -breeding Perennial stream				Ratio (%)	
		km ²	(%)	No. (A)	Length (B)		Density ³⁾ km ⁻¹	No. (C)	Length (D)		Density km ⁻¹	C/A	D/B
					km	(%)			km	(%)			
Qa	+	52.2	10.9	13	72.7	50.3	1.39	0	0.0	0.0	0.00	0.0	0.0
Qb	++	52.3	11.0	1	1.0	0.7	0.02	0	0.0	0.0	0.00	0.0	0.0
Qad	—	8.2	1.7	0	0.0	0.0	0.00	0	0.0	0.0	0.00	—	—
Qr-d	—	20.9	4.4	1	1.0	0.7	0.05	0	0.0	0.0	0.00	0.0	0.0
Qcc	++	2.5	0.5	0	0.0	0.0	0.00	0	0.0	0.0	0.00	—	—
Qva	+	89.0	18.7	1	6.9	4.8	0.08	0	0.0	0.0	0.00	0.0	0.0
Qp	++	105.9	22.2	17	12.6	8.7	0.12	9	3.2	11.5	0.03	52.9	25.4
Qac	+	13.8	2.9	0	0.0	0.0	0.00	0	0.0	0.0	0.00	—	—
Ta	+	30.6	6.4	7	2.4	1.7	0.08	5	1.4	5.0	0.05	71.4	58.3
Ti-a	—/+ ⁴⁾	96.1	20.2	196	44.6	30.9	0.46	99	21.1	75.9	0.22	50.5	47.3
Ti	+	3.6	0.8	2	0.5	0.3	0.14	0	0.0	0.0	0.00	0.0	0.0
Tc	—	1.2	0.3	2	0.9	0.6	0.75	2	0.7	2.5	0.58	100.0	77.8
Kg	—	0.5	0.1	6	1.8	1.2	3.60	4	1.4	5.0	2.80	66.7	77.8
Total		476.8	100.0	246	144.4	100.0	0.30	119	27.8	100.0	0.06	48.4	19.3

¹⁾ Rock unit abbreviations are explained in Table 1.

²⁾ Permeability was roughly estimated in the field by the proportion between rainfall and surface runoff.

³⁾ Stream density=Total stream length/Area.

⁴⁾ Ti-a is composed of impermeable lahars and permeable lavas.

almost exclusively above the contact with underlying impermeable rocks.

Although permeable rocks are not adequate for stream beds, they play an important role as aquifer or groundwater reservoir when they overlie impermeable rocks. In contrast to the stream-rich southern part of the Ti-a, its northern part has no perennial stream. While the southern outcrop of Ti-a lies at lower altitude than adjacent permeable rocks (Qb, Qp and Qva), the northern part is projecting above the adjacent permeable rocks (Qva and Qp). The Quaternary impermeable domes of Qad and Qr-d do not maintain perennial streams except on the foot of a Qr-d dome along the contact with overlying permeable Qb.

Qa recorded the maximum length of perennial streams (72.7 km or 50.3% of the total length in whole area). None of them, however, was infested with *S. ochraceum* larva. They are too gently sloped for breeding of *S. ochraceum*.

Comparing between geologic ages, older rocks showed higher density of *ochraceum*-breeding streams. In general, older rocks have more chance of being overlain by other rocks than younger ones. Furthermore, comparing between lahars of Qva and Ti-a, the older ones (Ti-a) are more cemented and less permeable than the younger ones (Qva).

Geomorphologic aspects of distribution of S. ochraceum larvae in the study area B

The study area B lies on the southwestern quarter of the study area A. It is composed of southern part of Ti-a and adjacent part of Qp (Fig. 1), and roughly coincides with the endemic area of onchocerciasis (Unpublished document of the Departamento de Oncocercosis, SNEM, Guatemala). In the study area B, distribution of streams was studied with respect to channel network. All the channel segments shown in the drainage map were visited by on-foot surveys.

Table 3 summarizes the number and length

Table 3. Number and length of channel segments, perennial streams and *ochraceum*-breeding perennial streams for different channel orders in the study area B.

Item		Channel order						Total ¹⁾
		0	1	2	3	4	5	
Channel segment	No.	—	1206	212	42	8	1	1469
(A)	Total length, km	—	126.8	41.5	18.2	12.7	2.5	201.7
	Mean length, km	—	0.11	0.20	0.43	1.59	2.5	0.14
Perennial stream	No.	21	90	70	34	8	1	203
(B)	Total length, km	1.0	9.5	12.3	10.8	12.7	2.5	47.8
	Mean length, km	0.05	0.11	0.18	0.32	1.59	2.5	0.24
<i>ochraceum</i> -breeding	No.	17	57	40	11	0	0	108
perennial stream	Total length, km	0.7	5.4	4.2	2.0	0.0	0.0	11.6
(C)	Mean length, km	0.04	0.09	0.11	0.18	—	—	0.11
B/A, %	No./no.	—	7.5	33.0	81.0	100.0	100.0	13.8
	Length/length	—	7.5	29.6	59.3	100.0	100.0	23.7
C/B, %	No./no.	81.0	63.3	57.1	32.4	0.0	0.0	53.2
	Length/length	70.0	56.8	34.1	18.5	0.0	0.0	24.3

¹⁾ The 0'th order is excluded.

of channel segments, perennial streams and the *ochraceum*-breeding perennial streams for channel order. Of total 1469 channel segments, only 203 (13.8%) were found maintaining perennial running water, of which 108 (53.2%) were infested with *S. ochraceum*. In addition to those streams on the channels registered in the drainage map, 21 perennial streams were found on the 0'th order channels, or those which are too small to be detected in the topographic map in 1:50,000 scale. Of these 21 streams, 17 (81.0%) were infested with *S. ochraceum* larvae.

