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LAE-MARKHAM VALLEY GEOPHYSICAL SURVEY, PNG, 1973

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CONTENTS

SUMMARY

A geophysical survey at Lae and the Markham valley, Papua New Guinea, during March, April, and May 1973 used seismic and resistivity techniques in order to assess the underground water potential of both areas. In addition, using the seismic data, a preliminary assessment of ground response to earthquakes was made for the Lae area.

In the groundwater studies, previous subsurface information was provided by existing bores which in the Lae area extend to a maximum depth of 80 m and provide the bulk of the town water supply. In the Markham valley relatively shallow bores have been drilled on cattle properties, and these yield small supplies of water for stock consumption. Both areas consist of large deposits of Quaternary sediments of unconsolidated clay, sand, minor gravel, and boulder gravel of unknown thickness.

The results of the survey work around Lae indicate that water-bores can be drilled to much greater depths than at present. The seismic results suggest a total thickness of 715 m of gravel overlying bedrock. Resistivity results indicate that large areas of potentially water-bearing sediment exist over the whole area, and in particular within the proposed new urban development areas, north of Lae.

The seismic data from the Markham valley indicate that the alluvial fan deposits extend to a depth of 600 m.

The earthquake response assessment suggests that, in the Markham floodplain area, earthquake motions are likely to be amplified, and that the area around the Hitech, on the upper reaches of the Busu River alluvial fan, would show low earthquake response. Further investigations are recommended.

1. INTRODUCTION

A geophysical survey was carried out at Lae and the Markham valley, Papua New Guinea, in order to assess the underground water potential of both areas. In addition, the ground response to earthquake motion for the Lae area was assessed. The survey used the seismic and resistivity techniques to determine the thickness and nature of unconsolidated Quaternary alluvial deposits of clay, sand, and gravel. A party from the Engineering Geophysics Group of the BMR, consisting of F.J. Taylor (party leader), G.R. Pettifer (geophysicist), R.D.E. Cherry (technical assistnat), and M. Pounder (technical officer), did the fieldwork in March, April, and May 1973.

1.1 Lae

Previous work on groundwater around Lae has been reported by Pounder & Jacobson (1972), who summarised the data from all water-bores previously drilled in the Lae area (Plate 2). At present most of all water used in the area of Lae and environs is pumped from about 20 highly productive bores. The water quality is generally good, with the portion of total dissolved solids in the range 185 to 315 ppm, HCO^{-}_{3} being the principal anion. At present the water consumption is slightly above 9000 m^3 per day, which is expected to increase rapidly with the rapidly expanding population and with the proposed expansion of industry. Industrial requirements for water may approach 136 000 m^3 per day within the next decade.

The aim of the present groundwater research in the area is to assess whether future requirements can be met with underground water supplies or whether expensive surface storage systems will be required.

A total of 22 resistivity depth probes and 11 seismic probes were completed in the Lae and environs area. The locations of these probes are shown in Plate 1.

1.2 Markham valley

A report on the groundwater resources of the Markham valley has been written by Jacobson (1971). There are a total of 81 known water-bores in the Markham Valley. Of these, 64 bores were successful in obtaining adequate supplies of water. The operating bores have been used both for domestic pruposes and for livestock. The present number of operating bores represents a density of about 1 bore per 20 km^2. The Markham valley is of economic importance through the cattle and agricultural industries, and has considerable potential for expanding these industries if sufficient water supplies are available during the dry season. To date, water-bores have been drilled to a maximum depth of 80 m.

The aim of the present work in the Markham valley is to determine the total thickness of unconsolidated alluvial sediments and hence provide a guide for future drilling operations.

Three seismic refraction probes were completed in the Markham valley: at the Leron Bridge, the Leron Plains, and the Rumu River (Plate 3). Information was obtained on sediments at depths greater than 700 m. The information is of particular interest since this is the first occasion that seismic work has been undertaken in the Markham valley. The sites were chosen for ease of access and to test depth estimates obtained from analysis of gravity anomalies on gravity traverses across the Markham valley; the gravity results suggest that the bedrock is much as 1000 m deep (Pettifer, 1974).

2. GEOLOGY

2.1 Geology of Lae

This description of the geology of the Lae area is based on a report on the geology and foundation conditions of the Lae urban area (Weber, 1972b; Plate 2). The existing Lae township and the proposed urban extensions are situated on a flat-lying alluvial and coastal plain which rises gently from the coast towards the foothills of the Saruwaged Range. This plain is bounded by the Saruwaged Range in the north and north-east, the Huon Gulf in the east and south, and the Markham River and Atzera Range in the west.

The relatively flat alluvial plain consists almost entirely of unconsolidated Quaternary deposits derived by erosion of the uplifted mountains of the Huon Peninsula, which comprises Tertiary sediments and volcanics subdivided into several strati-graphic-lithological units (Robinson, 1973). The most important sources of sediments for the Lae area are the Finisterre Volcanics (Oligocene) and the Gowop Limestone (Miocene). The Quaternary sediments to the north and east of Lae consist of sand, gravel, and boulder gravel, with the larger grain sizes being predominant. These sediments are derived from the Finisterre Volcanics and Gowop Limestone. Farther west the Gusap Argillite, probably of pre-Oligocene age, and the Leron Formation (Pliocene) are the most important sources of sediment for the Markham valley and the alluvial floodplain adjacent to the Markham River near Lae.

The Quaternary sediments around Lae have been derived from two principal sources. The coarsest clastic sediments in the eastern and northern part of the area (and the major section available for urban development) are derived by erosion of the Saruwaged Range. Existing borehole data indicates that the thickness of these sediments exceeds 80 m. The floodplain alluvium west of Lae between the Atzera Range and the Markham River comprises sediment deposited from the flood waters of the Markham valley. These sediments consist of sand, gravel, silt, clay, and mud, with the finer components being predominant. Drill holes at the Markham bridge show the thickness of these finer unconsolidated sediments to be greater than 50 m.

The Quaternary deposits are divided into several groups depending on the type of deposition. These groups are flood-plain alluvium, footslope colluvium terrace alluvium, and fan alluvium. Underground water is available in all of these deposits. Outcrops of the Leron Formation (sandstone, conglomerate, and shale) occur in the centre of the township. This formation is generally regarded as bedrock for water supplies.

2.2 Geology of the Markham valley

The geology of the Markham valley has been described by Best (1964), Grainger (1970), Jacobson (1971), and others. The Markham valley is a tectonic valley filled with piedmont fan alluvium. It is about 125 km long and 10 to 20 km wide. It is relatively flat, with the highest elevation being 400 m above m.s.l. at the Ramu-Markham divide and the lowest elevation being sea level at Lae. The valley consists mainly of grassland with some rainforest in the lower part near Lae. To the north the valley is bounded by the rugged Finisterre and Saruwaged Ranges, which rise steeply to 4000 m above m.s.l. To the south the valley is bounded by mountains rising to 2500 m above m.s.l.

The Ouba Formation (Pliocene) borders the valley to the north. It consists of sandstone and conglomerate moderately folded and faulted. The Ouba Formation flanks the Mena and Mebu Formations (Miocene) which form most of the Finisterre and Saruwaged Ranges. South of the valley a bedrock complex forms the Herzog Mountains. The complex consists of Miocene sedimentary rocks, Mesozoic and Palaeozoic metamorphic rocks, and Tertiary and Mesozoic intrusive igneous rocks. The bedrock to the south of the valley cannot be correlated with that to the north of the valley, indicating a large fault displacement.

Most of the Markham valley consists of piedmont alluvial fan deposits built up at the base of the rising Finisterre-Saruwaged mountain front by southward flowing streams. The Markham River flows mainly on the south side of the valley, having been forced there by the influx of sediments from the north. Individual fans are commonly several kilometres in radius, with the largest fan being the Leron fan of radius 20 km.

The maximum thickness of the piedmont alluvium is not known, but from borehole data it is known to be in excess of 80 m. Previous detailed gravity traverses across the Markham valley at Kaiapit, the Leron Plains, and the Rumu River-Pyramid Hill area suggest shallow source gravity anomalies, of maximum depths ranging from 300 to 1000 m, which may be attributable to the alluvium-bedrock interface (Pettifer, 1974). Resistivity work in the Leron Plains, Erap River, and Umi River areas (Wainwright, 1966) indicate at least 120 m of unconsolidated sediments.

3. METHODS AND EQUIPMENT

3.1 Seismic

Seismic refraction work was carried out using the 24-channel SIE PSU-19 refraction amplifiers with 8-Hz GSC-20D geophones. Geophone spacings ranged from 4 m to 35 m, and in general four shots were fired into each spread of geophones. Explosive charges ranged from less than 1 kg to 300 kg.

At two localities seismic reflection work was carried out using very small charges submerged in water or mud. The technique gave useful information on shallow discontinuities.

3.2 Resistivity

An Evershed and Vignoles Geophysical Megger (0-30 ohm, AC) was used to measure earth resistances. The instrumental accuracy was better than 3 percent for resistances above 0.1 ohm, but deteriorated to 5 percent at 0.05 ohm and 10 percent or more for still lower values. Throughout the survey, the Wenner configuration was used: four electrodes were placed at equal spacings, and the spacing was increased successively, allowing deeper penetrations. The Wenner tri-potential method (Carpenter & Habberjam, 1956) was used to determine and reduce lateral effects which produce values not permissible if a pure resistivity-depth variation is assumed.

Pettifer & Taylor (1976) summarised the theory and practice of the equispaced tripotential method. The adjustment was carried out by a computer program which produced a best-fitting layered-medium curve. The curve was then interpreted in the normal manner using two-layer curve-matching techniques. The final interpretation was obtained from an iterative computer modelling program (Vozoff, 1958) which modified the interpretation to agree best with the adjusted field data.

TABLE 1. LAE SEISMIC TRAVERSES

Traverse	Geophone spacing (m)	Location
A	35	Swiss Evangelical Mission, Highlands Hwy to Markham River
B	4	Public Works Department yard, Lae
C	10	Malahang plantation
D	10	Malahang plantation
E	10	DASF Quarantine Station
F	10	Hitech grounds
G	35	Wagan Road
H	4	DCA transmitter yard, Lae
J	4	Botany Building, Lae
K	5	Pepper Grove, Atzera Range
L	5	DCA ground between Lae airstrip and Post and Telegraph (P and T) Hill

From the results of all these depth probes the following classification of velocity was derived for the Lae area (Table 2).

TABLE 2. VELOCITY-LITHOLOGY RELATIONS, LAE

Velocity (m/s)	Interpreted lithology
300-500	Loose soil and clay
1000-1500	Clay, sand, and minor gravel, with varying water content
1800	Clay, sand, and silt completely saturated with water and containing little or no boulder gravel. Common in swampy terrain.
2000-2700	Boulder gravels. The deeper water-bores in the Lae area pump water from sand lenses within the boulder gravel
3500	Consolidated sedimentary rocks
5200	Possibly metamorphic or igneous rocks. Detected on traverse G, Wagan Road, at a depth of 1770 m.

In the Lae area, twenty-two depth probes were carried out (Plate 1); the maximum electrode spacing was 384 m. To comply with the adjustment method, standard electrode spacings were used in the field. Two concurrent geometric series of 0.5, 1, 2, 4, 8, 16, 32, etc., and 1.5, 3, 6, 12, 24, 48, etc. (all values in metres), were employed for each depth probe.

Water samples were taken from boreholes and surface waters in the Lae area, and resistivities were measured in the BMR mud-cell using an Evershed and Vignoles Megger Earth Tester. Appendix 1 shows the results of the resistivity measurements.

4. RESULTS

4.1 Seismic results - Lae

Eleven seismic traverses were completed near Lae (Plate 1). Their locations were determined by the availability of open spaces and accessibility. In the immediate town area open spaces suitable for seismic work are few because of restrictions imposed by the proximity of buildings, major roads, and the constant pedestrian traffic. In the outlying areas the sites are confined to those regions accessible by vehicle.

Information on seismic depth probes is given in Table 1. Time-distance plots and interpreted depths and velocities for traverses A to J are given in Plates 26 to 32.

As the seismic survey had a twofold purpose of assessing groundwater potential and earthquake response the seismic results will be discussed in two sections, each relating to these separate aspects of the investigation.

4.1.1. Groundwater studies

Seismic refraction and reflection methods were employed on traverse A (Plate 26). Refraction seismic indicated a refractor of 2400 m/s velocity at a depth of 234 m overlain by unconsolidated floodplain alluvium (1800 m/s). Reflections were recorded from seismic discontinuities at depths of 150 and 235 m. The lower reflector correlates well with the 2400 m/s refractor. This refractor probably represents boulder gravel. The significance of the reflector at 150 m is unknown, but it may be due to an increase in gravel content of the Markham sediments at that depth. This layer does not appear as a first arrival on the seismic refraction records, and this suggests that the layer is too thin to be recorded as a refractor, but has sufficient acoustic impedance contrast with the overlying 1800 m/s sediments to form a good reflector.

Traverse A results indicate a thick layer (72.5 m) of low-velocity (1200 m/s) material at the base of the Atzera Range. This causes a jump in the time-distance curve at the northern end of traverse A.

On traverse H (Plate 27), near the DCA transmitter yard, the results are similar to the Markham swamp area: one metre of soil overlies water-saturated mud with a velocity of 1800 m/s; and strong reflections were also recorded from depths of 150 and 240 m. Similarly, on traverse L, near Voco Point Wharf (Plate 1) a prominent reflection was recorded from a depth of 140 m. The significance of these reflectors in the Lae township is unknown but the seismic velocities suggest at least 140 m of predominantly fine-grained sediments overlie either boulder gravels or the Leron Formation in the area west of the bedrock ridge occupied by the Lae town centre.

Traverse K was located on Pleistocene terrace alluvium in a pepper grove at the base of the Atzera Range. The highest velocity detected was 1800 m/sec, which corresponds to water-saturated unconsolidated sediments. As with most areas around Lae there was insufficient space to shoot long shots to determine the velocity of the outcropping Leron Formation.

To the east of Lae township in the area covered by the fans of the Busu and Bumbu Rivers, seismic traverses B,C, D, E, F, and G (Plates 27 to 31) were shot. The depth profiles for these indicate between 10 and 26 m of sand, clay, and minor gravel underlain by boulder gravel. The 1500 m/s velocity on traverse C (Plate 28) indicates a shallow layer of water-saturated fine sediments.

A deep seismic refraction traverse (G, Plate 31) involved a maximum shot offset of 6 km. The interpreted results suggest a total depth of 715 m of gravels overlying bedrock (3500 m/s). A deeper layer of velocity 5200 m/s was detected here and its depth was calculated to be 1770 m. This velocity would probably represent metamorphic rocks. However, because of the absence of a reverse profile on this line, the 5200 m/s velocity should be accepted with reservations.

Boulder gravel velocity varies considerably over the area, (2000-2700 m/s). A velocity of 2900-3200 m/s recorded at the DASF Quarantine Station (traverse E, Plate 30) represents either tightly compacted boulder gravel of negligible porosity or shallow bedrock (50-60 m depth).

4.1.2. Earthquake response - Lae

At the time of this survey, accelerographs were stationed at P and T Hill, Botany Building site, PWD yard, and DCA transmitter yard. These accelerographs were being used to record the ground response to earthquakes which have epicentres close to Lae. The results indicate that sites on the Leron Formation (P and T Hill and Botany Building) are subjected to lower accelerations than sites on alluvium and colluvium. In fact the accelerations detected on the Markham swamp land (DCA transmitter yard) were of the order of 10 times those recorded on the P and T Hill.

Seismic refraction spreads were sited adjacent to three of these accelerograph sites; these are the DCA transmitter yard (traverse H), PWD yard (traverse B), and the Botany Building site (Botanical gardens, traverse J). The time-distance plots are shown in Plates 27 and 32. As can be seen there is no shallow high-velocity refractor at any of these sites.

Qualitatively, the ground response to an earthquake has been found to depend in part on the depth of weathering, or alternatively the degree of consolidation, of the near-surface material. This fact has been evident in accelerograph records associated with the Ramu and Musa hydroelectric schemes (Gaull, 1974).

Our experience with ground response due to seismic waves, both from seismic exploration work and the vibrations from a large power station, has indicated that the major factor determining the ground response, apart from the amplitude of the incoming seismic wave, is the degree of consolidation of the near-surface material. For example the amplitude of the recorded seismic wave (expressed in particle velocity) was found to increase by a factor of two when the detector was mounted on a few centimetres of gravel rather than on solid ground. In another area, one of us observed the ground response at one geophone station to be substantially greater than that at others, owing to 13 m of water-saturated coarse gravel near the surface; the near-surface sediment (0 to 16 m) at the other geophone stations was compacted clay.

In reference, then, to the seismic results at Lae, there is one significant difference between the Botany Building site and the other two sites. Thick compacted impervious clay (velocity 1000 m/s) with little associated groundwater underlies the

Botany Building site. The water-table is 7 m deep at the PWD site and 1 m deep at DCA. Hence, the different ground response observed at these accelograph sites at Lae may be due to the different water contents of the underlying sediments. If so, then those areas with lower ground accelerations associated with earthquakes would be expected to be underlain by lower-porosity sediments or lower water-tables, or both.

The area around Lae with a low water table and the highest sediment velocity (3200 m/s) is the DASF station. Hence, we believe that this section of urban land warrants further investigation as a suitable area for low earthquake response.

The Markham swamp area is characterized by high water-tables and fine-grained high-porosity sediments. The unconsolidated water-saturated muds will show the highest ground response to earthquakes; such a response to seismic waves was illustrated directly, but dramatically, in the course of seismic operations on traverse A (Plate 1). The ground quivered noticeably when the buried charges were exploded, and the ground motion continued for some time, causing tall trees to oscillate violently and dead tree branches to break loose.

Detailed seismic zoning studies have been carried out in the San Francisco Bay region, California (Borcherdt, 1975) using seismic S wave techniques. Further detailed investigation along these lines is recommended in the Lae area. However, difficulties may be encountered using S waves in water-saturated alluvium.

4.2 Seismic results - Markham valley

Seismic refraction work was undertaken along three traverses (Plate 3) to investigate the depth and nature of the sediments in the Markham valley. The traverse sites and the mode of investigation were restricted by the necessity to use large explosive charges (300 kg) and the length of traverse line required to give results (3 km). As a result, shots for each traverse had to be detonated at a fixed point, and the detectors had to be moved farther away from the shot-point for each shot.

Thus, no reverse shots were fired on any of the traverses, and the interpretation of the results must be considered in this light.

The three traverses (Plate 3) are near the Leron Bridge (S1), in the centre of the Leron Plains (S2), and the Rumu River (S3). A brief description of each of these areas, and the mode of shooting, is given below.

(1) Leron Bridge (S1): A single shot was fired into a 1-km line of detectors near the junction of the Highlands Highway and the Leron River. The shot was fired in the Leron River at a point 3.5 km south of the Leron bridge and the detectors were placed along a line proceeding roughly northwest from this point. The last detector on the line was about 20 m from the Highlands Highway.

(2) Leron Plains (S2): Shots were fired in the Gorambampan Creek, a tributary of the Markham River, at a point 7.5 km from the Highlands Highway and 6.8 km from the Leron River. The detector line extended 3.4 km roughly east-northeast of the shot-point.

(3) Rumu River (S3): The shot-point was sited in the Rumu River about 1 km south of the Highlands Highway, and the detectors were placed along the cleared electricity transmission line east of the river. The detector line extended to 2.3 km away from the river.

Plate 35 shows the time-distance plots for traverses S1, S2 and S3. The results of this work are given below in Table 3 along with the interpreted lithologies.

An apparent velocity of 5600 m/s recorded along traverse S2 (Plate 35) over a distance of 500 m could be caused by a dip of 17° in the 3500 m/s layer, or by a lateral change in the velocity of bedrock, which may represent metamorphic or igneous rocks. Tenuous gravity evidence suggests anomalously low gravity values in this area (Pettifer, 1974, Plate 3).

TABLE 3. SEISMIC INTERPRETATION, MARKHAM VALLEY

Trav.	Velocity (m/s)	Depth (m)	Thickness (m)	Lithology (interpreted)
S1		0		
	1550		77	Unconsolidated clay,
(Leron		77		silt, sand, and minor
Bridge)	2350		80	gravel
		157		Boulder gravel
	2800			Consolidated sediment-
				ary bedrock.
S2		0		Unconsolidated clay,
(Leron	1520		20	silt, sand, and minor
Plains)		20		gravel
	2030		115	Boulder gravel
		135		
	2500		465	Boulder gravel
		600		
	3500-5600			Consolidated sedi-
				mentary bedrock (hi-
				gher velocities pos-
				sibly metamorphic
				or igneous)
S3		0		
(Rumu	1600		90	Unconsolidated clay,
River)		90		silt, sand, and minor
	2100		130	gravel
		220		Boulder gravel
	2300		260	Boulder gravel
		480		
	3500		260	Consolidated sedi-
		740		mentary bedrock
	4900			Metamorphics?

On traverse S3, a velocity of 4900 m/s was recorded over a distance of 300 m (Plate 35). The depth profile may be as presented in Table 3, or the 3500 m/s, and 4900 m/s layers may represent high-velocity metamorphics dipping to the east and west respectively. Metamorphics crop out about 5 km east of the traverse line, at Pyramid Hill. Alternatively the increase in velocity may represent a lateral change in velocity in the bedrock, indicating a sedimentary/metamorphic contact.

