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CASE REPORT

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Illegal Route Estimation of the Seized Illicit Drug, Methamphetamine, by the Comparison of Striation Marks on Plastic Packaging Films

ABSTRACT: In Japan, the most common illicit drug is methamphetamine. It is possible to trace the origin of this drug by analyzing its organic and inorganic impurities and/or byproducts using several methods, such as GC, GC/MS, and inductively coupled plasma-mass spectrometry (ICP-MS). As reported here, one other method includes comparison of the striation lines of polymer sheet layers from packaging using a polarized light method. Other alternative methods include analyzing the heat sealer pattern, layer thickness surface characteristics, and/or components of polymer sheet layers using infrared spectroscopy. Several of these alternative methods were used to analyze the origins of 29 packages confiscated from three regions over a 1000 km distance in Japan. Results indicated that packages seized from different regions had some polymer sheet layers which contained striation lines and heat sealer patterns that were similar.

KEYWORDS: forensic science, methamphetamine, polymer, striation marks, polarizing plate, route estimation

The most abused drug in Japan is methamphetamine which is illegally imported from other countries mainly through ship exchanges on the open sea. Importation is believed to be the source of the methamphetamine found in Japan, as no clandestine laboratories for preparing illicit drugs have been discovered here (1). For the estimation and/or identification of the country of origin, the production method of the seized methamphetamines and the route of illegal import, there are numerous reports which compare the trace organic impurities and/or byproducts contained in the drug by GC, GC/MS, and/or LC/MS (2,3). There have also been a few reports that analyze the inorganic impurities in methamphetamine (4) as well as 3,4-methylenedioxymethamphetamine (MDMA) (5) using inductively coupled plasma-mass spectrometry (ICP-MS). The methamphetamine seized in the United States and Europe is presumed to be synthesized by the Leukart reaction (6,7), thus the byproducts and impurities are quite characteristic and the purity is low (8). Almost all the methamphetamine seized in Japan is presumed to be synthesized from natural ephedrine by one or two steps using a simple reduction method which produces drug of high purity. Because of the presence of mercury (Hg) in the crystal methamphetamine produced by this method, it is likely that molecular distillation has been used for purifying the drug.

There are some reports that the origin of some methamphetamine samples can be obtained from analyzing the packaging materials through a comparison of the striation lines using the transmittance of polarized light (8–11). In this case, we determined the common origins of the drugs by successfully matching the striation lines observed on the plastic films used to pack the drugs, such as polyethylene (PE) and polyethylene/polyvinylacetate (PE/EVA), using a cross-polarized transmittance method as previously described (12). Examined samples were seized over a 1000 km distance on the public Sea of Japan (region 1), southern region of Kyushu Island (region 2), and the west region of the mainland (region 3). As a first step in determining the common origin of these drugs, the organic impurities were examined; however, the methamphetamine seized in this case was quite pure, and thus, it was difficult to discriminate the samples by either GC or GC/MS.

Therefore, observation of striation lines on the polymer sheet layers of individual packaging materials using cross-polarized light was conducted. Observation of the heat seal marks using a differential interference microscope and infrared spectrometry (IR) of the organic components of the polymer sheet layers, a thickness measurement of each sheet layer of all samples, and observation of the characteristic surface of each sheet layer were conducted for

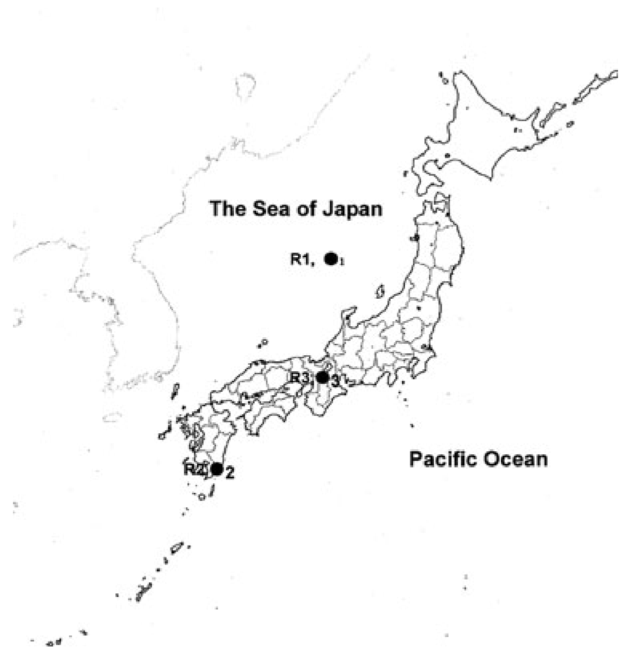

FIG. 1—*Location of the seized methamphetamine.*

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examination and comparison to prove the common origin of these packages. Using a combination of results, 29 packages were identified that appeared to be packed using the same polymer sheet supplied from the same manufacturer and closed using the same heat sealers.