The higher the order, the greater part of the channel segments were filled with perennial running water. It seems natural because the higher order channels have greater basin area, and thus greater chance of collecting water than the lower order ones. On the other hand, the ratio of perennial streams with *S. ochraceum* larvae decreased with order. It was observed in the field that higher order channels have smaller channel slopes, and are less favorable for breeding of *S. ochraceum* than the lower order ones. Channel segments of the fourth and fifth order were totally filled with perennial running water, but no *S. ochraceum* larva was found

there. As to the total number and length of *ochraceum*-breeding streams, the first order channels showed the greatest number (57) and length (5.4 km), followed by the second order (40, 4.2 km). The first and second order channels contributed as much as 90% in number and 83% in length of total *ochraceum*-breeding streams.

Figure 2 shows the distribution of perennial streams, both with and without *S. ochraceum* larvae in the study area B, together with channel network and contour lines. Of total 119 *ochraceum*-breeding stream segments, 116 (97%) were found within 1 km downstream, mostly within 500 m, from the headsprings. Only three were found from lower reaches of tributaries, but none was done from the main channels. Of total 176 headsprings, 116 (66%) harbored *S. ochraceum* larvae immediately downstream. Therefore, the distribution of *S. ochraceum* larvae is strongly related with the distribution of headsprings.

In the field, the neighboring headsprings were often found on the same elevation, suggesting existence of water tables. Nakamura *et al.* (1981) describes horizontal arrangement of headsprings along the contour line of 1300 m above sea level in the Los

Fig. 2 A drainage map of the study area B, showing the distribution of perennial streams both with and without *S. ochraceum*.

Lavaderos valley. Of total 176 headsprings in the study area B, 56 (32%) were found at around 1400 m above sea level (1300–1460 m), 52 (30%) at around 900 m (850–940 m) and 16 (9%) at around 1100 m (1050–1140 m). In addition, 12 headsprings (7%) were found at around 600 m (550–700 m) in the western part of the study area B, where the elevation of headsprings lowered toward downstream direction along the main channel.

DISCUSSION

According to the results of the present study, we suggest the following strategy for the pre-control surveys against *S. ochraceum*: Geologic analysis should be made for the purpose of delimiting *ochraceum*-rich areas from the preliminary settled control area. In the volcanic region, attention must be paid on older volcanic rocks, which are more important as *ochraceum*-breeding bed than the younger ones. The topographic map in

1:50,000 or larger scale is necessary for preparing the drainage map, which is an essential tool for conducting systematic surveys. All the channel segments in the drainage map should be visited with special emphasis on the lower order ones. Without a drainage map, some *ochraceum*-breeding streams on the lower order channels could be easily overlooked. Though the stream symbols in the topographic map describe some large streams on the fourth or higher order channels, they neglect most of the *ochraceum*-breeding streams on the third and lower order channels. The *ochraceum*-breeding streams on the 0'th order channels are usually discovered by upstream tracing of every stream branching. Those which escape upstream tracing due to partial underground flow could be detected by horizontal tracing along contour lines from known headsprings.

The infant, young and adolescent streams of Dalmat's classification (1955) roughly corresponded with the 0'th, first to second,

and third to fourth order channel segments, respectively. The channel order concept is more systematic and a better operational tool for our survey than the empirical concept of stream age by Dalmat.

Strong *et al.* (1934) reported onchocerciasis patients and their geographical distribution from the Pacific slope of the Sierra Madre volcanic range. Dalmat (1955) explained such a climatological factor for breeding of the vector blackflies that the Sierra Madre range blocks prevailing northeasterly wind and admits heavy seasonal rainfall on the Pacific slope. Although Dalmat could explain one of the reasons of the distribution of onchocerciasis in Guatemala, we should emphasize here that geology is also an essential component in specifying vector breeding streams. As far as the surveyed area is concerned, the volcanic range is composed of both old stream-rich rocks and recent stream-poor ones. Crosskey (1956, 1981) pointed out the distribution of both onchocerciasis patients and the vector species, *S. damnosum* s.l., in Nigeria is associated with Precambrian rocks, which provide rocky river beds adequate for vector breeding.

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摘 要

グアテマラにおける *Simulium ochraceum* の分布に関する地質・地形学的研究

グアテマラのオンコセルカ症流行地で、主要媒介種である *Simulium ochraceum* の発生源の分布を調査し、地質および地形との関係を検討した。調査面積 477 km² 内で計 246 本 (144.4 km) の不断水流が発見もしくは確認され、うち 119 本 (48.4%) 27.8 km (19.3%) で *S. ochraceum* の発生が認められた。*S. ochraceum* 幼虫は主として古い不透水性の岩に分布していた。これに対して新しい火山岩は透水性が高く、不断水流を保持しないため、*S. ochraceum* の発生に不適だが、不透水性岩の上に位置した時、地下水の供給源として重要になる。沖積地では水流密度が高かったが、これらの水流ではまったく *S. ochraceum* の発生が見られなかった。第三紀泥流・溶岩地帯は *S.*

ochraceum の発生源を最も多く有し、かつ オンコセルカ症流行地とも一致した。この地帯 (77 km²) にある計 1469 本の谷セグメントを踏査した結果、203 本 (13.8%) が不断水流を持ち、このうち 108 本 (53.2%) が *S. ochraceum* の発生源となっていた。谷次数が高くなる下流ほど、谷セグメントが不断水流を持つ率が

高くなったが、それらの水流が *S. ochraceum* を発生させる率は逆に低くなった。*S. ochraceum* の分布は、主として源流の湧泉から下流 1 km 以内の谷次数の低い谷セグメントに多く見られた。湧泉は主として海拔 900 m, 1100 m, 1300-1460 m の 3 段階の高度に沿って、ほぼ水平に分布していた。