4.3 Resistivity results, Lae

The field data, smoothed resistivity curve, computer layer model, and theoretical curve are shown in Plates 4 to 25 for the 22 resistivity depth probes carried out in the Lae area.

In the legend of Plates 4 to 25 the Wenner (α array) means the electrodes are equally spaced and arranged in the conventional CPPC Wenner order. Wenner (γ array) means the electrodes are equally spaced in the order CPCP. The lateral inhomogeneity ratio (LIR) plot is included to give an indication of the magnitude of the effect of lateral resistivity changes on the data (Habberjam & Watkins, 1967).

The interpreted depth probes, together with existing borehole data and the seismic results, are compiled into a series of interpreted cross-sections of the survey area (Plates 33 and 34).

4.3.1 Resistivities of sediments in the Lae area

Appendix 1 summarises measurements of water resistivities in the Lae area. In situ water resistivities range from 15 to 24 ohm-m in Lae township area, to 21 to 26 in the area between the Bumbu and Busu Rivers. Surface waters in the Markham swamp are as low as 10 ohm-m, and the resistivity of the Busu River water measured 42 ohm-m.

For a clay-free, porous, fully saturated sediment of fractional porosity ϕ and interstitial water resistivity R_w, the resistivity R_o of the sediment (assuming effectively infinite resistivity for the sediment matrix), is given by $R_o = R_w \phi^{-1.25}$ (Wiebenga & Jesson, 1952). Todd (1959) gives a relation between lithology of unconsolidated sediments and porosities. Using the measured water resistivities, the formula of Wiebenga & Jesson (1965) and the lithology-porosity relationship of Todd (1959), a table of theoretical resistivities of unconsolidated sediments for the Lae area has been compiled (Table 4).

The values quoted in Table 4 are subject to several limitations. If clays are present in a porous rock, the non-ohmic conduction of the clays lowers the sediment resistivities in an ambiguous manner, and hence porosities calculated from measured resistivities are unrealistically high and meaningless. If the sediments are not completely water-saturated (e.g., above the water-table) then resistivities are higher and porosity is underestimated. For the Lae area, water-table depths range from 3 to 30 m. Further, if the sediment matrix material is weathered rock containing appreciable quantities of clay material, the effect on resistivity may be similar to that observed with interstitial clay material.

Some of the depth probes were carried out near existing boreholes (Plate 2) and trench excavations, enabling correlations of interpreted resistivity results with known lithologies. Table 5 summarizes these correlations; also included in Table 5 is a resistivity-lithology correlation from a previous resistivity survey (Andrew & Wainwright, 1965; see Plate 1) which successfully predicted the depth to water-bearing gravel and boulder materials in the Igam Barracks area.

The data in Table 5 show generally good qualitative agreement between the theoretically calculated resistivity-versus-lithology relation, (Table 4) and observed field resistivities/borehole lithology relation, subject to the limitations of the drillers' descriptive logs of lithologies (Pounder & Jacobson, 1972). Detailed quantitative comparisons of the data from Tables 4 and 5 cannot be made because sieve analyses on samples from boreholes are available for only two of the bores in Table 5 (NG 181 and NG 182) and may be unrepresentative of the larger volume of material being sampled by the resistivity depth probe.

TABLE 4 THEORETICAL RESISTIVITY-LITHOLOGY RELATIONS FOR UNCONSOLIDATED CLAY-FREE SEDIMENTS IN THE LAE AREA

Resistivity (ohm-metres Lae township (R_w=15-24 ohm-m)	Resistivity (ohm-metres Bumbu-Busu Rivers area (R_w= 21-26 ohm-m)	Porosity (%)	Lithology	Max.*10% grainsize (mm.)
145-180	190-245	17	Boulders	256
125-170	180-225	18	Coarse gravel	128
100-130	135-175	22	Coarse gravel	64
75-100	105-135	27	Medium gravel	32
65-90	95-120	30	Medium gravel	16
60-80	85-105	33	Fine gravel	8
52-70	70-90	37	Gravelly sand	4
48-60	65-85	39	Coarse sand	2
44-55	60-80	42	Coarse sand	1
44-55	60-80	42	Medium sand	½
42-54	58-78	43	Fine sand	¼
40-53	55-75	45	Fine sand	1/8

* 10% of the material by weight has a diameter greater than the values quoted.

TABLE 5. COMPARISONS OF RESISTIVITIES AND LITHOLOGIES FROM DEPTH PROBES NEAR BOREHOLES AND EXCAVATIONS, LAE

Location	Resistivity (ohm-m)	Lithology (Pounder & Jacobson, 1972)
Depth probe 2 (trench)	15	Organic mud
	30	Black organic soil
	5-6	Clay (saturated)
Depth probe 5 (NG 175)	85	Water-bearing medium gravel coarse sand
Depth probe 7 (NG 183)	90-95	Gravel and coarse sand
Depth probe 9 (NG 124)	150-160	Boulders and gravel
	50-60	coarser bearing gravel, boulders and some clay
Depth probe 14 (NG 189)	40-45	Fine sand-fine gravel
	30	Silt and sand
	3-4	Silt and mud
Depth probe 15	110-140	Boulders and gravel
(NG 38)	65-75	Fine gravel, coarse sand, some clay and boulders
Depth probe 20	90-95	Boulders and moist clays
(NG 181)	55	Coarse sand-fine gravel
Depth probe 21 (NG 182)	65	Sand and coarse gravel, minor clay
Depth probe 12 (NG 272)	10	Clay and boulders
(Andrew & Wainwright, 1965)	90	Boulders, gravel, sand (water-bearing)

However, the sieve analysis results, supplied by PWD from NG 181 bore sampled from the 55 ohm-metre layer defined by depth probe 20, show a maximum 10 percent grainsize of 25 mm, which corresponds to a resistivity of 70-90 ohm-m in Table 4. For NG 182 bore, in Milford Haven Road, near depth probe 21 (Plate 24, Table 5), samples taken from a depth of 28 m have a 10 percent maximum grainsize of 19 mm, corresponding to a medium gravel of resisitivity 70 to 95 ohm-m (Table 4). Depth probe 21 indicates a resistivity of between 60-70 ohm-m at these depths. In these two examples, the theoretical resistivity-lithology relation of Table 4 shows reasonable agreement with the resistivity field results and laboratory sieve analyses.

Weber (1972a), investigating gravels of the Busu and Bumbu rivers as possible sources of aggregate for Lae wharf, concluded from surface indications that the rapid rates of deposition and generally high stream velocities have produced well-graded fans of gravels and sands, with most of the free material (silts and clays) being washed to the sea. The grainsize of the gravels decreases downstream and generally towards the sea. The Bumbu-Busu gravels have a composition as shown in Table 6.

TABLE 6 COMPOSITION OF BUMBU AND BUSU RIVERS GRAVELS (AFTER WEBER, 1972a)

Rock type	Percent
Dark hard volcanics	37%
White limestone	9%
Hard greywacke-siltstone	18%
Soft weathered tuff	21%
Assorted quartz, intrusives, sandstones	15%

The tuff represents a major potential source of in situ clay within the gravel.

TABLE 7 LATERAL INHOMOGENEITY INDEX VALUES, LAE DEPTH PROBES

Probe No.	L.I.I.	Classification
1	0.030	Low
2	0.172	Low
3	0.253	Intermediate
4	0.292	Intermediate
5	0.175	Low
6	0.103	Low
7	0.136	Low
8	0.033	Low
9	0.103	Low
10	0.019	Low
11	0.162	Low
12	0.107	Low
13	0.059	Low
14	0.241	Intermediate
15	0.077	Low
16	0.364	Intermediate
17	0.103	Low
18	0.064	Low
19	0.077	Low
20	0.067	Low
21	0.221	Intermediate
22	0.370	Intermediate

Clay and silt are largely present as thin bands in the fan gravels. Elsewhere, clay and silt are widespread in the swamps of the Markham River, in the clay and gravel of the Pleistocene terrace deposits, and on the narrow outcrop of the Tertiary bedrock (e.g., Chinatown). Clay resistivities can be expected to range from 5 to 10 ohm-m. Weathered bedrock is interpreted as having a resistivity of 3 to 4 ohm-m from the results of depth probes 4 (Plate 7) and 5 (Plate 8).

4.3.2. Interpretation of resistivity depth probe results

4.3.2.1 Lateral effects and difficulties in interpretation

For the Lae area, the effects of lateral resistivity changes do not appear to be too great. Table 7 summarizes the lateral inhomogeneity indices of the depth probes.

In the interpretation of the results, difficulties were encountered, particularly in the Busu-Bumbu Rivers area. The resistivity equipment was not powerful enough to penetrate the large thickness of gravel deposits. The deepest boundary which is defined by resistivity depth probing in the Busu-Bumbu area is at 330 m in depth probe 9. The seismic results (section 4.1.1) suggest as much at 715 m of gravels beneath the Wagan Road area.

In the Lae township area, some of the probes were done near grounded fences and structures but generally grounded fences were avoided if possible. In Table 7 all depth probes showing intermediate L.I.I. values (except for depth probe 3) were near grounded fences or structures. Depth probe 3 was carried out in partly drained muddy swamp, and the L.I.I. value probably reflects the variability of the lower resistivity surface clay layer.

4.3.2.2 Lae airstrip and Markham floodplain areas

Plate 33 shows four interpreted cross-sections across the Aztera Range and its extensions as a bedrock ridge beneath the main town centre of Lae (sections A-A', B-B', C-C', and D-D[1]).

On Sections A-A[1], B-B[1], and C-C[1], on the airstrip side of Lae township, the geophysical results indicate three main features of the subsurface geology in this area:

(1) at least 140 m of fine-grained sediments;

(2) variable resistivity of the near-surface aquifer, suggesting variable porosity and clay content;

(3) evidence of sea-water intrusion in coastal areas.

Firstly, seismic reflection evidence on traverses H and L indicate a strong reflector at 150 and 140 m respectively. A deeper reflector (240 m) is also evident on traverse H. The reflection results on traverse H correlate closely with those of traverse A on section D-D[1] (see section 4.4.1). The significance of the shallow reflector is uncertain, but the low-resistivity (16 ohm-m) layer defined in depth probe 20 (Plate 23) near Lae airport at a depth of 180 m almost certainly corresponds to the reflector. If the reflector represents boulder gravel then the low-resistivity value (16 ohm-m) suggests that the boulder gravel is either highly weathered or contains a high proportion of fine sediments or clay. The deeper reflector may then represent the top of weathered Leron Formation. The interpretation is uncertain but a thickness of at least 140 m of fine-grained sediments is inferred from these results.

Secondly the variability of resistivity of the near-surface aquifer layer is evident in depth probes 20, 21, and 22 (Plates 23 to 25). In depth probe 20, near the airstrip, a 55 to 60-ohm-m layer extending to a depth of 180 m suggests that the coarse sand to fine gravels in borehole NG 183 (Plate 2; Pounder & Jacobson, 1972) extend much deeper. Farther west, in depth probe 22, sediment resistivities of 20 ohm-m are interpreted between the water-table and a depth of 100 m. Farther west again, depth probe 21 indicates 60 to 70-ohm-m sediment to a depth of 30 m overlying a low-resistivity layer (7 ohm-m). This suggests a marked increase in clay content below 30 m. On these results, variation in clay content of the aquifer is inferred, and bore NG 181, near depth probe 20, might be considered the better prospect for increasing yield by deepening, than bores farther west.

Thirdly, a low-resistivity layer (0.8 ohm-m) was interpreted in depth probe 22 at a depth of 103 m. Unless this anomalously low resistivity is caused by interfering grounded structures, the results of this depth probe provide strong evidence for salt-water intrusion beneath this depth; so care should be exercised in increasing water yield from this section of the Lae township aquifers. A possible interpretation of the salt water interface is shown in Plate 33.

On section D-D^1 on the southwestern side of the Atzera Range, depth probe 2 and seismic traverses A indicate silt and silty sand (35 to 45 ohm-m, 1800 m/s) varying in thickness from 79 m near the Highlands Highway to 234 m under the Markham River. The reflection recorded at a depth of 150 m probably corresponds to the base of the silt and sand and the top of boulder gravel. The material between 150 and 235 m may be boulder gravel and weathered bedrock. Water-bearing sand and silt are extensively developed in depth opposite the Swiss Evangelical Mission in depth probe 2. Farther downstream, depth probe 3 (Plate 6) indicates low-resistivity clays and muds to a depth of more than 60 m.

4.3.2.3 <u>Bumbu-Busu Rivers area</u>

The area north-east of Lae is represented by sections A-A^1, B-B^1, C-C^1, D-D^1 (Plate 33) E-E^1 and F-F^1 (Plate 34). In this area section A-A^1 extends from bedrock outcrop at Mount Lunaman to east of the Busu River, and passes through or near depth probes 13, 18, 17, and 16 and seismic traverse G. The water-table along this section is interpreted as ranging from 2 m at depth probe 18, to 15 m at depth probe 16.

Below the water-table and above a depth of 45-55 m, resistivities range from 55 ohm-m (depth probe 16) to 160 ohm-m (depth probe 13), indicating lithologies ranging from fine silty sand to coarse gravel (Table 5). The seismic results of traverse G (Plate 31), however, indicate a velocity of 2000 m/s, corresponding to boulder gravel to a depth of 100 m. The range of resistivities (55 to 160 ohm-m) then suggests various amounts of fine sediment in the boulder gravel. Seismic and resistivity results thus suggest that the Holocene floodplain alluvium (Plate 2; Wever 1972b) is less than 100 m thick in the lower reaches of the Busu-Bumbu fans. Prospects for finding water at depths less than 50 m appear to be good in this area. Below 100 m on section A-A[1], higher velocity (2200 m/s) gravels occur. A 300 ohm-m layer interpreted in depth probe 18 almost certainly corresponds to the boulder gravel.

Section B-B[1] extends from Lae town centre, through Malahang plantation to the Busu River near Malahang speedway. Depth probe 14 (Plate 17) near Chinatown bore (NG 189, Table 5) indicates extensive development of clay and silts close to bedrock. Across the Bumbu River (depth probe 19, Plate 22) the river gravels have developed to a depth of 56 m and overlie a 20-ohm-m layer which probably correlates with clays and silts encountered in Chinatown bore (NG 189). The 20-ohm-m layer extends to a depth of 90 to 100 m. However, below this depth is a 55-65-ohm-m layer, which should be a good prospect for water. Gravels can be expected to extend to depths of at least 200 m nearer the Busu River (depth probe 15, Plate 18).

On the northern side of Lae township, section C-C[1] crosses from the Lae botanical gardens to the Busu River. In depth probe 4 (Plate 7) weathered bedrock (4 ohm-m) is interpreted at a depth of 65 m, and above this depth - from 24 to 65 m, - a 60-70-ohm-m layer correlates with surface aquifers in borehole NG 182 (Table 5). In Bumbu Road, depth probe 5 (Plate 8) indicates silt and clay (21 ohm-m) below 19 m and extends to a depth of 130 m, where a low-resistivity layer (2 ohm-m) is interpreted as representing weathered bedrock. Section C-C[1] indicates how steeply bedrock dips away beneath the Recent sediments. Depth probe 5 (Plate 8) is in a zone where recharge is thought to come from north of Lae into the township area. The resistivity results suggest that this recharge zone is predominantly within the first 20 m of sediments.

Depth probe 6 (Plate 9), across the Bumbu River from depth probe 5, shows the recent Bumbu gravels to be at least 44 m thick. The 15 to 25-ohm-m layer below the gravels correlates with the silt and clay (21 ohm-m) layer of depth probe 5. Section B-B[1] and C-C[1] are very similar in this respect near the northeastern edge of the bedrock ridge. Depth probe 11 (Plate 14) indicates water-bearing gravel to a depth of at least 270 m.

On the northeastern side of the Atzera Range, section D-D[1] passes from near the colluvium which underlies the site of a proposed housing development on portion 233 (depth probe 8, Plate 11), through the Hitech area, to the Busu River.

Depth probe 8 indicates a 60-ohm-m layer, extending to depths of between 90 and 120 m, underlain by a 35-ohm-m layer. The interpreted resistivity depth section suggests that water may be found below 3 m (Plate 1) in the area of portion 233; however, in view of the known high clay content of the colluvium (Weber, 1972b), the interpretation is uncertain as to the lithology of any possible aquifers.

Depth probe 1 (Plate 4) in the industrial area opposite the Hitech shows gravel (80 ohm-m) extending to 150 m. As the Bumbu River is so close, plentiful groundwater supplies might be expected. The 80-ohm-m layer correlates with the 90-ohm-m gravel aquifer of the Hitech 1 bore (NG 183, Table 5; depth probe 7, Plate 10). In depth probes 1 and 7, lower resistivities (10 to 25 ohm-m) at depths of 110 to 150 m suggest an increase in clay content of the sediment with depth.

Depth probe 12 shows the boulder gravel fan of the Busu River to extend to a depth of 23 m beneath the soil cover. The water-table is also at a depth of 23 m, below which a 45-50-ohm-m layer extends to a considerable depth.

Sections E-E[1] and F-F[1] (Plate 34) extend from Huon Gulf northwards to the top of the boulder gravel fans of the Busu and Bumbu Rivers. Section E-E[1], near the Bumbu River, indicates the variation in thickness of the high-resistivity (65-190 ohm-m) surface boulder gravel of the Bumbu gravel deposits, ranging from a general thickness of 45 m up to 110 m in the Hitech area. The gravels are underlain by a lower-resistivity (10-30 ohm-m) layer which probably represents the transported clays and silts of the nearby Atzera Range and possibly some clay-filled weathered boulder gravel.

Section Section F-F[1] from the mouth of the Busu River to north of the DASF Quarantine station shows an interpreted cross-section in the deep part of the colluvial fan. Lower-resistivity silt and clay layers are suggested only on depth probe 13 (Plate1; Andrews & Wainwright, 1965) on section F-F[1], and, below it, resistivity results indicate thick water-saturated gravel, probably with some clay (45-75 ohm-m). The water bearing potential of this area must be considered high on the basis of the resistivity and seismic results.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The resistivity survey was carried out using a low-powered geophysical Megger which was unable to penetrate the thick sequence of gravels northeast of Lae. However, information has been gained about the first 100-200 m or more of sediments. The interpretation of the resistivity results is based on the smoothed resistivity curves derived from the Wenner tripotential method. Lateral effects are generally small in the Lae area, and hence the smoothed data differ little from the field data. Future resistivity work should make use of higher-powered equipment and the Schlumberger configuration which is more convenient for field operations than the Wenner configuration. Comparison between existing boreholes and resistivity soundings indicates good correlation between resistivity and lithology in the Lae area, presumably owing to the general relatively low clay contents throughout most of the sediments.

The Lae area, particularly on the Busu-Bumbu fans, is considered ideally suited to resistivity methods for this reason.

The seismic results are based on refraction, and in places on reflection soundings. Along some traverses, refraction soundings were taken without reversed profiles, and their interpretations are based on one-way profiles. This limitation must be borne in mind in considering the interpretation of the data from the deeper refraction soundings in the Markham valley and the Wagan Road area, Lae.

5.2 Lae groundwater

5.2.1 A one-way seismic refraction probe on the Wagan Road indicates 715 m of boulder gravel on the lower reaches of the Busu-Bumbu fans. Resistivity results suggest the Holocene alluvial floodplain material is less than 100 m thick northeast of Lae, and that the prospects of water-bearing sand and gravel shallower than 50 m is good over all areas investigated. Further detailed work is recommended in areas of interest.

5.2.2 Fine grained sediments appear to predominate near the surface in the lower reaches of the Bumbu river near the weathered bedrock; however resistivity results suggest boulder gravel below 100 m. Northeast of the Bumbu River, in the Hitech area, low-resistivity sediments occur at depths of 100 m or more. Groundwater prospects appear better at shallower depths.

5.2.3 In the Lae township area south of the bedrock ridge the variable resistivities of the sediments suggests variability of the aquifers. A low-resistivity layer (0.8 ohm-m) in one depth probe (22) suggests salt-water intrusion at a depth of 100 m. The coarse-grained sediments which comprise the existing aquifer systems thicken towards the airstrip and thin towards the Markham swamp. Reflections were recorded from depths of 150 and 240 m in the DCA transmitter yard, and from 140 m on the coastal end of Lae airstrip. The significance of these events is not known, but the reflector at 150 m may represent either boulder gravels or weathered Leron Formation. Because of the possibility of salt-water intrusion, further groundwater development for the existing township might be advisable north, rather than south, of the bedrock ridge.

5.2.4 Farther up the Markham flood plain, silt, clay, and fine-grained sand predominate, possibly to a depth of 150 m. Reflections were recorded at depths of 150 and 235 m. The deeper reflector correlates with a 2400 m/s refractor, which is interpreted as boulder gravel.

5.3 Lae earthquake response

Preliminary assessment suggests that away from the bedrock ridge, ground response to earthquakes would be minimal on the fan boulder gravel in the upper parts of the Busu-Bumbu fan, and maximum response can be expected on the muds and silts of the Markham swampland. A more comprehensive investigation is recommended.