Materials and Methods

Samples

All illegal methamphetamine abused in Japan is completely imported by transfer on the public ocean using small fishing boats from other countries. The drug used in this case came from methamphetamine seized from the Sea of Japan (region 1, R_1, $\bullet_1$ in Fig. 1, seven packages were seized), and this drug was unloaded at region 2 (region 2, R_2, $\bullet_2$ in Fig. 1, 13 packages were seized), and probably delivered to region 3 (region 3, R_3, $\bullet_3$ in Fig. 1, nine packages were seized). A total of 29 packages were seized at regions 1, 2, and 3, respectively. Packages (described as "P") analyzed were described as region 1 (ascribed as R_1-P_1 to R_1-P_7, seized on the Sea of Japan, $\bullet_1$), region 2 (ascribed as R_2-P_1 to R_2-P_{13}, seized at southern region of Kyushu Island, $\bullet_2$), and region 3 (ascribed as R_3-P_1 to R_3-P_9, seized at the western region of mainland, $\bullet_3$). The locations of the confiscated regions are shown in Fig. 1.

Layer Constitution of Each Sample and Thickness Measurement

The examined layers of polymer sheets from the sample packages had different and complex layer structures. The thickness of each polymer sheet of layers was measured by a micrometer (Kobunshi Keiki Company Limited, Tokyo, Japan) with a precision of ±0.002 mm. The measurement was made three times and average values were calculated.

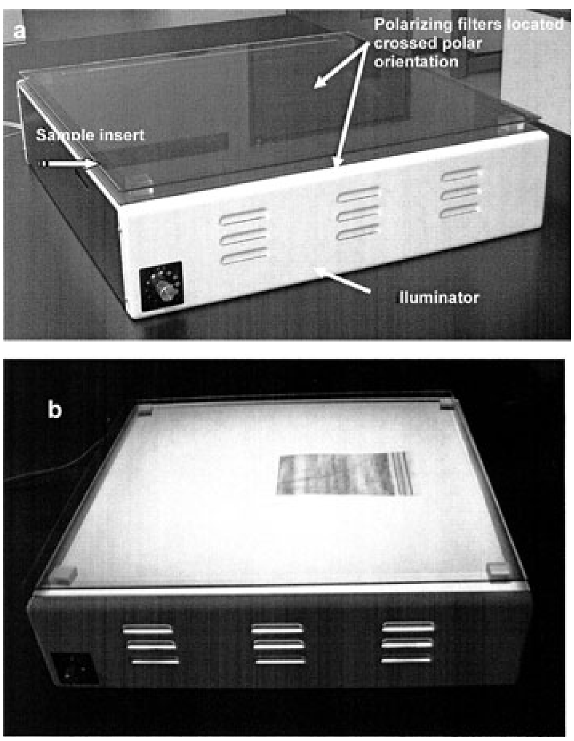

FIG. 2—*Device for the cross-polarized light observations; (a) outer view, (b) illuminated backlight with sample.*

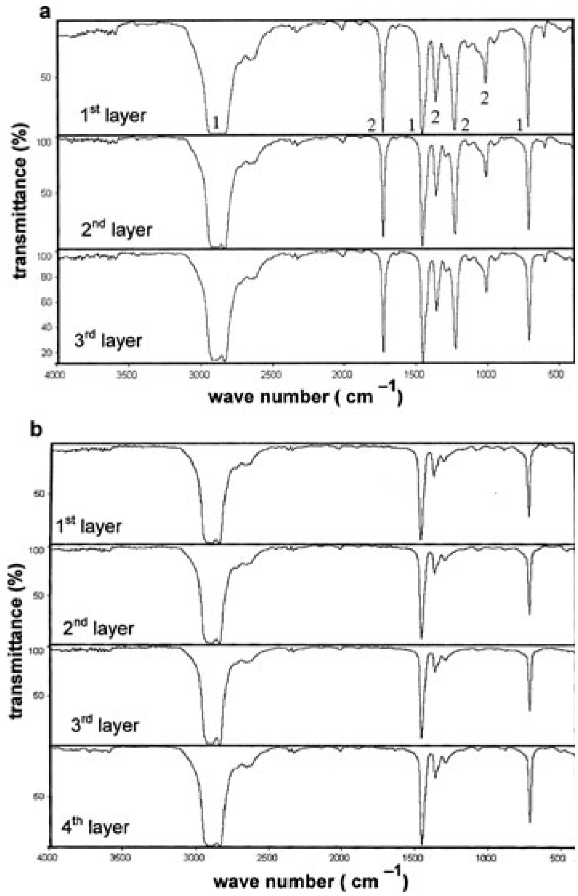

FIG. 3—*Infrared spectra of each layer; (a) is polyethylene (1)-polyvinylacetate (2) copolymer of R_2-P_6 (three sheet layers), and (b) polyethylene, R_2-P_{13} in Table 2 (four sheet layers).*

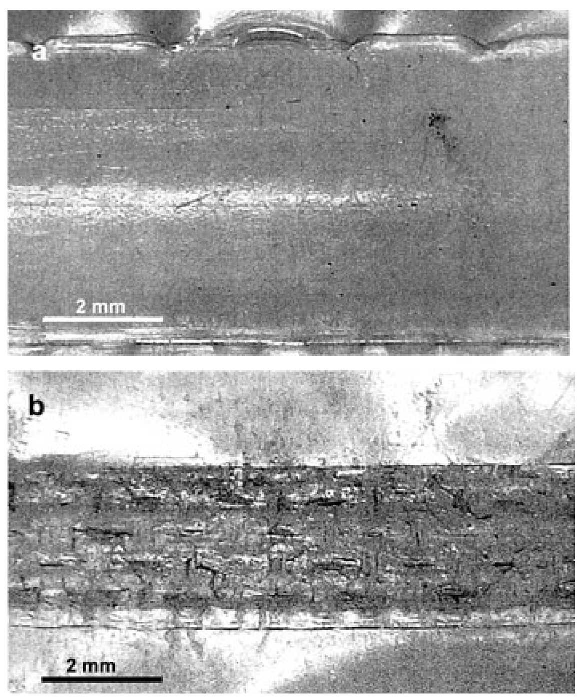

FIG. 4—*Heat sealer impressions: Heat sealer impressions are divided into two types, the observed heat sealer impressions are listed in Table 1–3.*

Observation of Machining Marks Using Cross-Polarized Light

The characteristic striation lines of all polymer sheet layers that compose the package from regions 1, 2, and 3 were observed and compared with each other using a Polamax (Police Science Industries Company, Limited, Tokyo, Japan). Each polymer sheet layer from the package was placed between two polarizing filters aligned in a cross-polar orientation and the apparatus was illuminated using backlight. The device and its configuration are shown in Fig. 2.

Layer Constitutions of the Packaging Materials, the Results of Fourier-transform Infrared (FT-IR) Analysis and Observation of Heat Sealer Marks

For the infrared spectra measurement, a small part of every polymer sheet layer was cut and prepared into a KBr tablet for analysis using a Nicolet Magna 700 type FT-IR spectrometer (Thermo Nicolet Limited, Waltham, MA) using a transmittance method of preparing the KBr tablet. The standard material for the correction of the device was polyethylene supplied by Scientific Polymer Products (Ontario, NY). Other reagents were of analytical grade, purchased from Wako Pure Industries, Limited (Osaka, Japan).

Observation of the Heat-Sealed Ridge and Sheet Surface

Observation of the heat sealed ridges was conducted using a differential interference contrast microscope "Axiophoto" (Carl Zeiss Japan Incorporated, Tokyo, Japan). The character of the surface of each sheet was also observed and divided into four classes, such as smooth (s), rough (r), dirty (d), and rough and dirty (rd).

Results and Discussion

Results of the Infrared Spectroscopy Analysis

The typical infrared spectrum obtained using a film method of IR is shown in Fig. 3. These samples depicted in the figure correspond to R_2-P_6 (three polymer sheet layers) and R_2-P_{13} (four polymer sheet layers). In the former sample package, all the layers consisted of a PE/EVA copolymer. In the latter sample package, all the layers consisted of only PE. In both samples, the infrared spectra obtained were identical to the spectra of PE and PE/EVA, respectively, as shown in Fig. 3.

Comparison of the Heat Sealer Mark

There were two types of heat seal marks observed on the packaging. The marks are shown in Fig. 4*a* (type a) and *b* (type b). Every package was sealed using two different types of heat sealer (type a or b). The observed heat sealing methods for each package are listed in Tables 1–3.

Layer Constitution of Each Sample, Results of the Thickness Measurements and Infrared Spectrometry

The packages retrieved from region 1 (7 packages) consisted of three to six polymer sheet layers, region 2 (13 packages) consisted of two to eight polymer sheet layers, and region 3 (9 packages) consisted of two to eight polymer sheet layers. The typical polymer sheet configuration that composes packages R_2-P_{10} (three polymer sheet layers) and R_2-P_7 (eight polymer sheet layers) are shown in Fig. 5*a,b*.

In regard to the polymer sheet layers of each package, R_1-P_1 to R_1-P_7, R_2-P_1 to R_2-P_{13}, and R_3-P_1 to R_3-P_9, the layer structure was