5.4 Markham valley groundwater

5.4.1 One way refraction profiles on the Leron fan indicate bedrock depths of 150 m 3 km south of the Leron bridge, and depths of 600 m immediately northeast of the Markham River/Gorambampan Creek area. Lateral changes in apparent bedrock velocity may reflect dip or lithological changes.

5.4.2 One-way refraction profiles 1 km south of Chivasing village, on the Rumu River, indicate 480 m to the base of boulder gravel. Again changes in apparent velocity are evident.

5.4.3 Further seismic work may be inhibited by the size of charges required and drilling difficulties, and would probably have to be confined to river banks. Future geophysical work should concentrate on deep resistivity soundings in areas of particular interest.

6. ACKNOWLEDGEMENTS

We are grateful for the assistance provided by the Public Works Department and the Geological Survey in Papua New Guinea. Thanks are also due to individual members of the public in Lae and the Markham valley for their co-operation during this survey.

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APPENDIX 1: WATER RESISTIVITIES - LAE AREA

(including data from Pounder & Jacobson, 1972)

		Resistivity (ohm-m)	Temperature (C°)
(a)	**Lae township area**		
	Lae Powerhouse Bore (NG. 20)	16.0	29.2
	PWD bore (NG. 170)	16.6	30.8
	Bugandi High School (NG. 171)	18.5	29.2
	Milford haven/Bumbu Rds (NG. 172)	19.1	28.4
	Lae Showgrounds (NG. 173)	20.4	25.0
	Lae golf links (NG. 174)	18.9	25.0
	Milford Haven Rd/Doyle St. (NG.176)	17.6	28.4
	Lae Technical School (NG. 177)	15.3	28.4
	Lae Technical School (NG. 179)	19.3	26.0
	Aircrops Rd/Mangola St (NG. 181)	18.2	25.9
	Milford Haven Rd (NG. 182)	15.3	29.4
	Morobe Ave/Malatia St (NG. 188)	24.4	25.0
(b)	**Markham valley swamp**		
	Depth probe 2 (surface sample)	10.0	34.5
(c)	**Bumbu-Busu Rivers area**		
	Busu River (depth probe 16)	42.2	29.4
	Bowali Primary School well, Wagan Road	21.1	28.6
	Malahang plantation bore 1 (NG. 37)	25.6	25.0
	Balob Teachers College (NG. 49)	22.3	29.4
	Hitech 2 (NG. 184)	26.4	25.0
	Igam Barracks 1 (NG. 271)	21.1	27.5
	Igam Barracks 2 (NG. 272)	24.9	27.2

SUMMARY

Water resistivities (in situ)

AREA	RANGE (ohm-m)
Lae-Township	15-24
Busu-Bumbu River area	
Groundwaters	21-26
Surface waters	42
Markham swamp (surface)	10

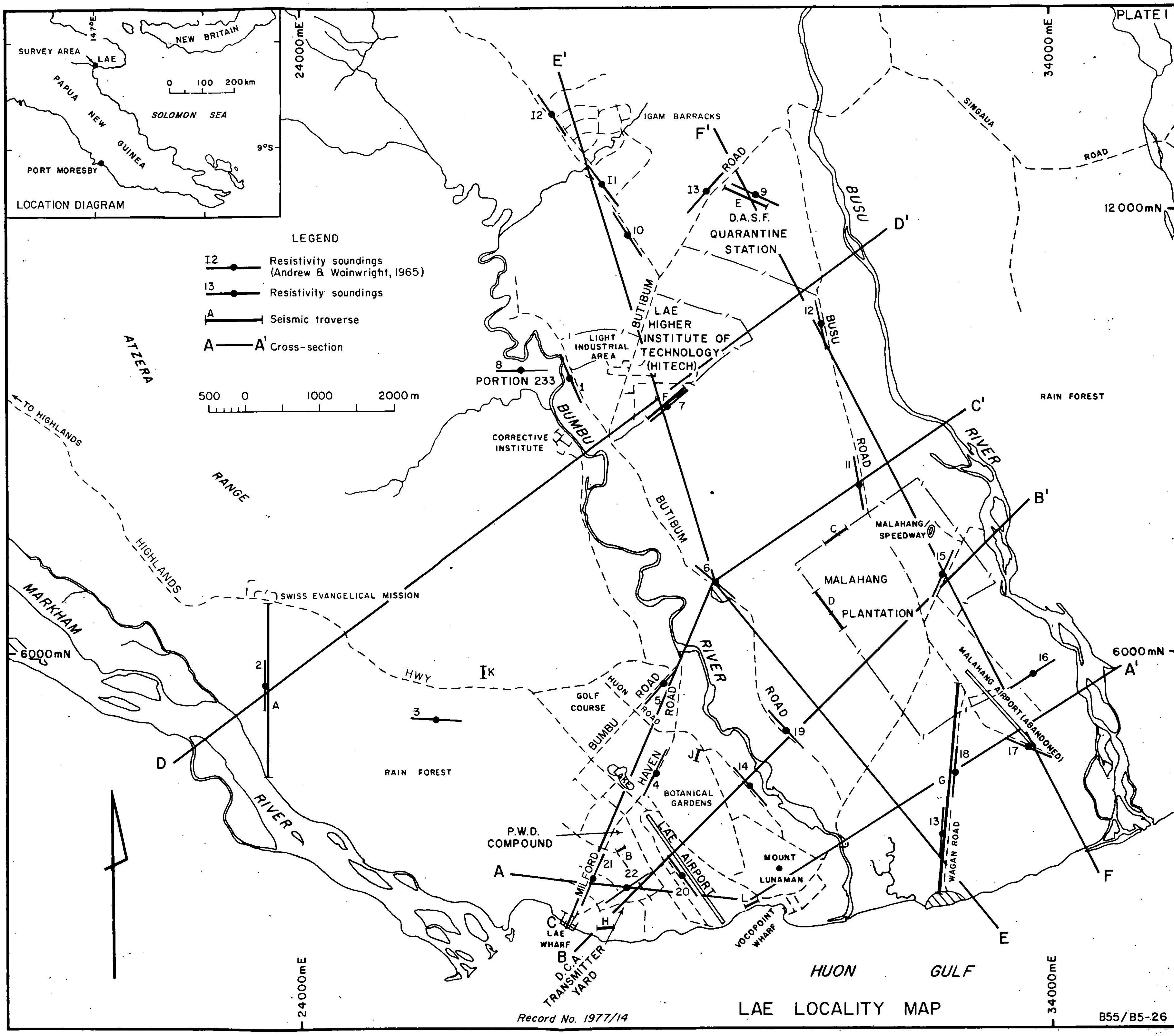
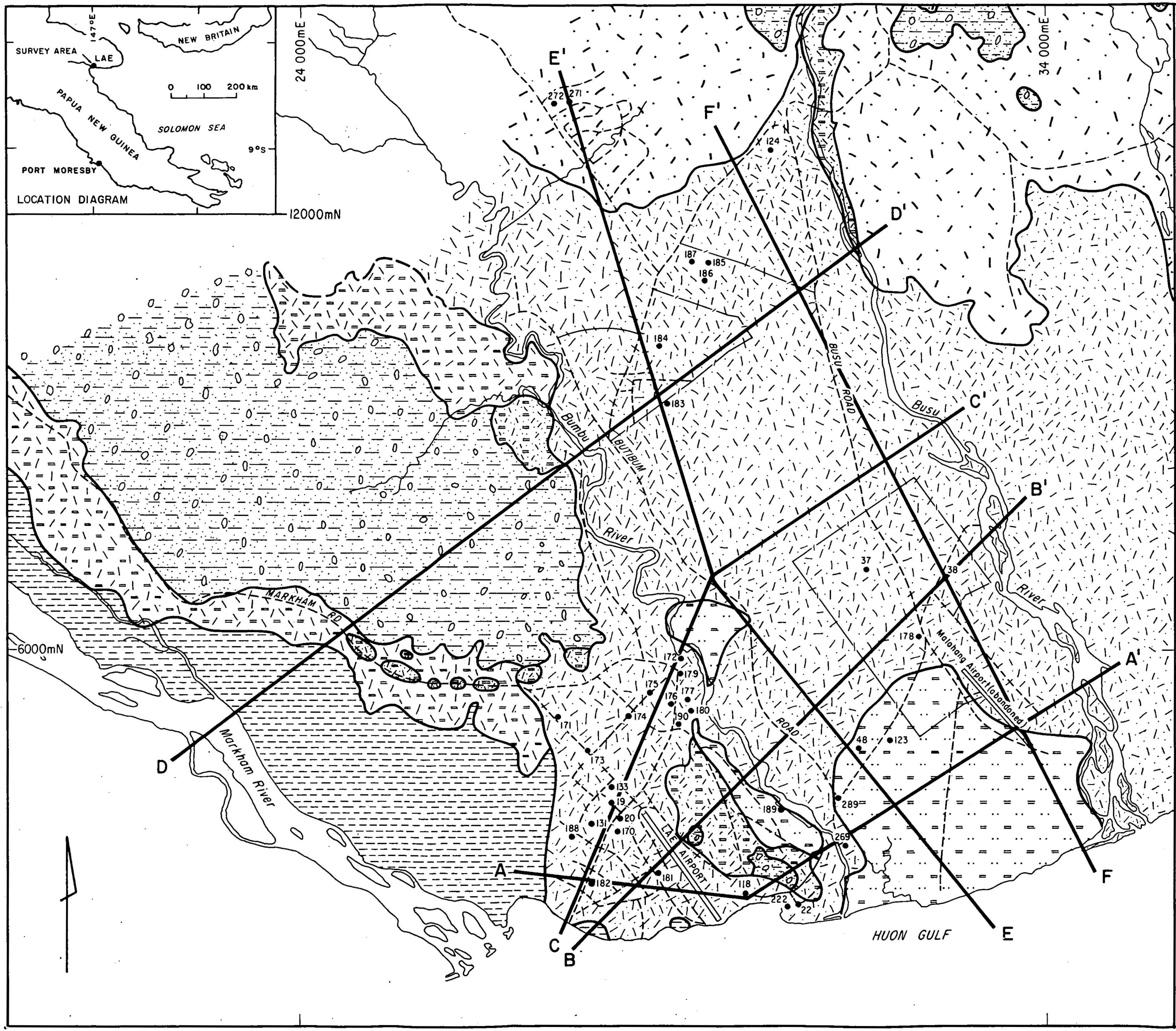


PLATE 1
LAE LOCALITY MAP
LOCATION DIAGRAM
SURVEY AREA
LAE
NEW BRITAIN
PAPUA NEW GUINEA
SOLOMON SEA
PORT MORESBY
147°E
9°S
0 100 200 km
LEGEND
I2 Resistivity soundings (Andrew & Wainwright, 1965)
13 Resistivity soundings
A Seismic traverse
A—A' Cross-section
500 0 1000 2000 m
24000 mE
34000 mE
12000 mN
6000 mN
IGAM BARRACKS
D.A.S.F. QUARANTINE STATION
LAE HIGHER INSTITUTE OF TECHNOLOGY (HITECH)
LIGHT INDUSTRIAL AREA
PORTION 233
CORRECTIVE INSTITUTE
ATZERA RANGE
TO HIGHLANDS
HIGHLANDS HWY
SWISS EVANGELICAL MISSION
MARKHAM RIVER
BUMBU RIVER
BUTIBUM ROAD
BUSU ROAD
BUSU RIVER
SINGAUA ROAD
RAIN FOREST
MALAHANG SPEEDWAY
MALAHANG PLANTATION
MALAHANG AIRPORT (ABANDONED)
GOLF COURSE
HUON ROAD
BUMBU ROAD
HAVEN ROAD
LAKE
BOTANICAL GARDENS
P.W.D. COMPOUND
MILFORD
LAE AIRPORT
MOUNT LUNAMAN
LAE WHARF
D.C.A. TRANSMITTER YARD
VOCOPOINT WHARF
WAGAN ROAD
HUON GULF
Record No. 1977/14
B55/B5-26

PLATE 2



LEGEND

- - - - -	*Road*		
—/—/—/—	*Fence line*		
	HOLOCENE	*Floodplain alluvium*	*Swamp mud*
	HOLOCENE	*Floodplain alluvium*	*Silt, clay*
	HOLOCENE	*Floodplain alluvium*	*Gravel, sand*
	HOLOCENE – PLEISTOCENE	*Footslope colluvium*	*Clayey gravel, clay*
	PLEISTOCENE	*Terrace alluvium*	*Clayey gravel, gravel, sand, silt*
	PLEISTOCENE	*Fan alluvium*	*Boulder gravel, sand, silt*
	PLIOCENE	*Leron Formation*	*Sandstone, conglomerate, shale*

A —— A' *Cross-section*

Geological boundary

38● *Borehole*

Geology after Weber, 1972b

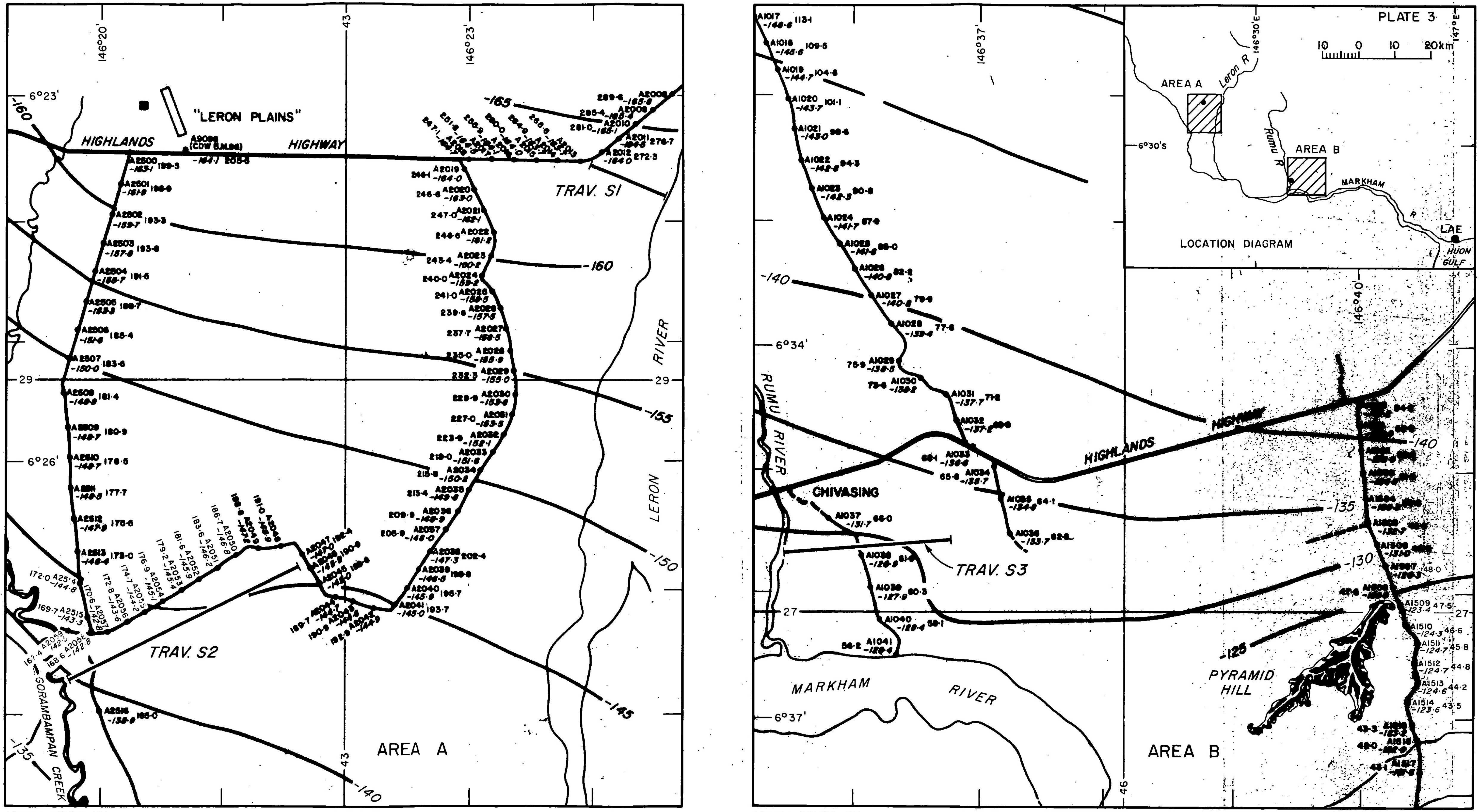
METRES

1000 0 1000 2000 3000 4000

GEOLOGY OF LAE, AND BOREHOLE SITES

Record No. 1977/14

B55/B5-66



(Based on B55/B2-49)

(Based on B55/B2-48)

0 — 2 km

LEGEND

Seismic traverse 1973

Gravity Stn. (1972) — No. of gravity station: A 2000; R.L. (m): 123·4; Bouguer anomaly at density 2·0 g/cm^3: -112·0