TABLE 1—*Layer structures of the packages seized at the Sea of Japan (●$_1$).*

Packages	R_1-P_1	R_1-P_2	R_1-P_3	R_1-P_4	R_1-P_5	R_1-P_6	R_1-P_7
Heat sealer type	a	a	a	a	a	a	a
Surface of the package							
L_1							
Thickness (mm)	0.068–0.072	0.070–0.072	0.071–0.072	0.068–0.070	0.080–0.082	0.040–0.043	0.068–0.072
Surface	s	s	s	r	s	s	s
Component	PE	PE	PE	PE	PE	PE	PE
L_2							
Thickness (mm)	0.073–0.080	0.039–0.049	0.039–0.041	0.071–0.073	0.080–0.080	0.038–0.040	0.077–0.078
Surface	s	r	r	s	s	s	rd
Component	PE	PE	PE	PE	PE	PE	PE
L_3							
Thickness (mm)	0.065–0.072	0.040–0.041	0.039–0.040	0.068–0.072	0.072–0.080	0.037–0.041	0.068–0.073
Surface	r	r	r	s	s	rd	s
Component	PE	PE	PE	PE	PE	PE	PE
L_4							
Thickness (mm)	0.072–0.078		0.040–0.041			0.041–0.045	
Surface	r		r			r	
Component	PE		PE			PE	
L_5							
Thickness (mm)	0.040–0.021		0.039–0.041			0.039–0.043	
Surface	r		r			r	
Component	PE		PE			PE	
L_6							
Thickness (mm)						0.041–0.043	
Surface						r	
Component						PE	
Inner side of package							

Heat sealer type a and b are shown in Fig. 4.

L, layer number; R, confiscated region; P, means package number; PE/EVA, polyethylene/polyvinylacetate copolymer; PE, polyethylene; s, smooth surface; r, rough surface; d, dirty surface; rd, rough and dirty surface; R, packages correspond to regions in Fig. 1; P, package numbers confiscated at each region; L, layer numbers of each package.

TABLE 2—*Layer structures of the packages seized at seashore of the southern region of Japan (*$\bullet_2$*).*

Packages	R_2-P_1	R_2-P_2	R_2-P_3	R_2-P_4	R_2-P_5	R_2-P_6	R_2-P_7	R_2-P_8	R_2-P_9
Heat sealer type	b	a	a	b	b	b	a	a	b
Surface of the package									
L_1									
Thickness (mm)	0.108-0.116	0.071–0.073	0.111–0.118	0.098–0.107	0.109–0.111	0.110–0.120	0.032–0.038	0.038–0.042	0.100–0.105
Surface	rd	r	s	d	s	s	s	s	s
Component	PE/EVA	PE	PE/EVA	PE/EVA	PE/EVA	PE/EVA	PE	PE	PE
L_2									
Thickness (mm)	0.100–0.105	0.061–0.074	0.111–0.113	0.031–0.037	0.032–0.035	0.109–0.119	0.031–0.035	0.029–0.032	0.040–0.040
Surface	rd	r	rd	rd	r	r	s	s	r
Component	PE/EVA	PE	PE/EVA	PE	PE	PE/EVA	PE	PE	PE/EVA
L_3									
Thickness (mm)		0.034–0.038		0.040–0.042	0.031–0.037	0.108–0.130	0.027–0.030	0.027–0.030	0.030–0.040
Surface		r		rd	s	r	s	s	rd
component		PE		PE	PE	PE/EVA	PE	PE	PE
L_4									
Thickness (mm)		0.042–0.045			0.035–0.040		0.035–0.036	0.039–0.041	0.030–0.038
Surface		rd			s		s	s	rd
Component		PE			PE		PE	PE	PE
L_5									
Thickness (mm)					0.040–0.041		0.033–0.039	0.037–0.040	0.040–0.047
Surface					r		s	s	s
Component					PE		PE	PE	PE
L_6									
Thickness(mm)							0.032–0.038	0.033–0.039	
Surface							d	d	
Component							PE	PE	
L_7									
Thickness (mm)							0.038–0.048	0.032–0.038	
Surface							rd	s	
Component							PE	PE	
L_8									
Thickness (mm)							0.041–0.048	0.040–0.042	
Surface							rd	d	
Component							PE	PE	

Packages	R_2-P_{10}	R_2-P_{11}	R_2-P_{12}	R_2-P_{13}
Heat sealer type	b	b	b	a
Surface of the package				
L_1				
Thickness (mm)	0.103–0.112	0.104–0.108	0.112–0.120	0.077–0.079
Surface	s	s	s	s
Component	PE/EVA	PE/EVA	PE/EVA	PE
L_2				
Thickness (mm)	0.110–0.120	0.104–0.113	0.110–0.112	0.072–0.083
Surface	r	rd	s	s
Component	PE/EVA	PE/EVA	PE/EVA	PE
L_3				
Thickness (mm)	0.113–0.132			0.041–0.045
Surface	rd			r
Component	PE/EVA			PE
L_4				
Thickness (mm)				0.040–0.050
Surface				rd
Component				PE
Inner side of package				

Heat sealer type a and b are shown in Fig. 4.

L, layer number; R, confiscated region; P, package number; PE/EVA, polyethylene/polyvinylacetate copolymer; PE, polyethylene; s, smooth surface; r, rough surface; d, dirty surface; rd, rough and dirty surface; R, packages correspond to regions in Fig. 1; P, package numbers confiscated at each region; L, layer numbers of each package.

clarified and the thickness and polymer components of each layer sheet were determined by IR analysis. The 29 seized packages from regions 1, 2, and 3 consisted of multiple layers that were described as L_N with N representing the position of each layer. The layer structures of each package, the components measured by IR, the surface condition of the polymer sheet layers, and the thickness of each layer in every package are shown in Tables 1–3. The images of smooth, rough, dirty, and rough and dirty surfaces are shown in Fig. 6.