Prefix A = 7210

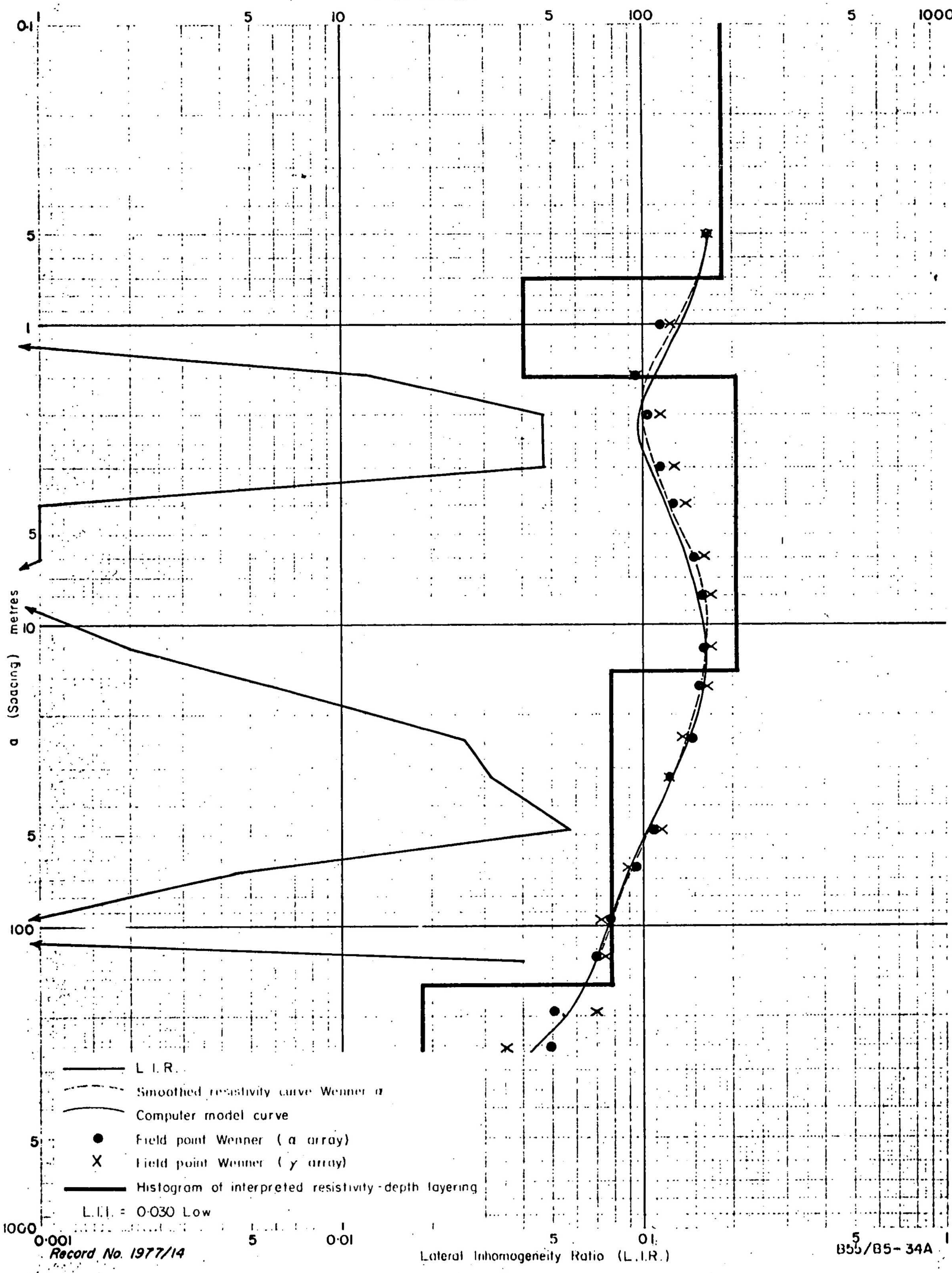
SEISMIC TRAVERSES MARKHAM VALLEY 1973

Record No. 1977/14

B55/B5-68

D.P. No. 1 LAE PNG

PLATE 4



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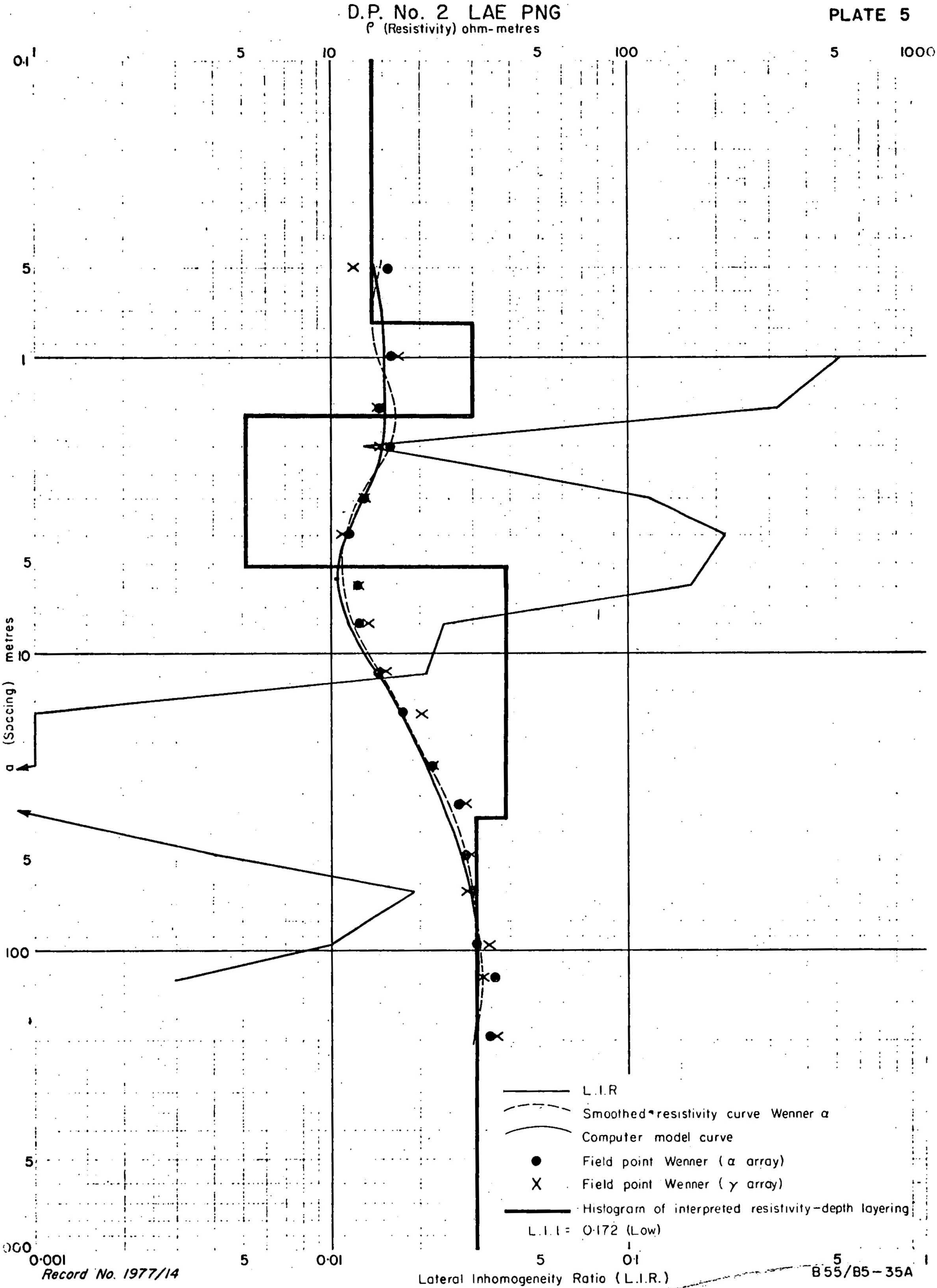
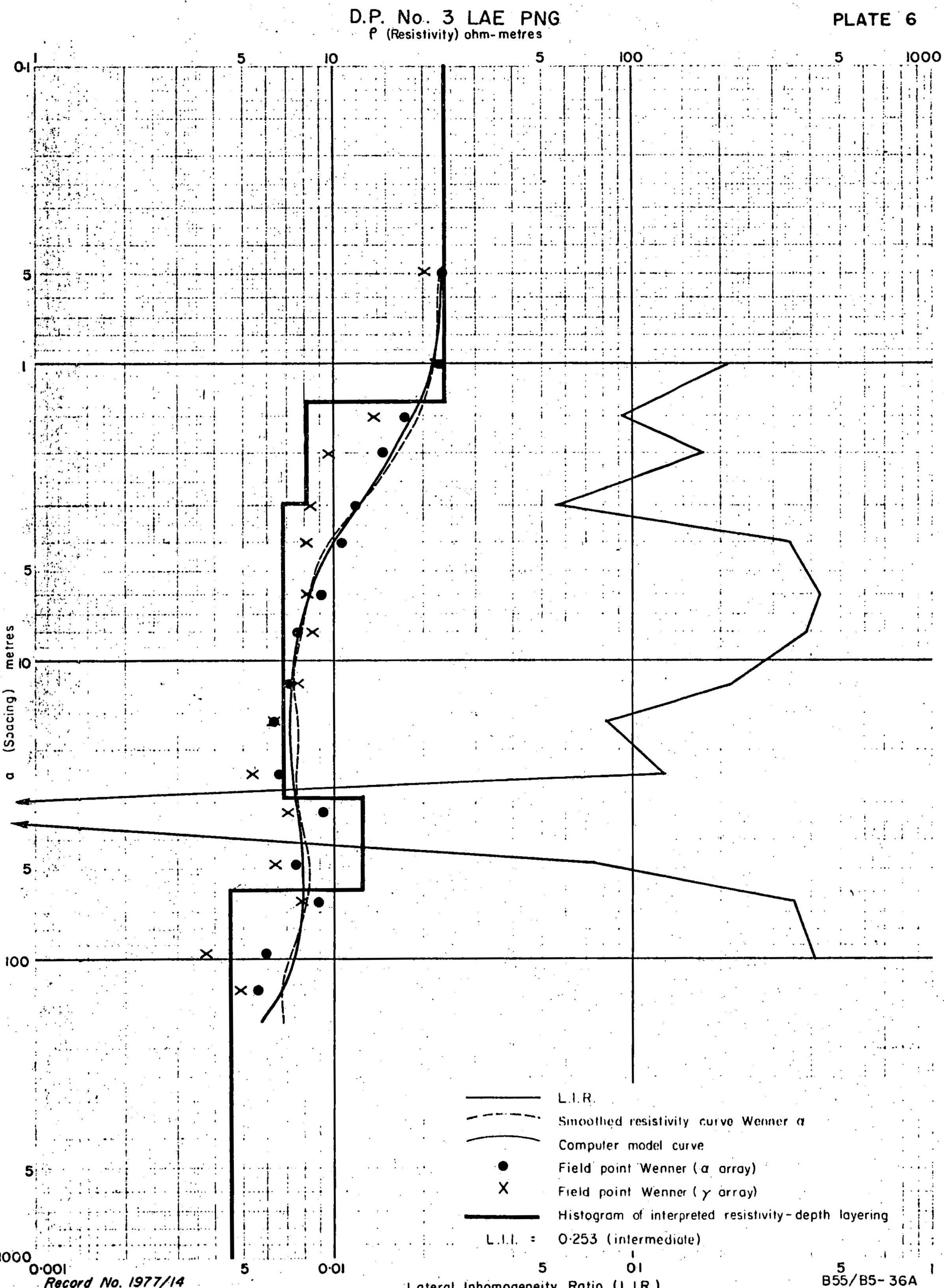

D.P. No. 2 LAE PNG
ρ (Resistivity) ohm-metres
0.1
5
10
5
100
5
1000
a (Spacing) metres
1
5
10
5
100
5
1000
L.I.R
Smoothed resistivity curve Wenner α
Computer model curve
Field point Wenner (α array)
Field point Wenner (γ array)
Histogram of interpreted resistivity-depth layering
L.I.I = 0·172 (Low)
0·001
5
0·01
5
0·1
5
1
Lateral Inhomogeneity Ratio (L.I.R.)

PLATE 6



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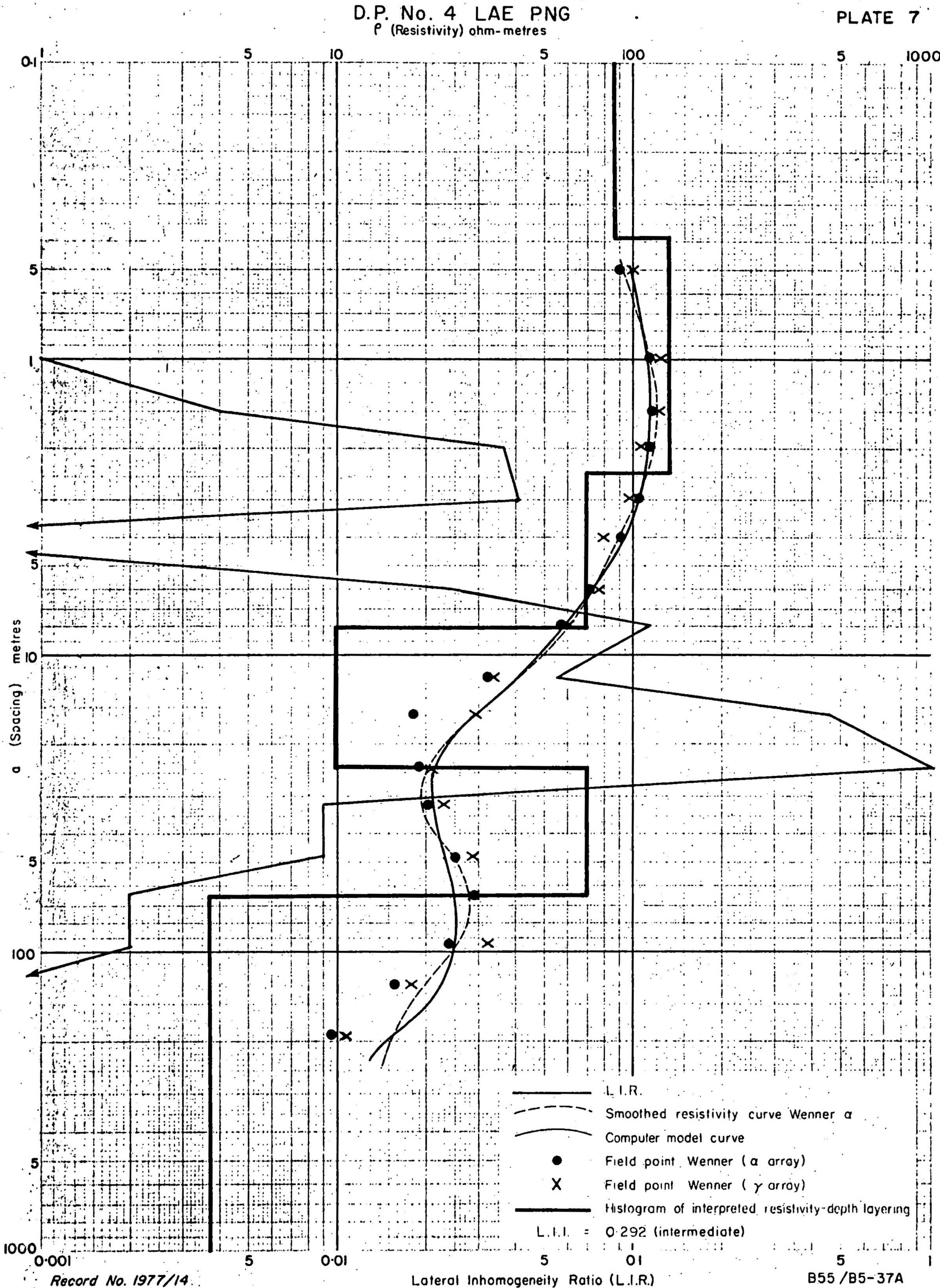
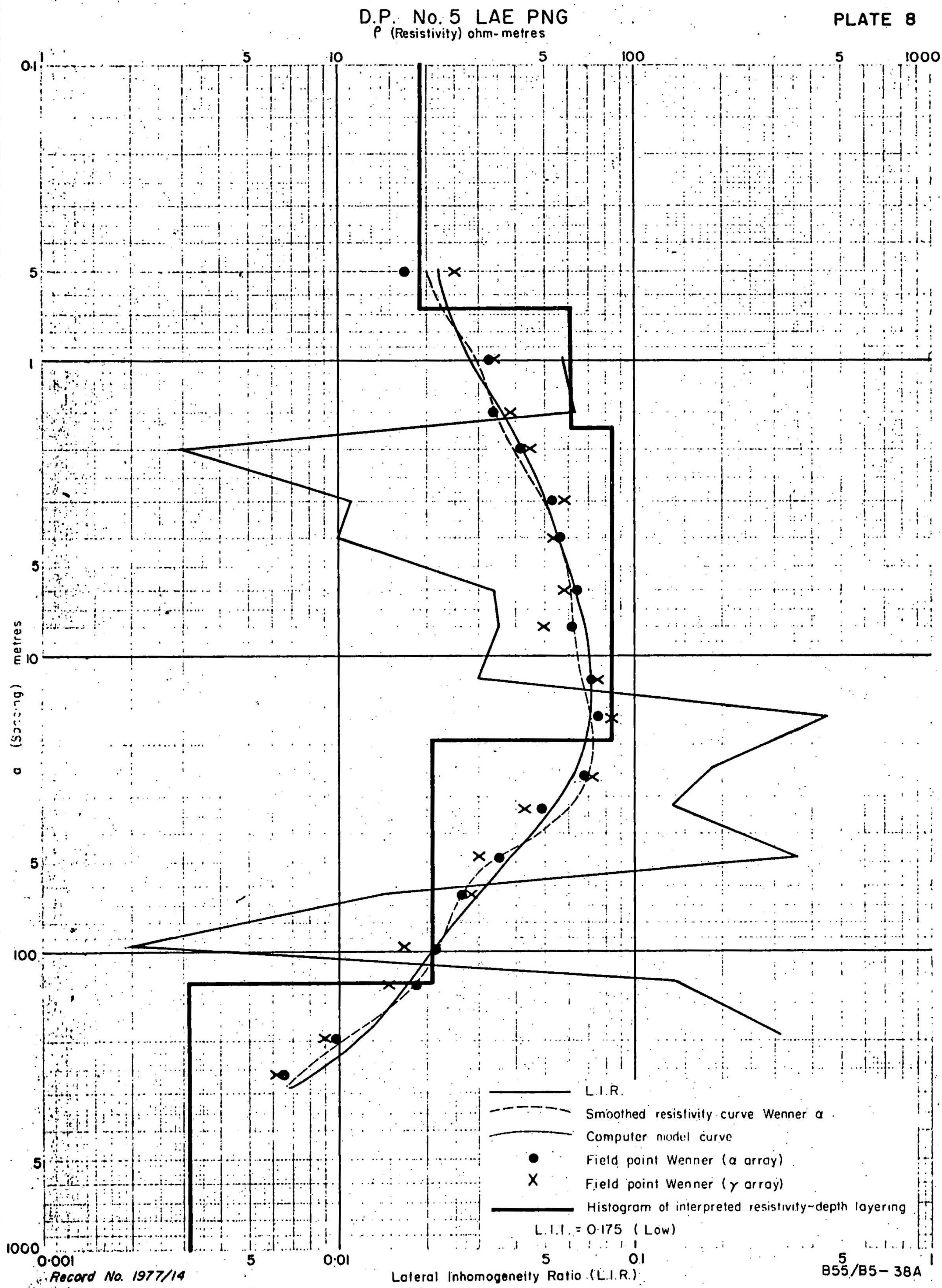
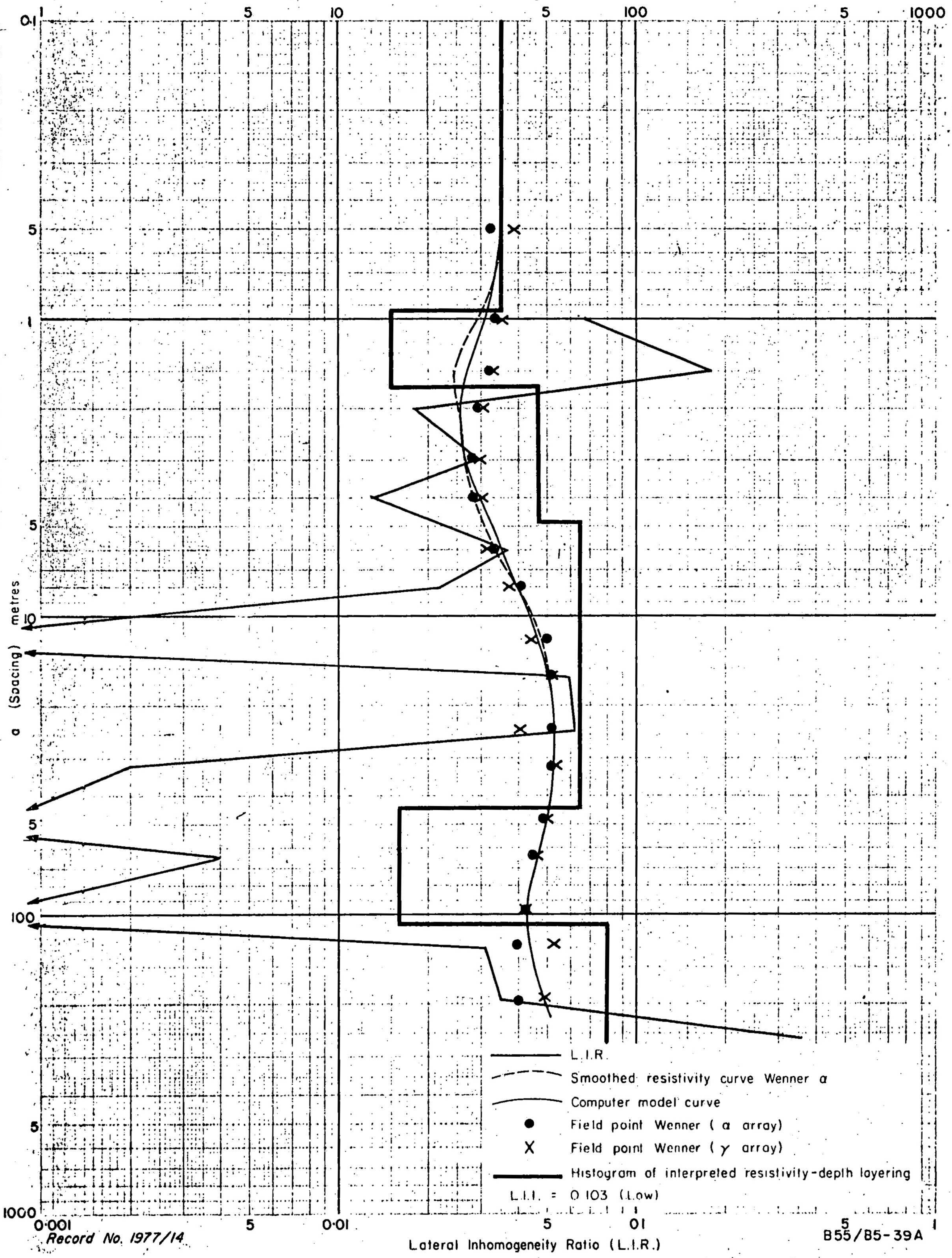

D.P. No. 4 LAE PNG
ρ (Resistivity) ohm-metres
1
5
10
5
100
5
1000
0·1
5
1
5
10
5
100
5
1000
a (Spacing) metres
0·001
5
0·01
5
0·1
5
1
Lateral Inhomogeneity Ratio (L.I.R.)
L.I.R.
Smoothed resistivity curve Wenner α
Computer model curve
Field point Wenner (α array)
Field point Wenner (γ array)
Histogram of interpreted resistivity-depth layering
L.I.I. = 0·292 (intermediate)


D.P. No. 5 LAE PNG
ρ (Resistivity) ohm-metres
a (Spacing) metres
0·1
5
10
5
100
5
1000
1
10
100
1000
0·001
0·01
0·1
1
L.I.R.
Smoothed resistivity curve Wenner α
Computer model curve
Field point Wenner (α array)
Field point Wenner (γ array)
Histogram of interpreted resistivity-depth layering
L.I.I. = 0·175 (Low)
Lateral Inhomogeneity Ratio (L.I.R.)