Matching the Striation Lines Using a Polarized System

The result of optical and physical matching using a polarized light system was conducted with all sheet layers from 29 packages

TABLE 3—*Layer structures of the packages seized at the western region of Japan (●$_3$).*

Packages	R_3-P_1	R_3-P_2	R_3-P_3	R_3-P_4	R_3-P_5	R_3-P_6	R_3-P_7	R_3-P_8	R_3-P_9
Heat sealer type	b	b	a	a	a	b	b	b	a
Surface of the package									
L_1									
Thickness (mm)	0.109–0.111	0.110–0.120	0.032–0.038	0.100–0.105	0.100–0.105	0.103–0.112	0.104–0.108	0.112–0.120	0.077–0.079
Surface	s	r	s	s	rd	s	s	r	s
Component	PE/EVA	PE/EVA	PE	PE	PE/EVA	PE/EVA	PE/EVA	PE/EVA	PE
L_2									
Thickness (mm)	0.032–0.035	0.109–0.119	0.031–0.035	0.029–0.032	0.040–0.040	0.110–0.120	0.104–0.113	0.110–0.102	0/772–0.079
Surface	s	s	s	s	r	r	rd	r	r
Component	PE	PE/EVA	PE	PE	PE	PE/EVA	PE/EVA	PE/EVA	PE
L_3									
Thickness (mm)	0.031–0.037	0.108–0.130	0.035–0.036	0.027–0.030	0.030–0.038	0.102–0.113			0.041–0.045
Surface	s	d	s	s	rd	rd			r
Component	PE	PE/EVA	PE	PE	PE	PE/EVA			PE
L_4									
Thickness (mm)	0.035–0.040		0.035–0.038	0.039–0.041	0.030–0.038				0.040–0.050
Surface	s		s	s	rd				rd
component	PE		PE	PE	PE				PE
L_5									
Thickness (mm)	0.021–0.040		0.033–0.039	0.037–0.040	0.040–0.047				
Surface	s		s	s	s				
Component	PE		PE	PE	PE				
L_6									
Thickness (mm)			0.032–0.038	0.033–0.039					
Surface			d	s					
Component			PE	PE					
L_7									
Thickness (mm)			0.038–0.048	0.032–0.038					
Surface			rd	s					
Component			PE	PE					
L_8									
Thickness (mm)			0.041–0.048	0.040–0.042					
Surface			rd	d					
Component			PE	PE					
Inner side of package									

Heat sealer type a and b are shown in Fig. 4.

L, layer number; R, confiscated region; P, package number; PE/EVA, polyethylene/polyvinylacetate copolymer; PE, polyethylene; s, smooth surface; r, rough surface; d, dirty surface; rd, rough and dirty surface; R, packages correspond to regions in Fig. 1; P, package numbers confiscated at each region; L, layer numbers of each package.

using a Polamax. Images of the polymer sheet layer comparison where a positive match was observed using the Polamax are shown in Figs. 7*a–e* and 8*a–h*).

Observation of Machining Striation Marks Using Cross-Polarized Light

It is well known that characteristic lines can be observed which reflect the manufacturing process of the plastic using a method of cross-polarized light (13). If the lines are the same between two samples of polymer sheet packaging materials, they are presumed to be produced by same extension roller. The results of the comparison of the striations observed in each polymer sheet layer and relation of the matched striation lines of layers is described in Tables 4 and 5. Furthermore, each polymer sheet layer which had matching striation lines was shown to be composed of the same polymer components of similar thickness.

The Relationship of Three Regions of Confiscated Methamphetamine Packages

Although there were no polymer sheet layers that showed similar striation lines in all regions, a relationship between the packaging materials confiscated in some of the regions was established. The relationships consisted of identical samples being confiscated from

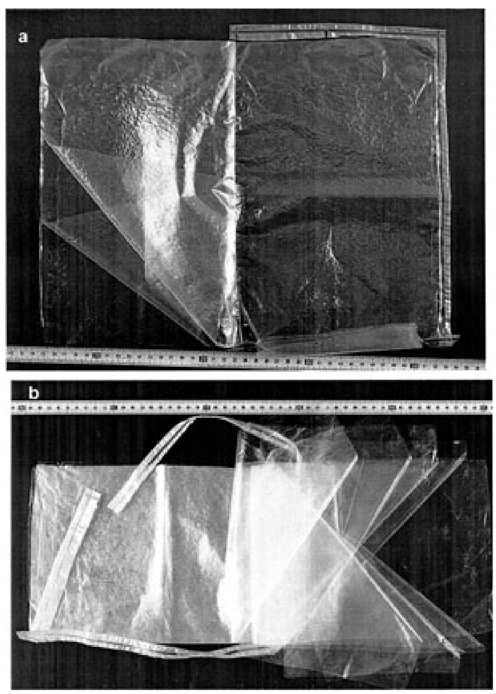

FIG. 5—*Typical layer structure of the package sample, (a) R_2-P_{10} (three sheet layers) and (b) R_2-P_7 (eight sheet layers).*