D.P. No. 6 LAE PNG

PLATE 9



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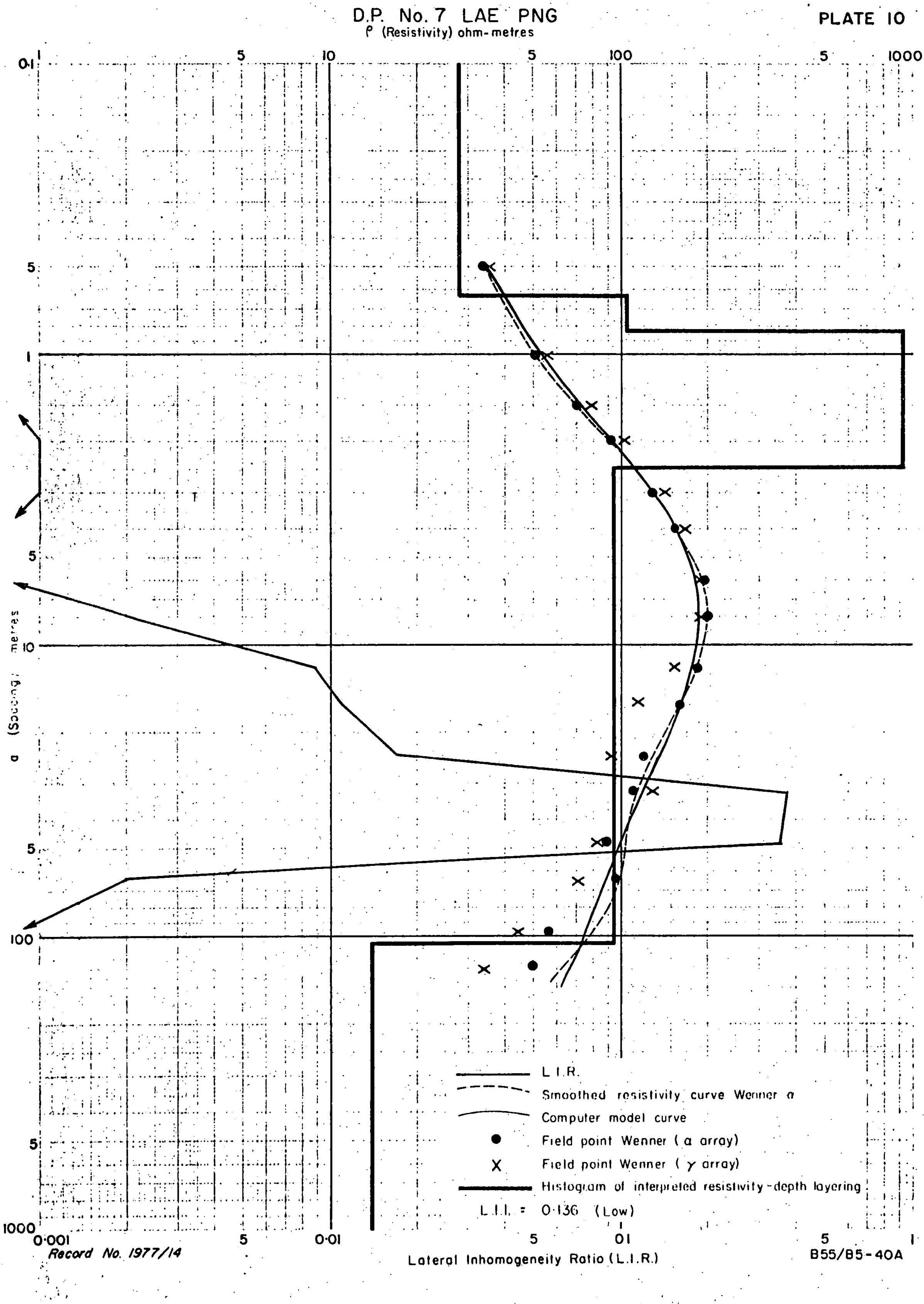
B55/B5-39A

PLATE 10



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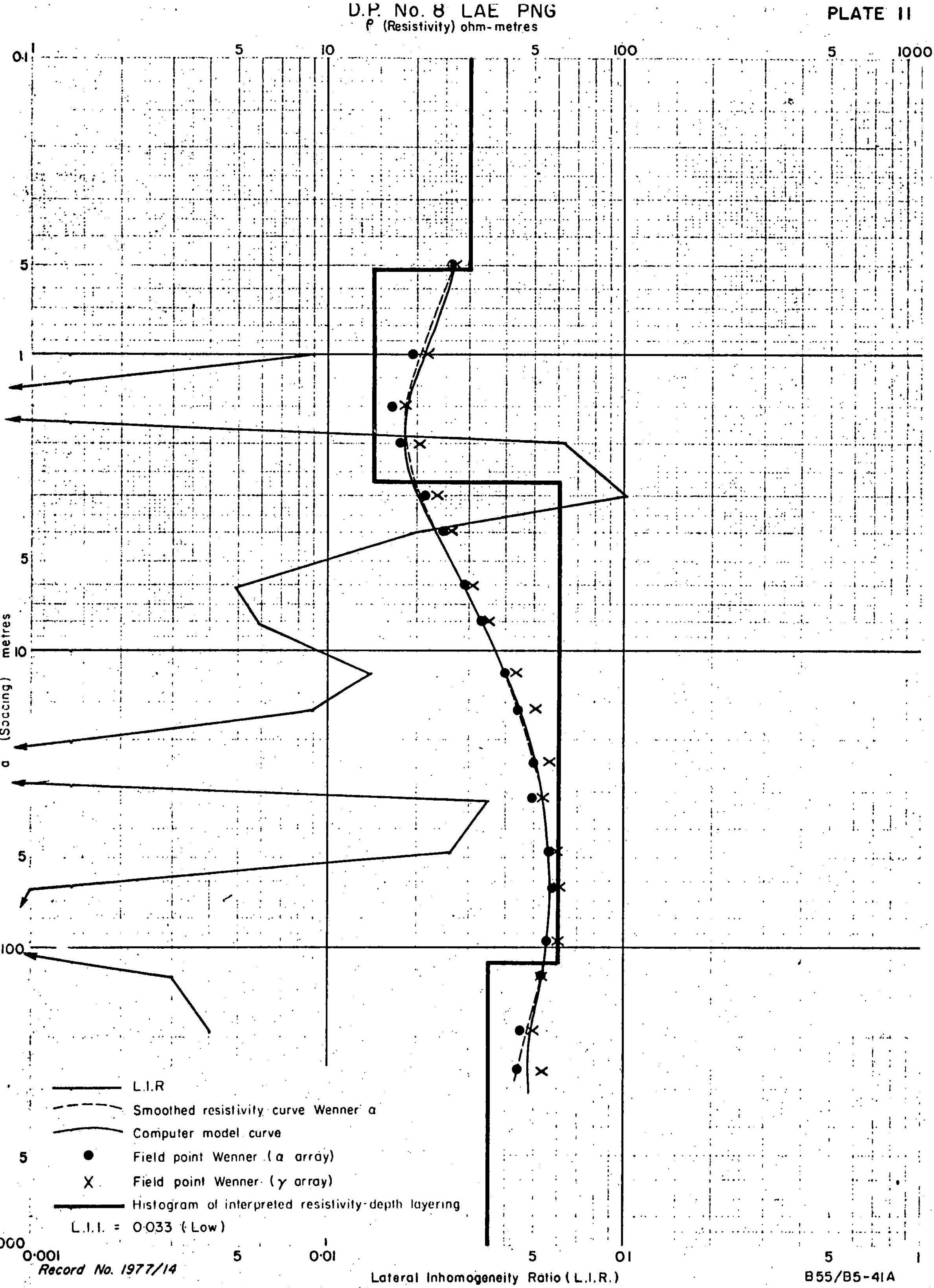
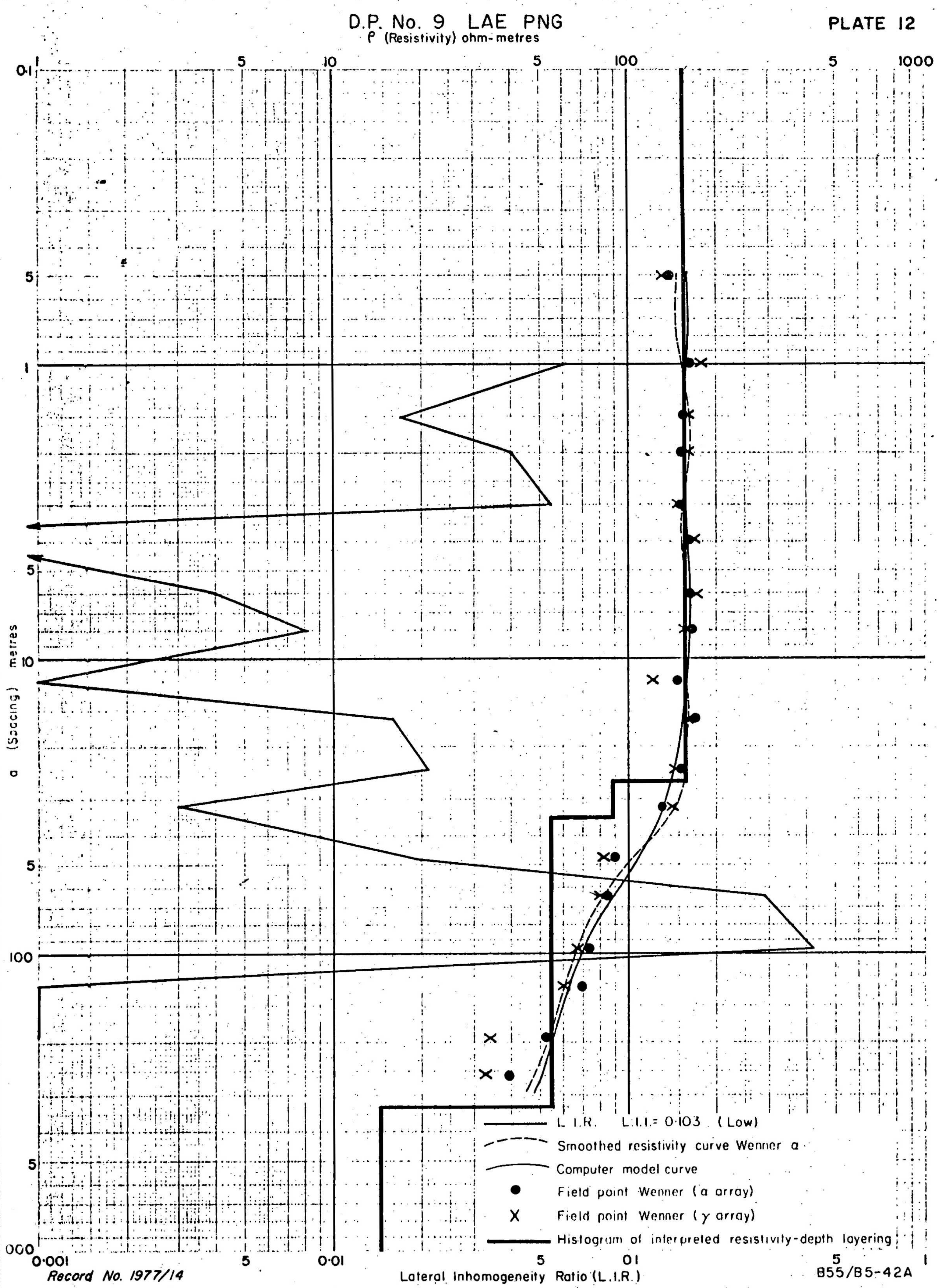
B55/B5-40A



Record No. 1977/14

B55/B5-41A

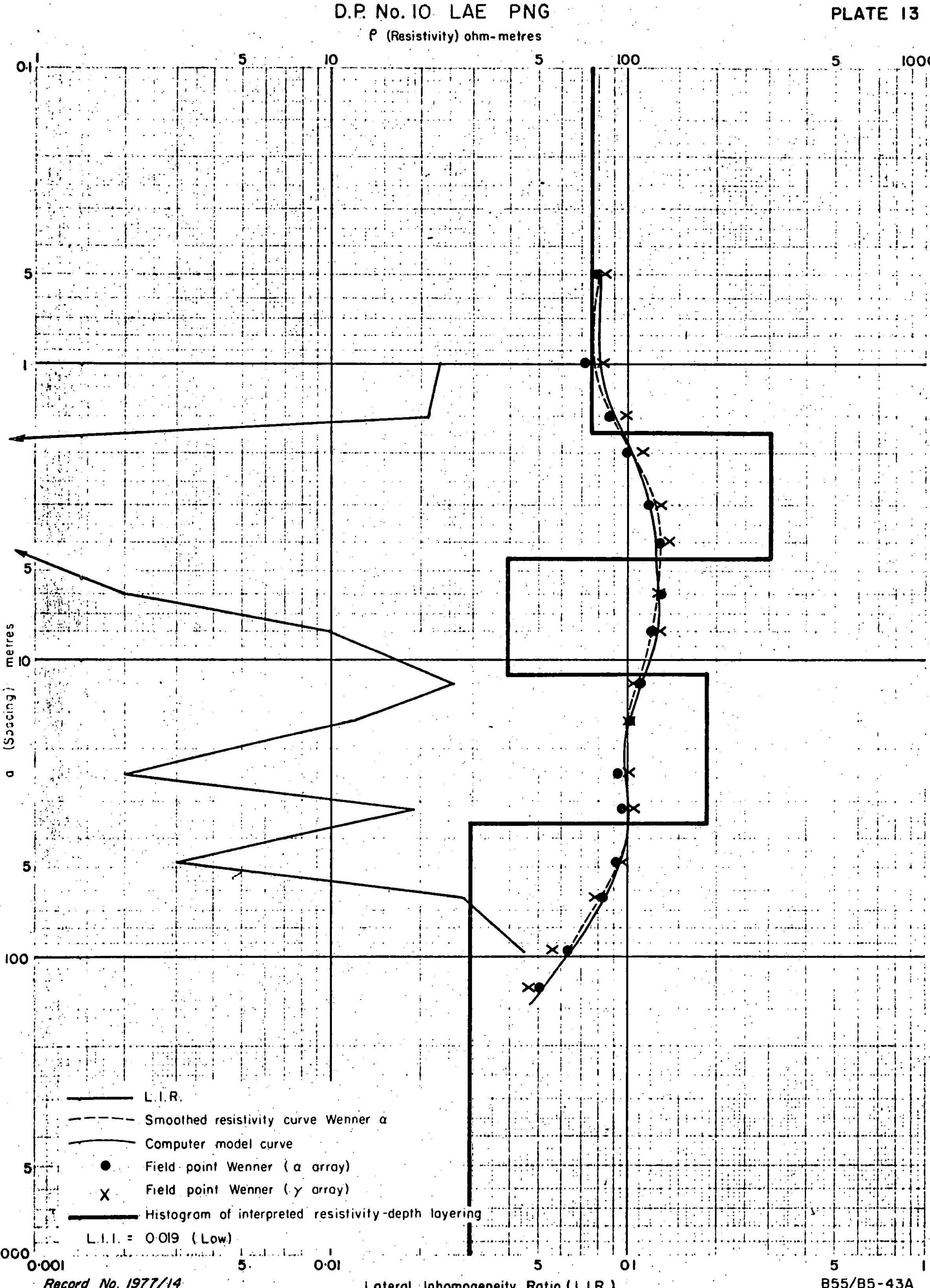
PLATE 12



Record No. 1977/14

B55/B5-42A

PLATE 13

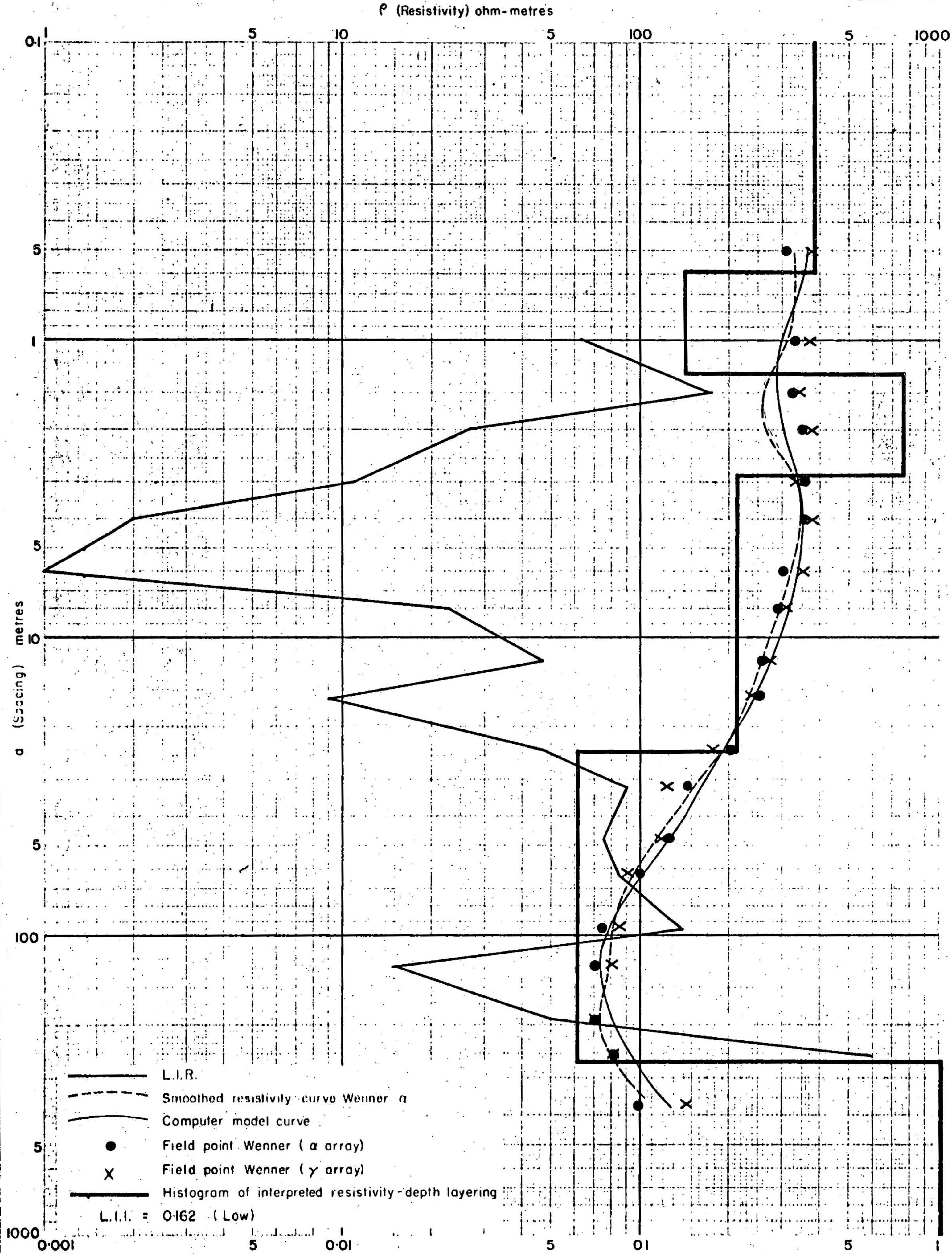


Record No. 1977/14

B55/B5-43A

D.P. No. 11 LAE PNG

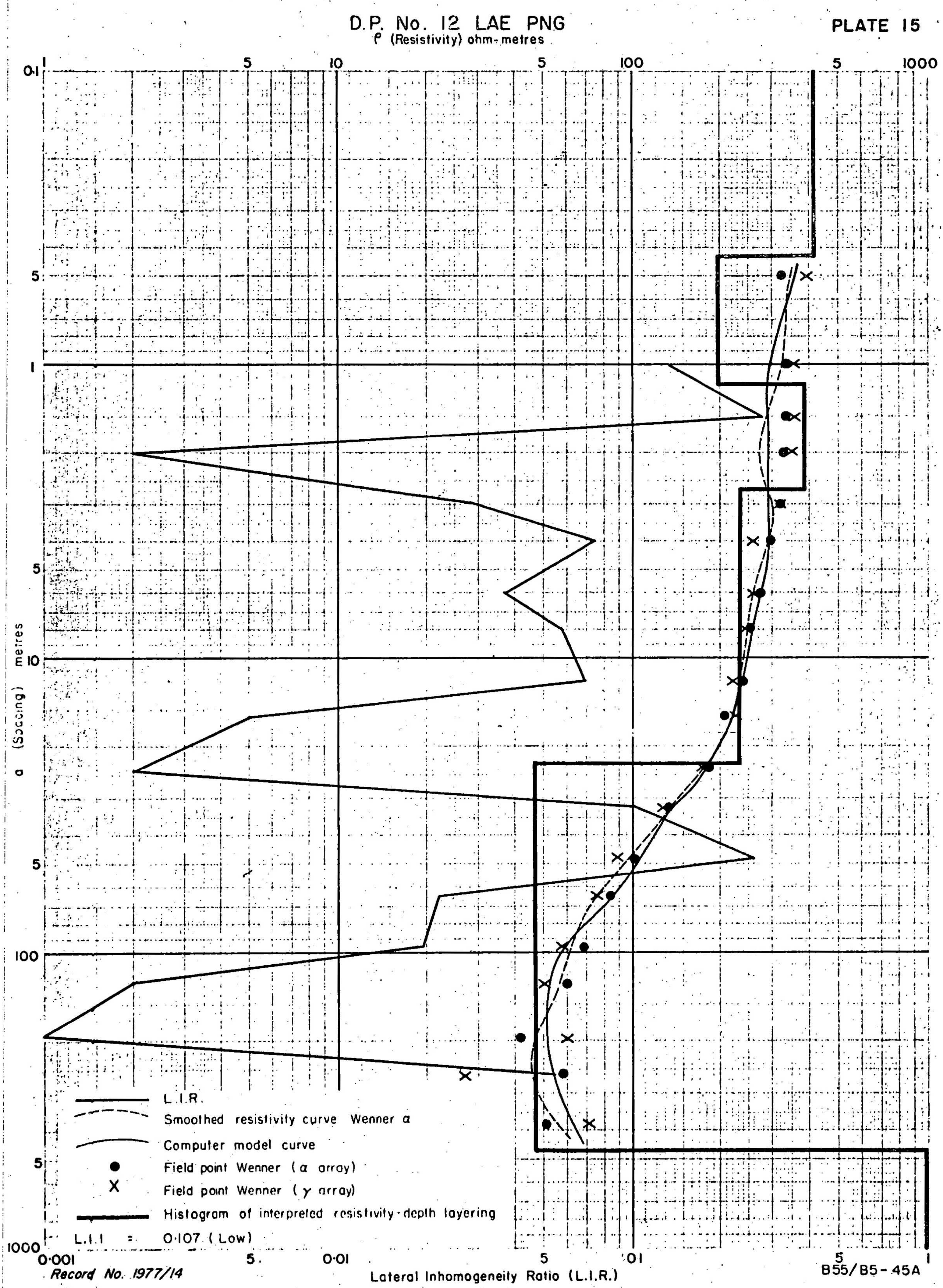
PLATE 14



Record No. 1977/14

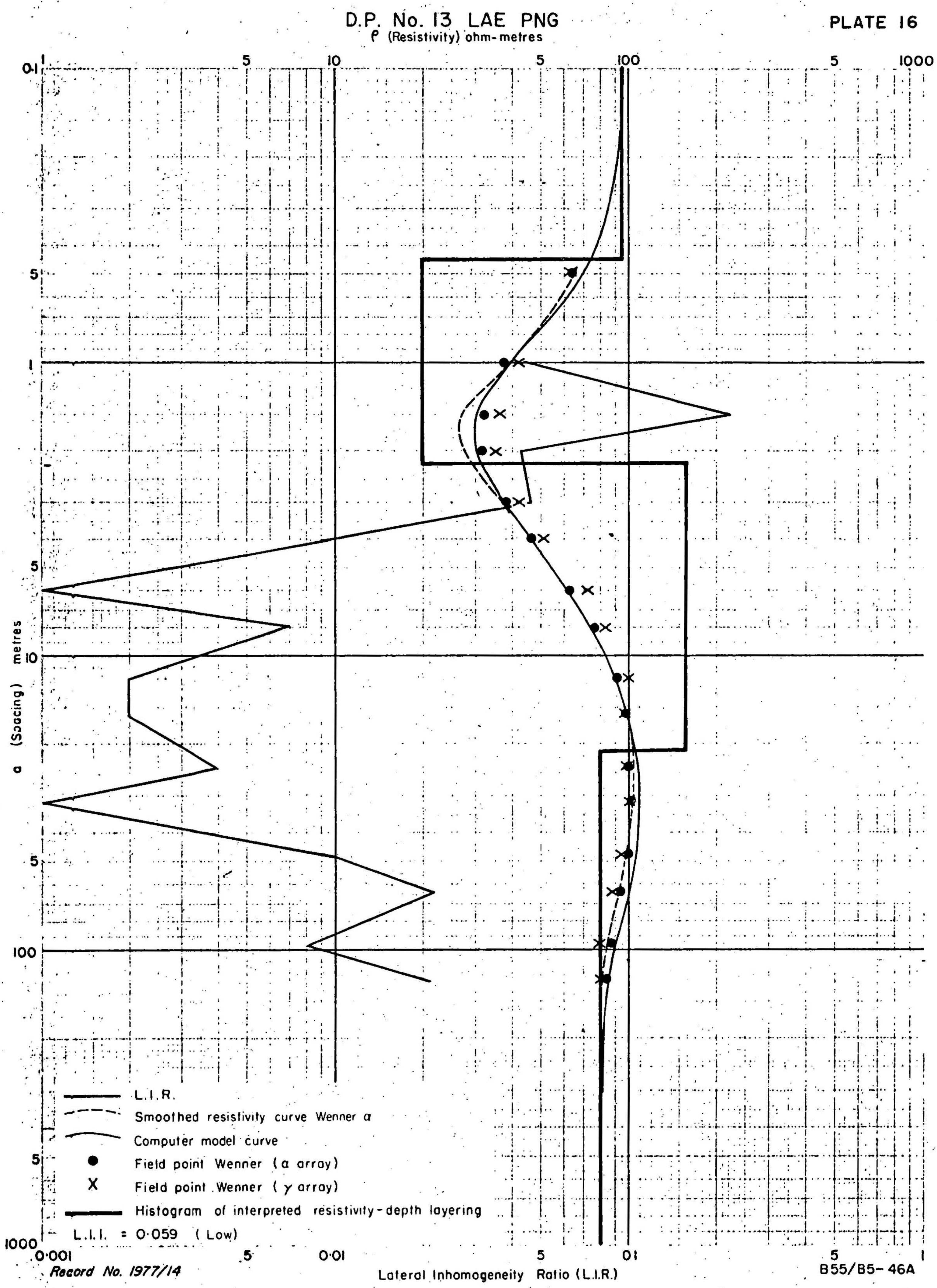
B55/B5-44A

PLATE 15



Record No. 1977/14

B55/B5-45A

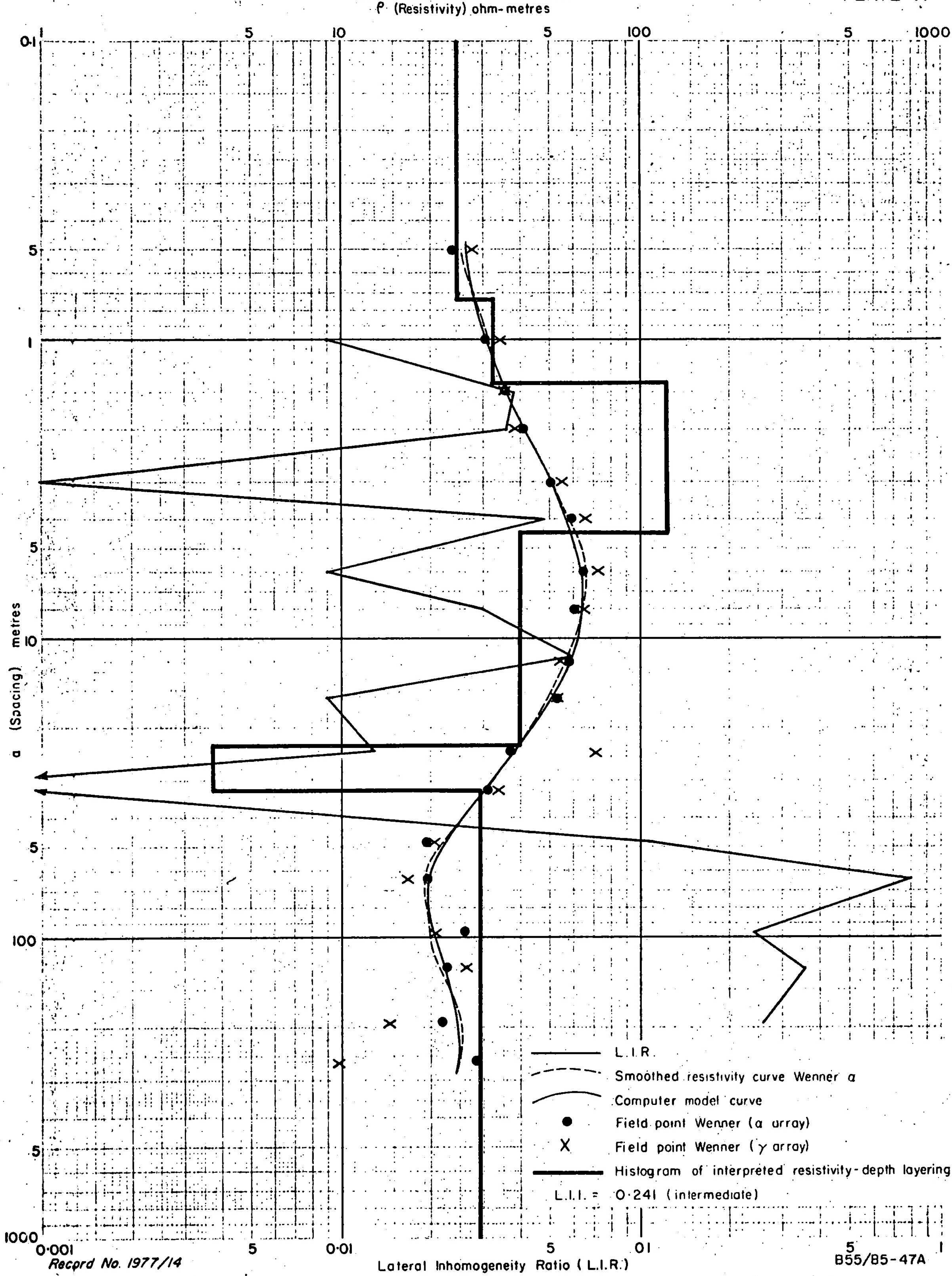


Record No. 1977/14

B55/B5-46A

D.P. No. 14 LAE PNG

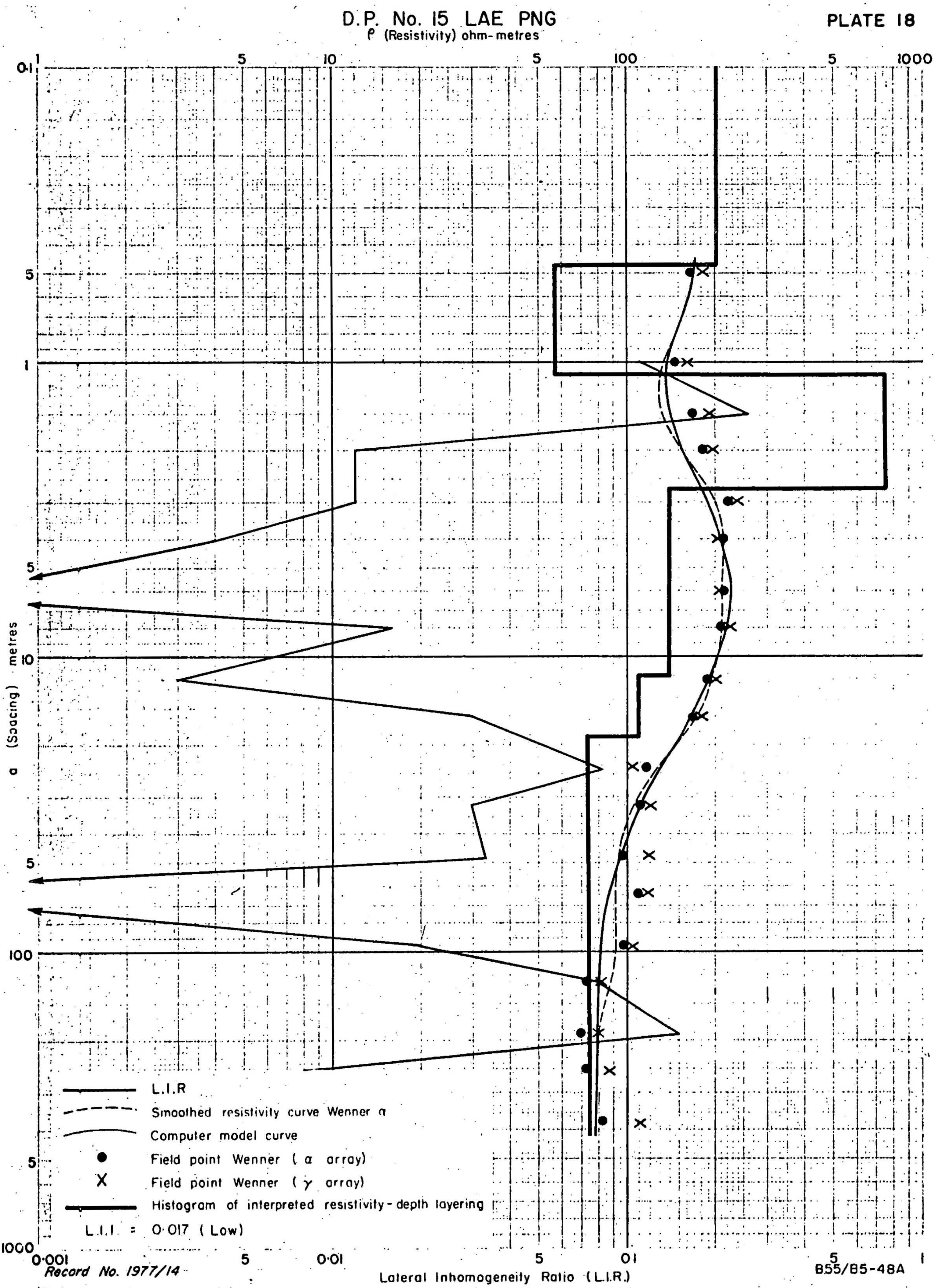
PLATE 17



Record No. 1977/14

B55/B5-47A

PLATE 18

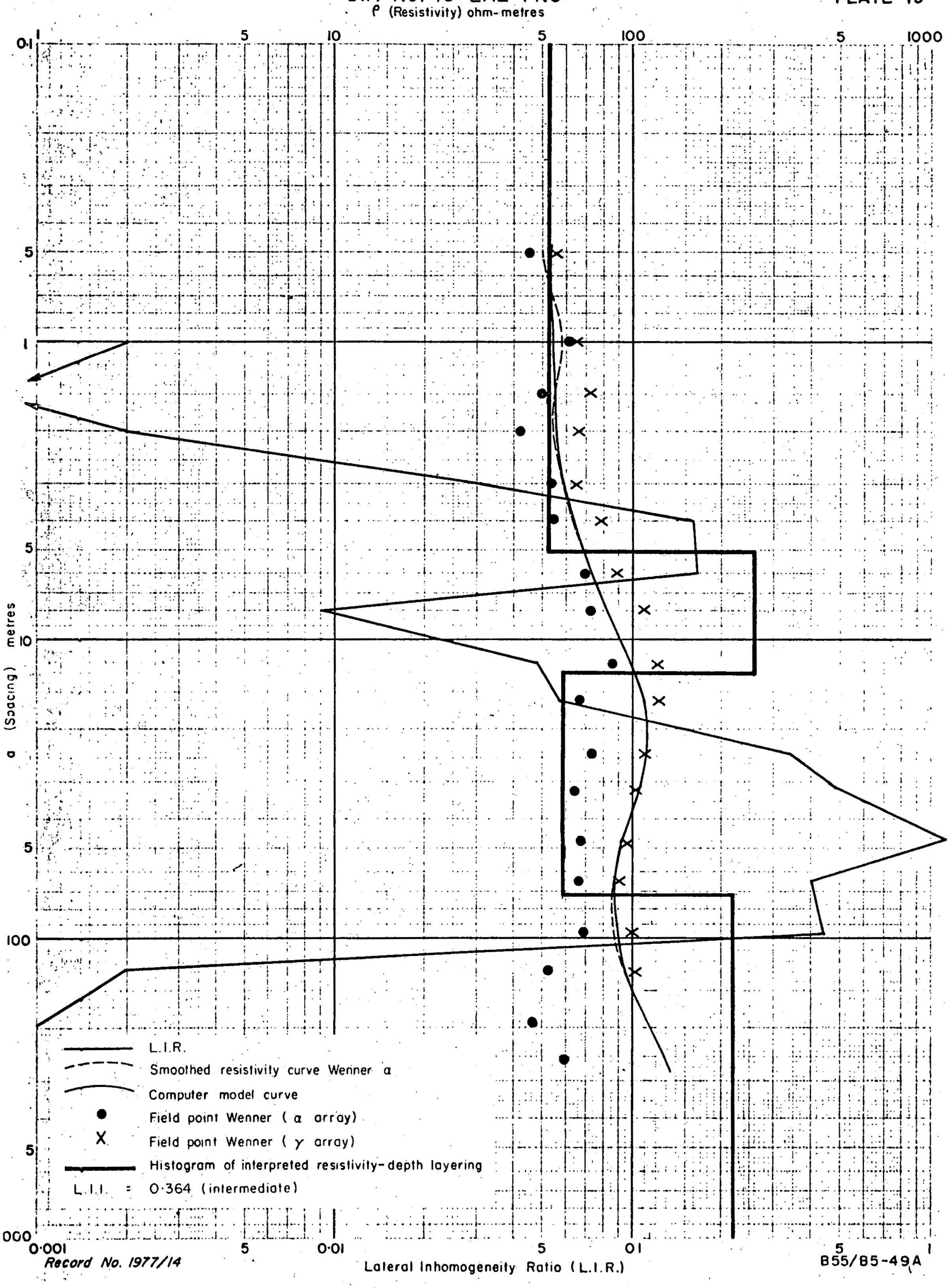


Record No. 1977/14

B55/B5-48A

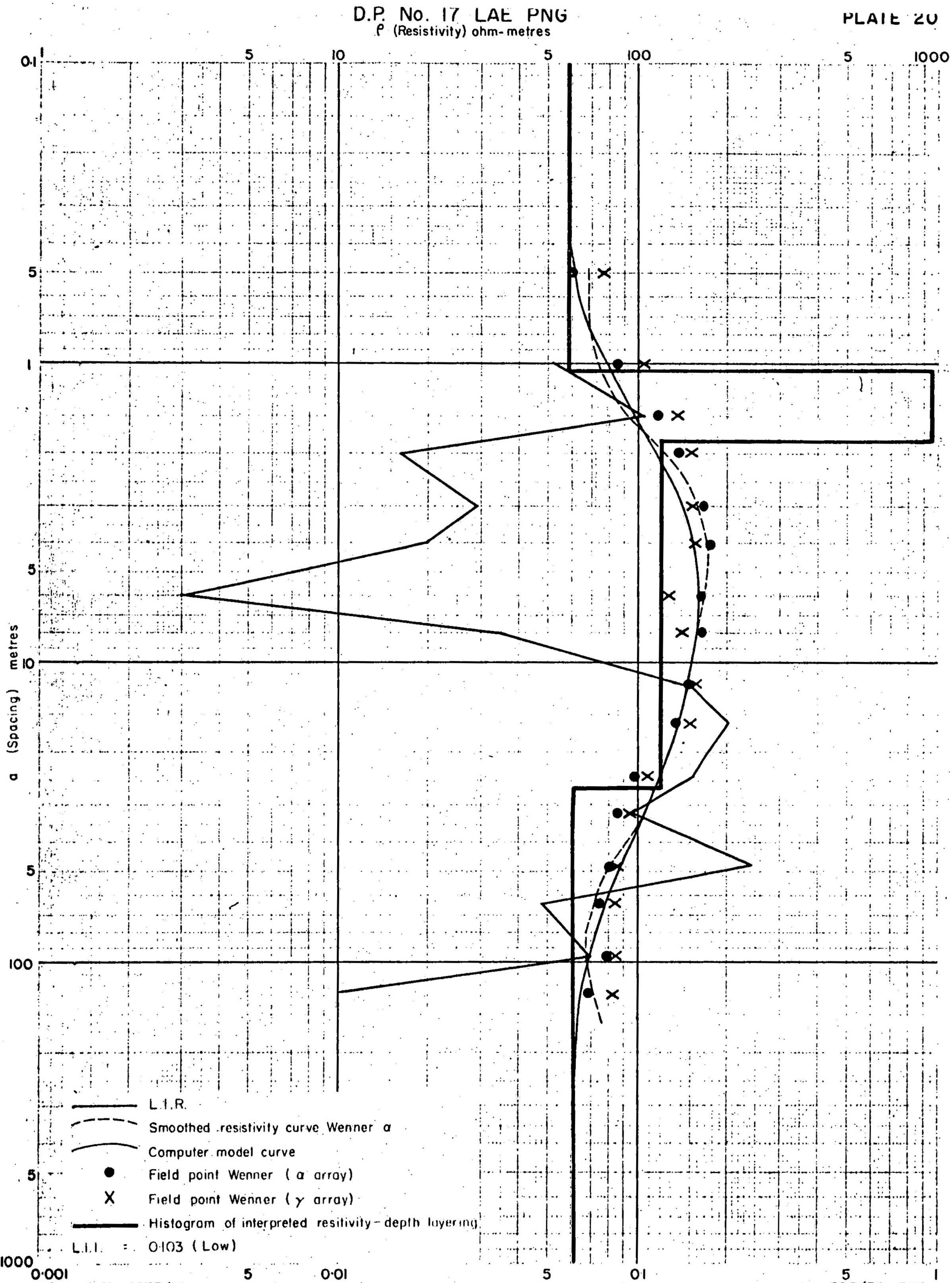
D.P. No. 16 LAE PNG

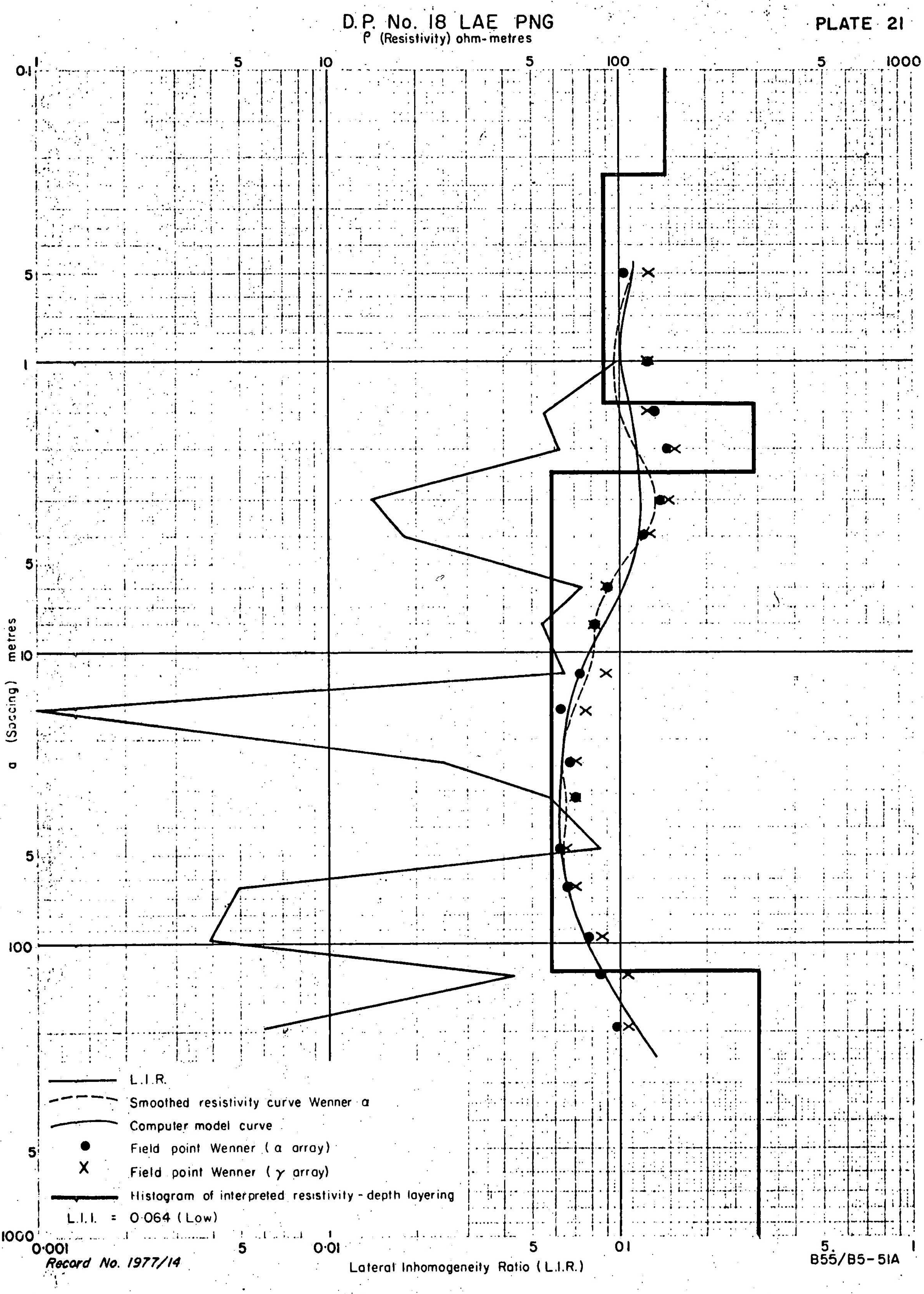
PLATE 19



Record No. 1977/14

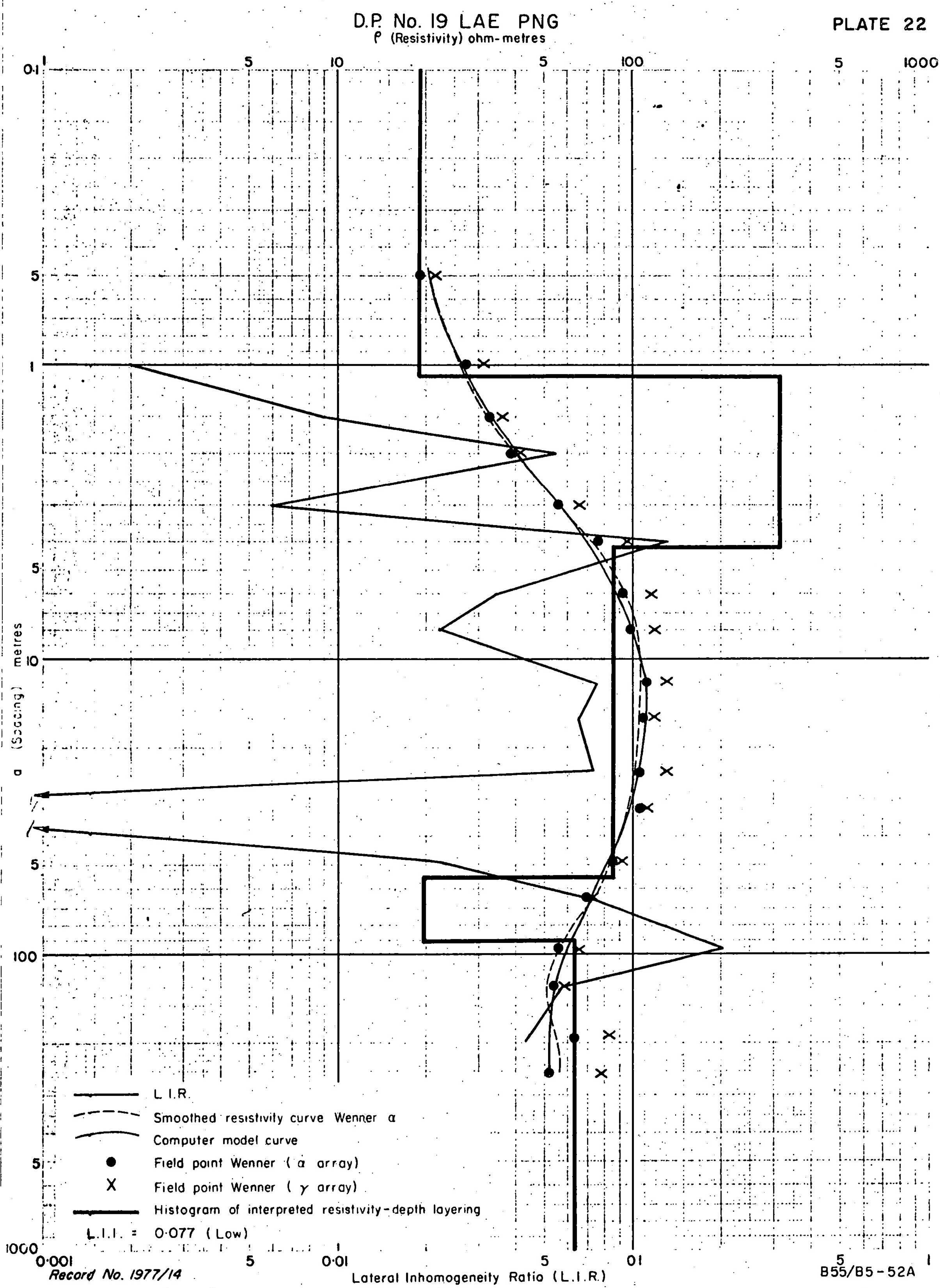
B55/B5-49A


D.P. No. 17 LAE PNG
ρ (Resistivity) ohm-metres
0·1
5
10
5