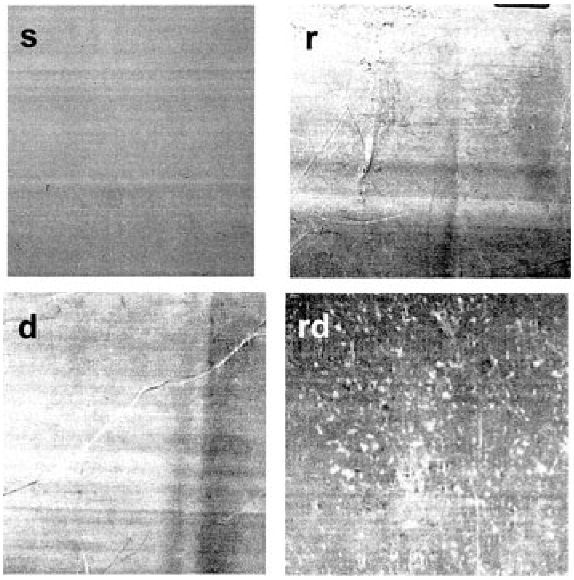

FIG. 6—*Surface conditions of the polymer sheets of each layers. s, smooth; r, rough; d, dirty; and rd, rough and dirty.*

regions 1 and 2, and regions 2 and 3. The details of these relationships are summarized in Fig. 9.

Conclusions

Polymer sheet layers of 29 individual packages used for packaging methamphetamine were retrieved from three different regions in Japan. Each region was located over a 1000 km distance and included the public sea. In Japan, there are many different colorless PE and PE/EVA manufacturing companies. Therefore, there is a large supply of PE and PE/EVA films available and the roller that is used to prepare the film is replaced frequently. In this case, all polymer sheets in the packaging were colorless and consisted of PE and PE/EVA. A comparison of striation lines of polymer sheet layers and heat sealer marks was used to determine if a common origin existed.

From the results of these examinations, it was observed that there were some polymer layer sheets which showed the same striation lines when these samples were analyzed using cross-polarized glass with backlight. In these samples, the organic component, the thickness, the surface characteristics, the striation lines of the polymer layer sheets, and the heat-sealing marks were similar. Although there were no polymer sheet layers which showed similar striation lines in

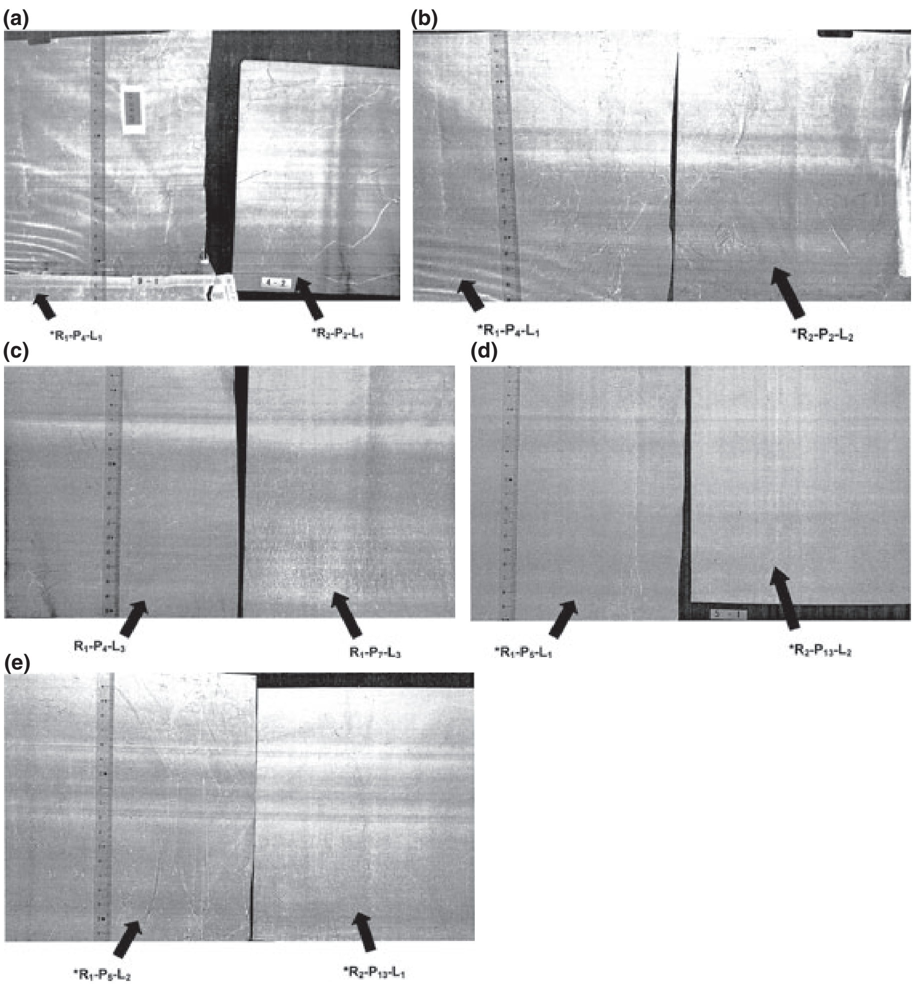

FIG. 7—*Matched pairs of striation lines. (a) *R_1-P_4-L_1 and *R_2-P_2 L_1, (b) *R_1-P_4-L_1 and *R_2-P_2 L_2, (c) R_1-P_4-L_3 and R_1-P_7-L_3, (d) *R_1-P_5-L_1 and *R_2-P_{13}-L_2, (e) *R_1-P_5-L_2 and *R_2-P_{13}-L_1. *: means these samples were retrieved from different regions; R: packages correspond to regions in Fig. 1; P: package numbers confiscated at each region; L: sheet layer numbers of each package.*