100
5
1000
1
5
10
5
100
5
1000
a (Spacing) metres
L.I.R.
Smoothed resistivity curve Wenner α
Computer model curve
Field point Wenner (α array)
Field point Wenner (γ array)
Histogram of interpreted resitivity-depth layering
L.I.I. = 0·103 (Low)
0·001
5
0·01
5
0·1
5
1
Lateral Inhomogeneity Ratio (L.I.R.)



Record No. 1977/14
B55/B5-51A

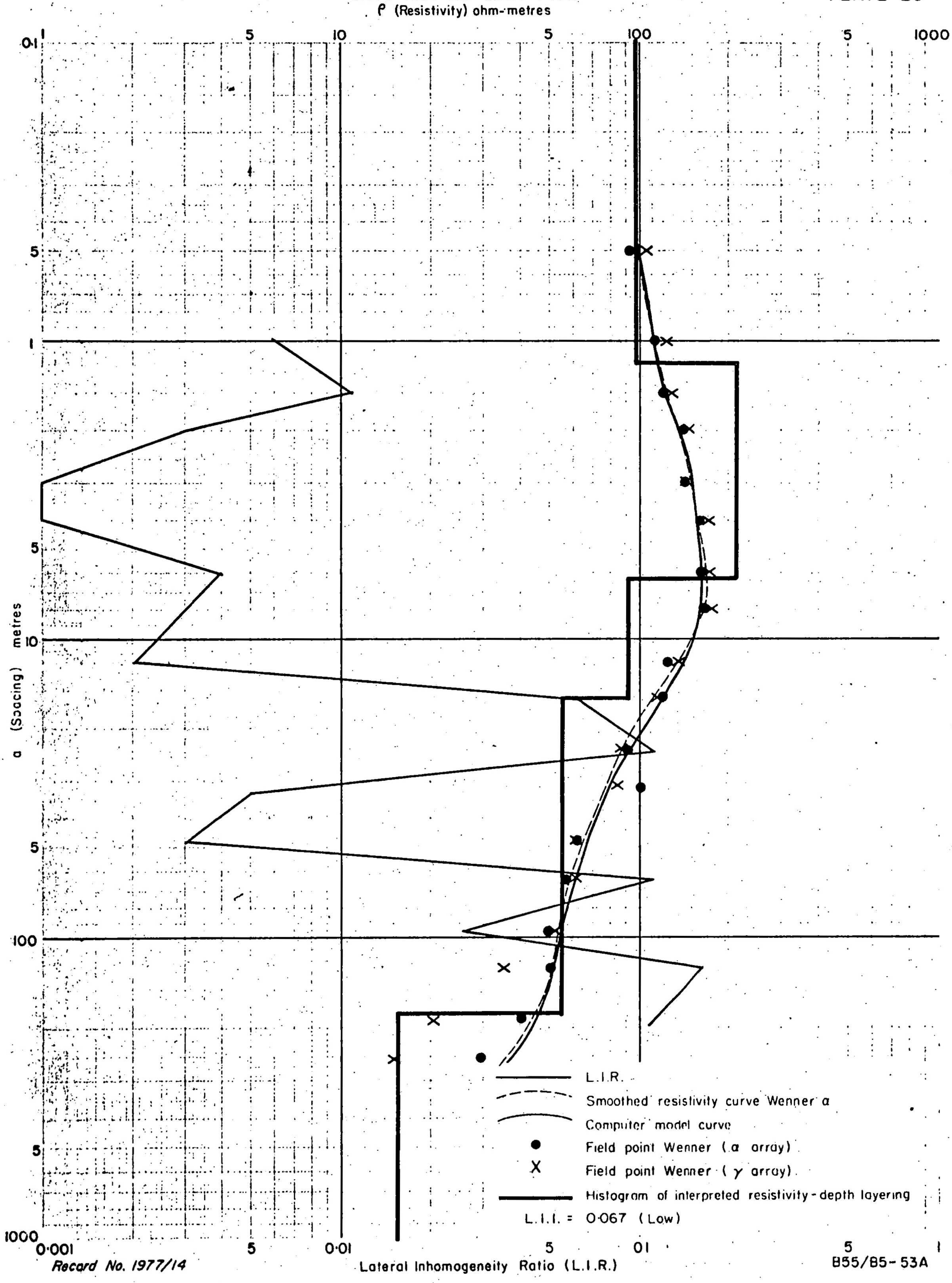
PLATE 22

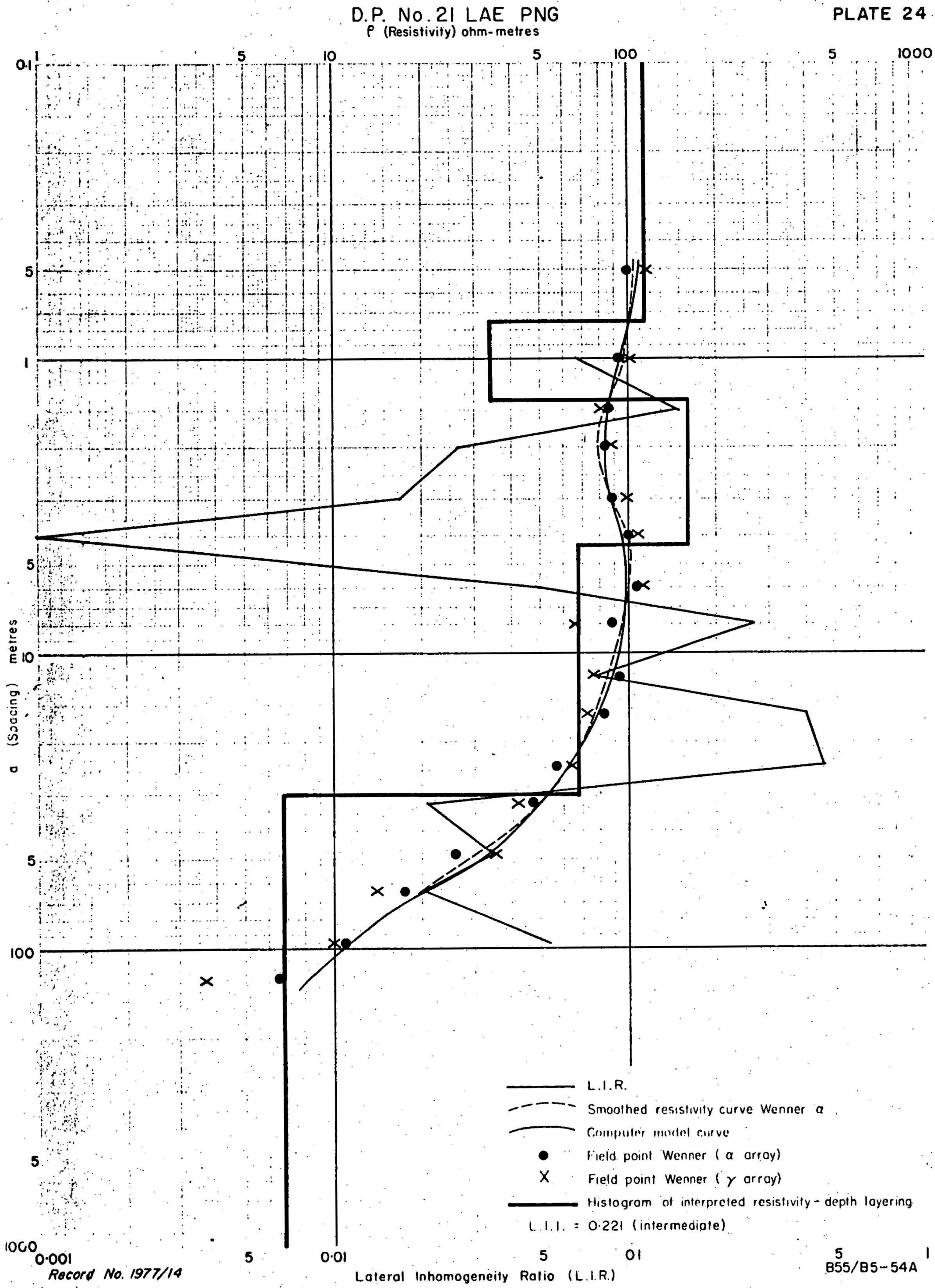


Record No. 1977/14

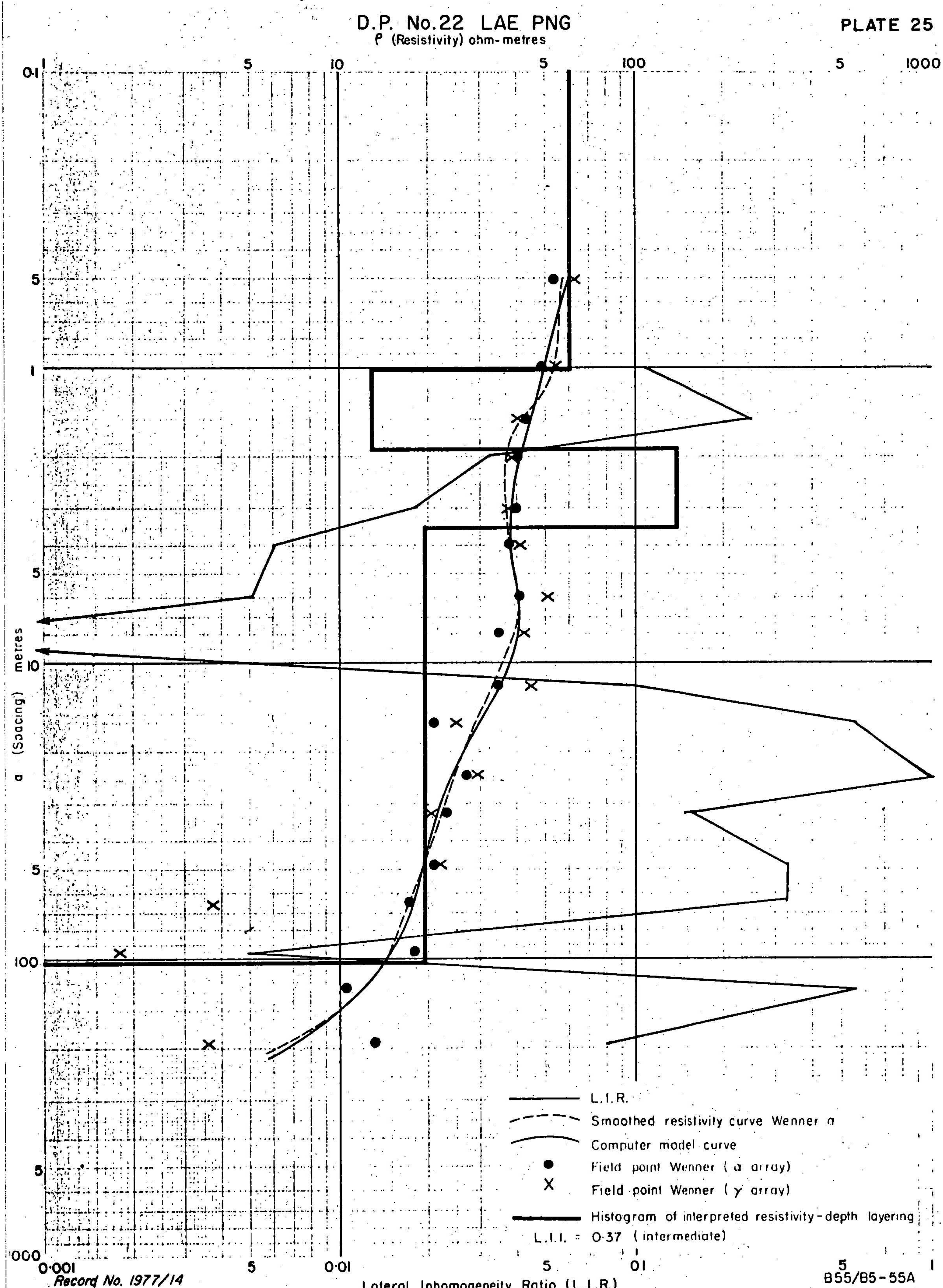
B55/B5-52A

D.P. No. 20 LAE PNG




D.P. No. 21 LAE PNG
ρ (Resistivity) ohm-metres
0.1
1
5
10
5
100
5
1000
5
1
5
10
5
100
5
1000
a (Spacing) metres
L.I.R.
Smoothed resistivity curve Wenner α
Computer model curve
Field point Wenner (α array)
Field point Wenner (γ array)
Histogram of interpreted resistivity - depth layering
L.I.I. = 0·221 (intermediate)
0·001
5
0·01
5
0·1
5
1
Lateral Inhomogeneity Ratio (L.I.R.)