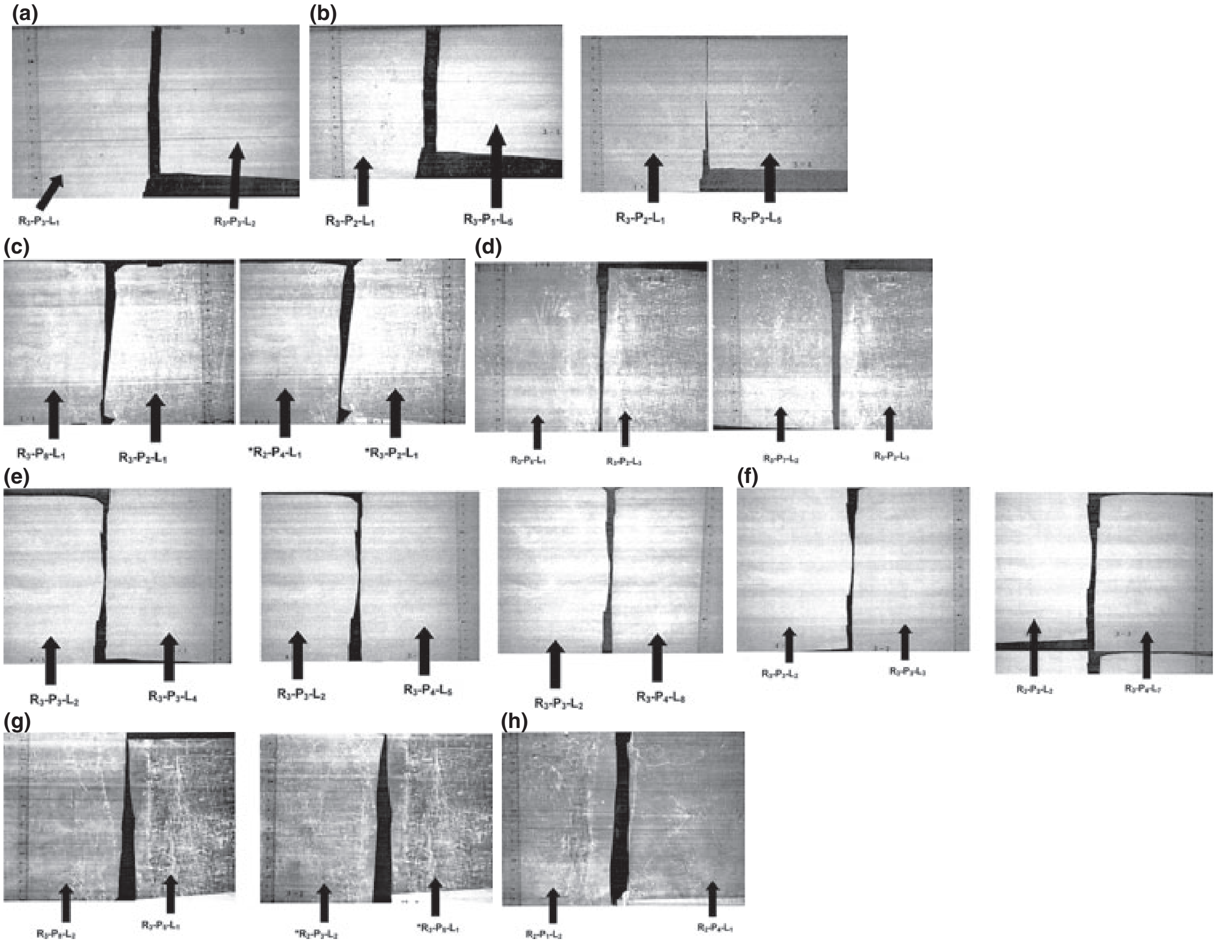

FIG. 8—*Matched pairs of striation lines. (a) R_3-P_3-L_1 and R_3-P_3-L_2, (b) R_3-P_2-L_1, R_3-P_1-L_5 and R_3-P_3-L_5, (c) *R_3-P_8-L_1, *R_3-P_2 L_1 and *R_2-P_4-L_1, (d) R_3-P_6-L_1, R_3-P_2-L_3 and R_3-P_7-L_2, (e) R_3-P_3-L_2, R_3-P_3-L_4, R_3-P_4-L_5 and R_3-P_4-L_8, (f) R_3-P_3-L_2, R_3-P_3-L_3 and R_3-P_4 -L_7, (g) *R_3-P_8-L_2, *R_3-P_5-L_1 and *R_2-P_3-L_2, (h) R_2-P_1-L_2 and R_2-P_4- L_1. *: means these samples were retrieved from different regions; R: packages correspond to regions in Fig. 1; P: package numbers confiscated at each region; L: sheet layer numbers of each package.*

TABLE 4—*The matched combinations of layer striations between sheets of package samples retrieved from the Sea of Japan (●$_1$ in Fig. 1, region 1) and seized at seashore of southern region of Japan, unloaded seashore (●$_1$ in Fig. 1, region 2).*

Confiscated Region	Package	Layer		Confiscated Region	Package	Layer	Fig.
R_1	P_4	L_1	=	R_2	P_2	L_1	7*a*
R_1	P_4	L_1	=	R_2	P_2	L_2	7*b*
R_1	P_4	L_3	=	R_1	P_7	L_3	7*c*
R_1	P_5	L_1	=	R_2	P_{13}	L_2	7*d*
R_1	P_5	L_2	=	R_2	P_{13}	L_1	7*e*

packages from all three regions, there were some polymer sheet layers which showed similar striation lines retrieved from regions 1 and 2 and regions 2 and 3. The existence of matched layers between confiscated packages from different regions over a 1000 km distance showed an obvious relationship between the methamphetamine that has been illegally transferred on the open sea (region 1), unloaded at region 2, and delivered to the mainland (region 3). This smuggling route is presumed to be controlled by organized crime in Japan. After a few months of investigation by the police, this route of illegal import and delivery was identified and inactivated.

TABLE 5—*The matched combinations of layer striations between the sheets of package samples retrieved from the west region of Japan (●$_3$ in Fig. 1, region 3) and seized at unloaded seashore, southern region of Japan (●$_2$ in Fig. 1, region 2).*

Confiscated Region	Package	Layer		Confiscated Region	Package	Layer		Confiscated Region	Package	Layer		Confiscated Region	Package	Layer	Fig.
R_3	P_1	L_1	=	R_3	P_2	L_2									8*a*
R_3	P_1	L_1	=	R_3	P_1	L_5	=	R_3	P_3	L_5					8*b*
R_3	P_2	L_1	=	R_3	P_8	L_1	=	R_2	P_4	L_1					8*c*
R_3	P_2	L_3	=	R_3	P_6	L_1	=	R_3	P_7	L_2					8*d*
R_3	P_3	L_2	=	R_3	P_3	L_4	=	R_3	P_4	L_5	=	R_3	P_4	L_8	8*e*
R_3	P_3	L_2	=	R_3	P_3	L_3	=	R_3	P_4	L_7					8*f*
R_3	P_5	L_1	=	R_3	P_8	L_2	=	R_2	P_3	L_2					8*g*
R_2	P_1	L_2	=	R_2	P_4	L_1	=								8*h*

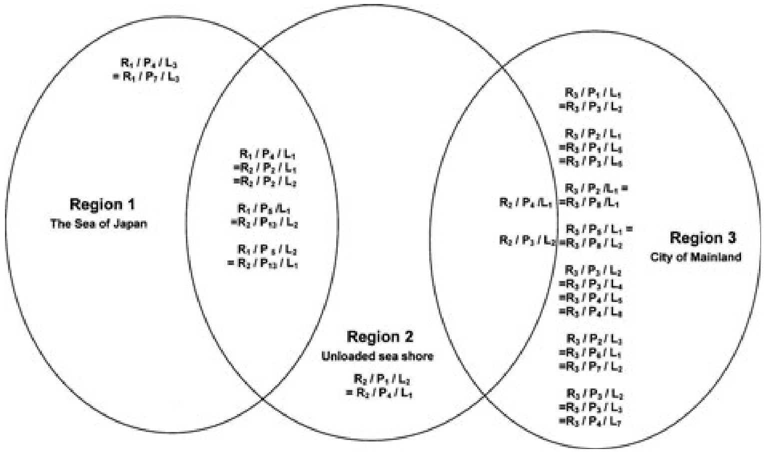

FIG. 9—*The relationship between the physical matching of striation marks and seized illicit drug package area.*

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