B55/B5-54A

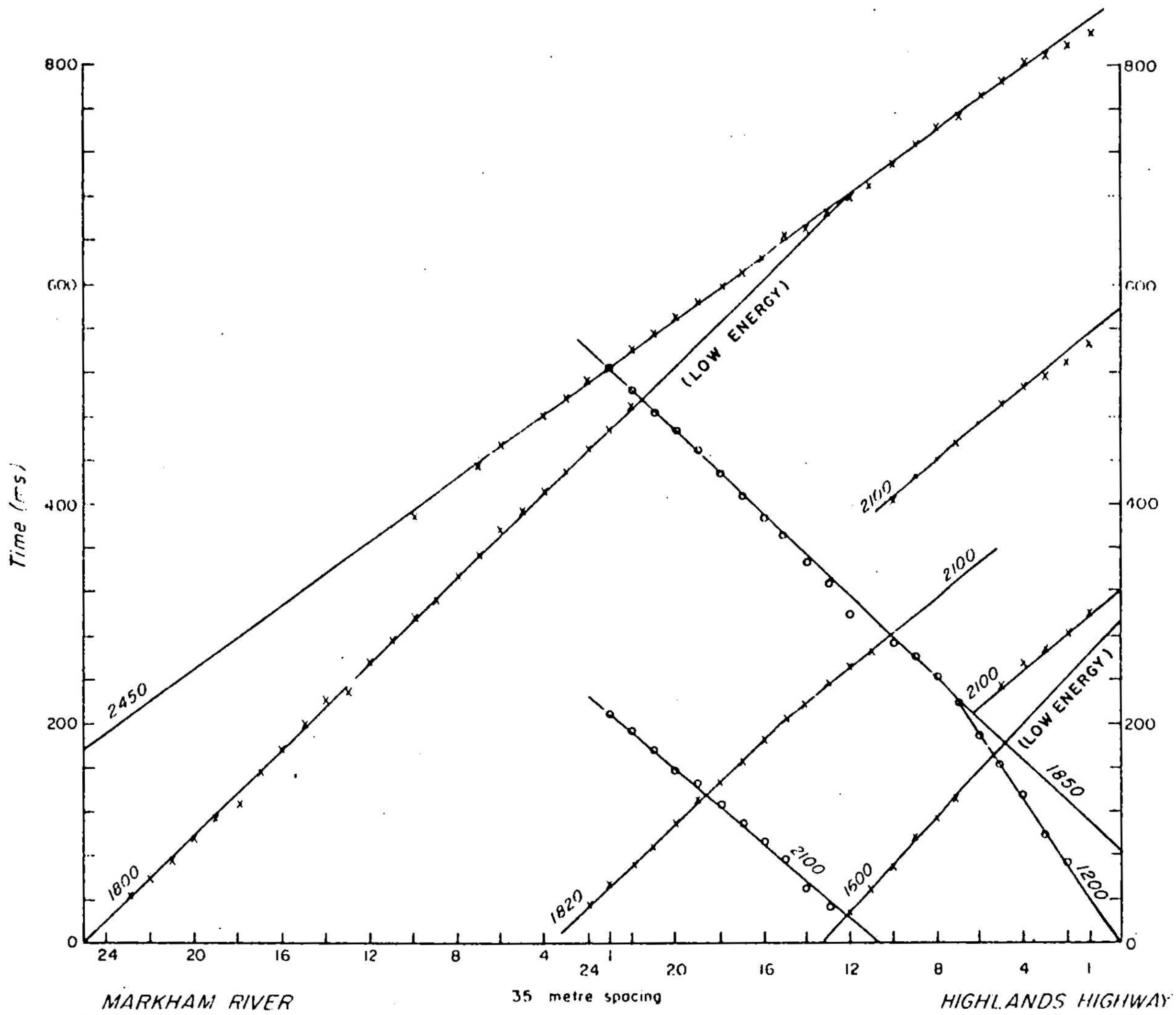


Record No. 1977/14

B55/B5-55A

T	V	Depth (metres)
0	1800	
176	2450	233·5

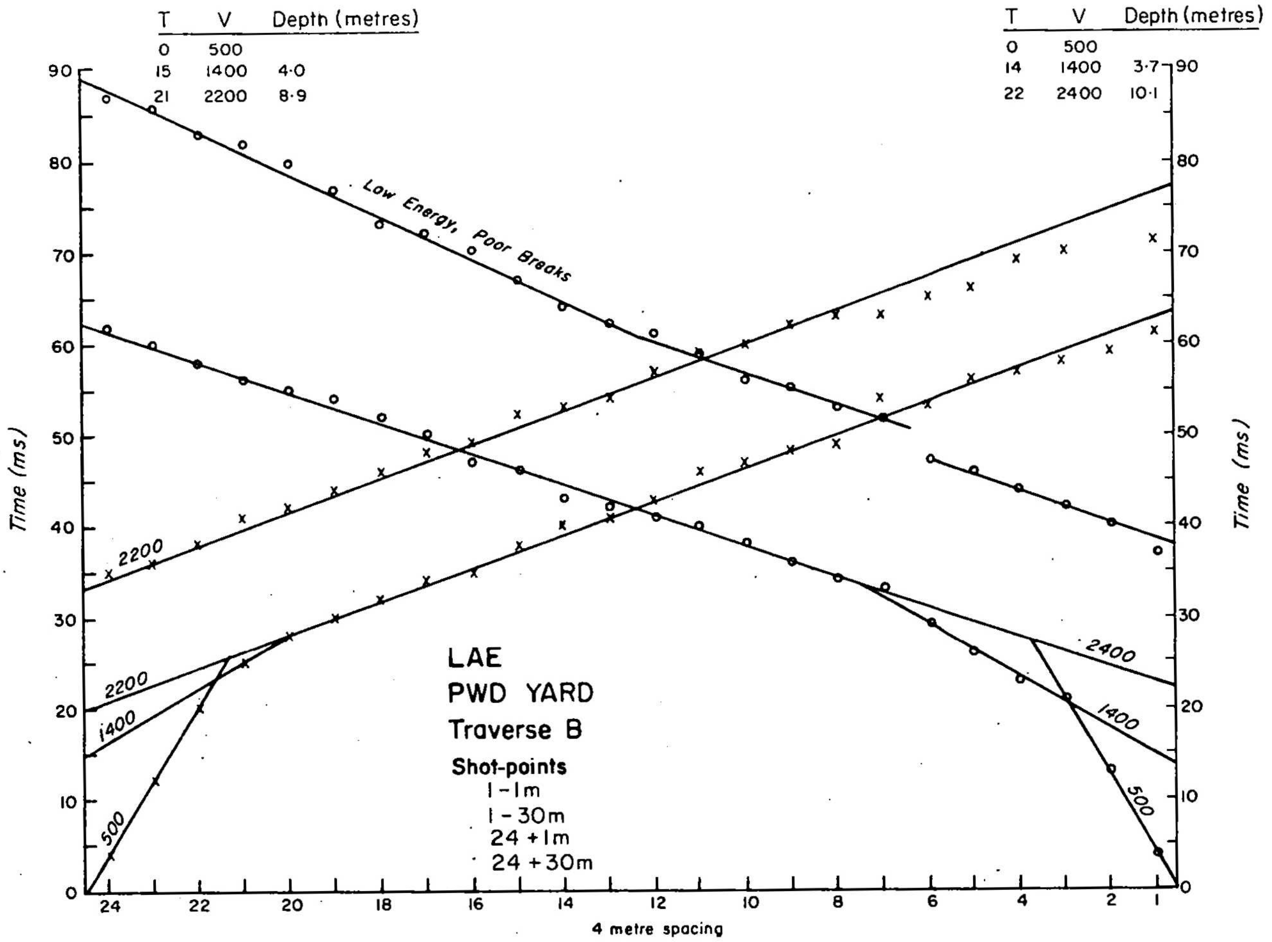
T	V	Depth (metres)
0	1200	
92	1850 (APPARENT)	72·5

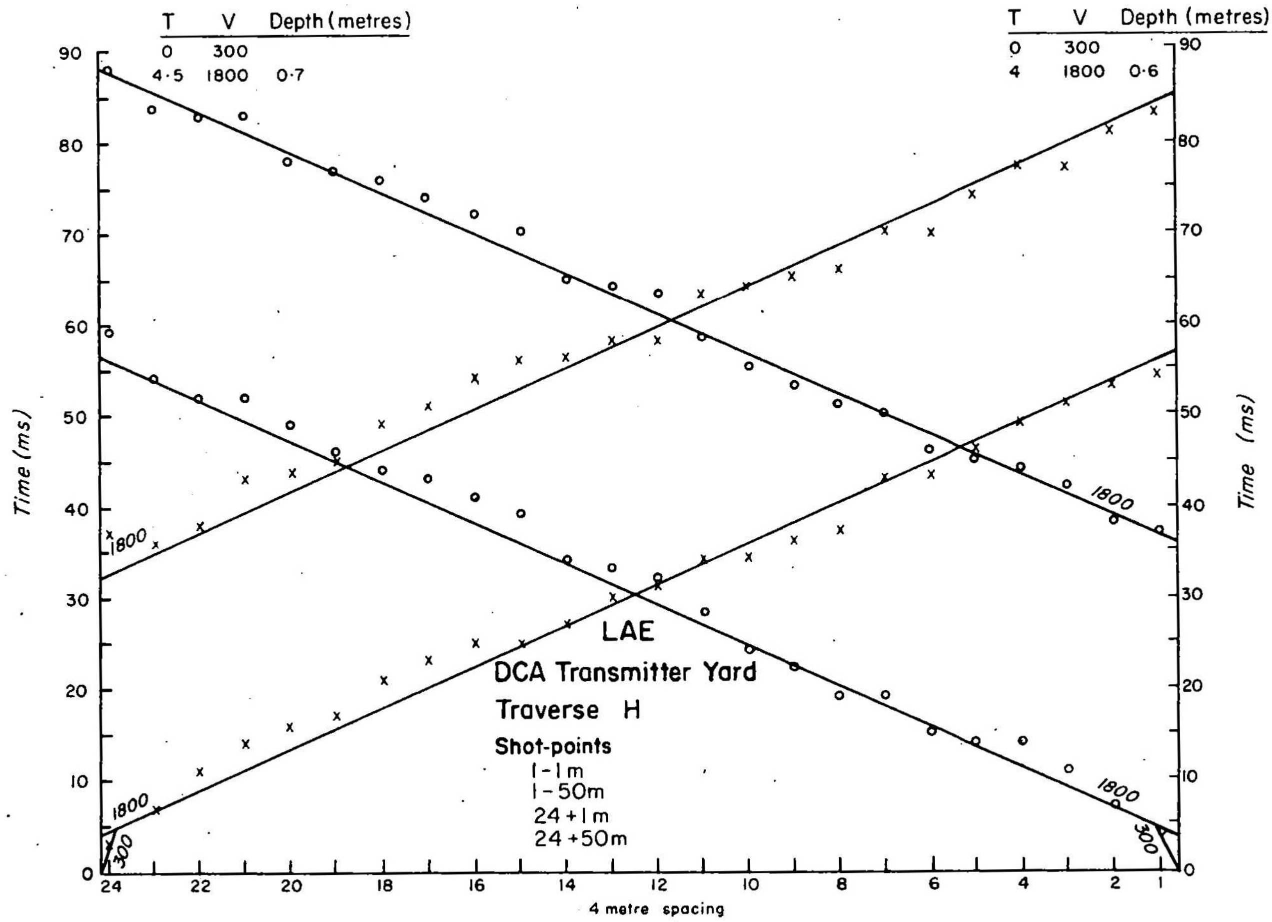


SHOT-POINTS
24 + 35 m

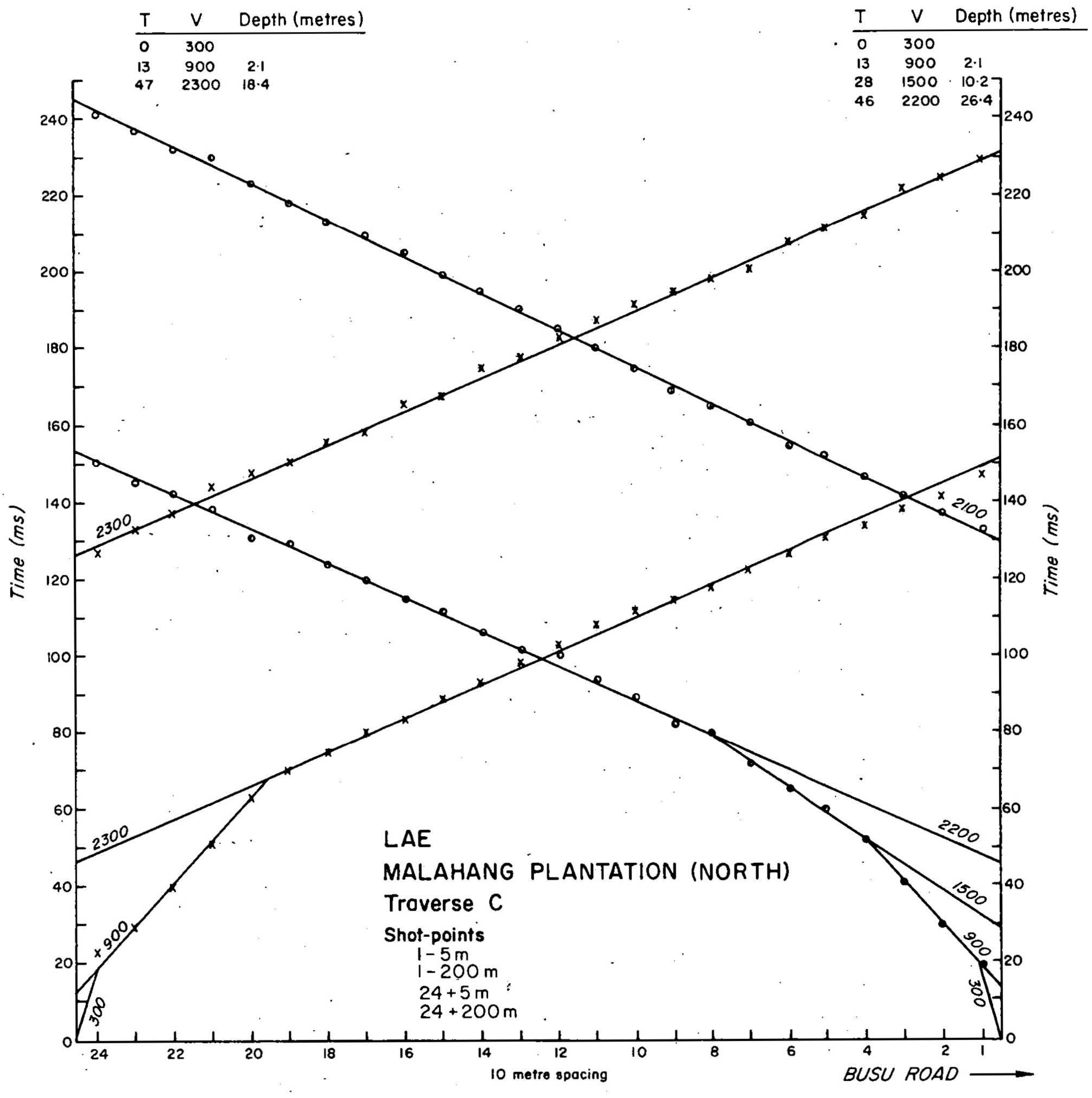
SHOT-POINTS
24 + 805 m
24 + 35 m
12 - 13 m
1 - 50 m

SEISMIC TRAVERSE A, MARKHAM RIVER SWAMP - EVANGELICAL MISSION, LAE

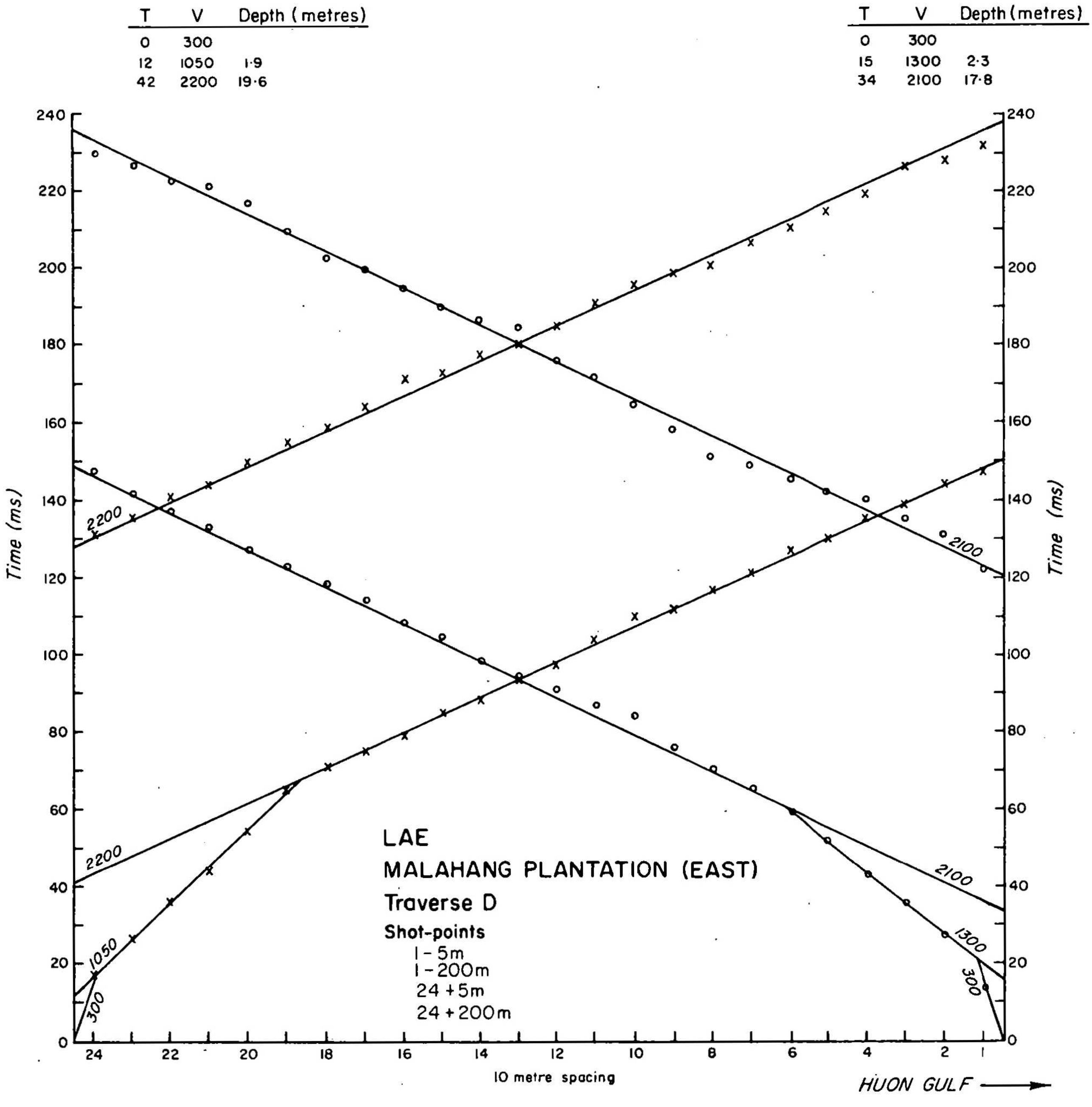




SEISMIC TRAVERSES B AND H



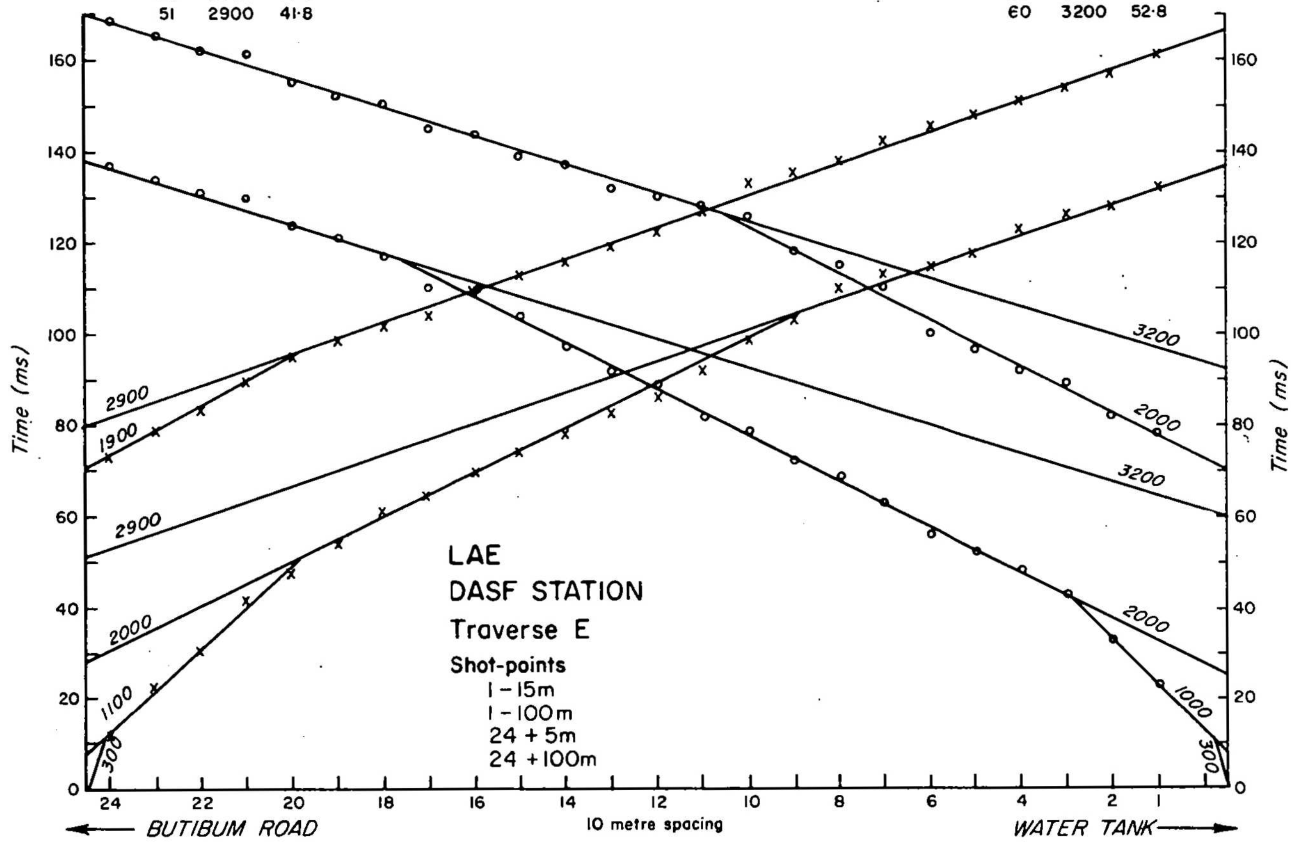
SEISMIC TRAVERSE C



SEISMIC TRAVERSE D

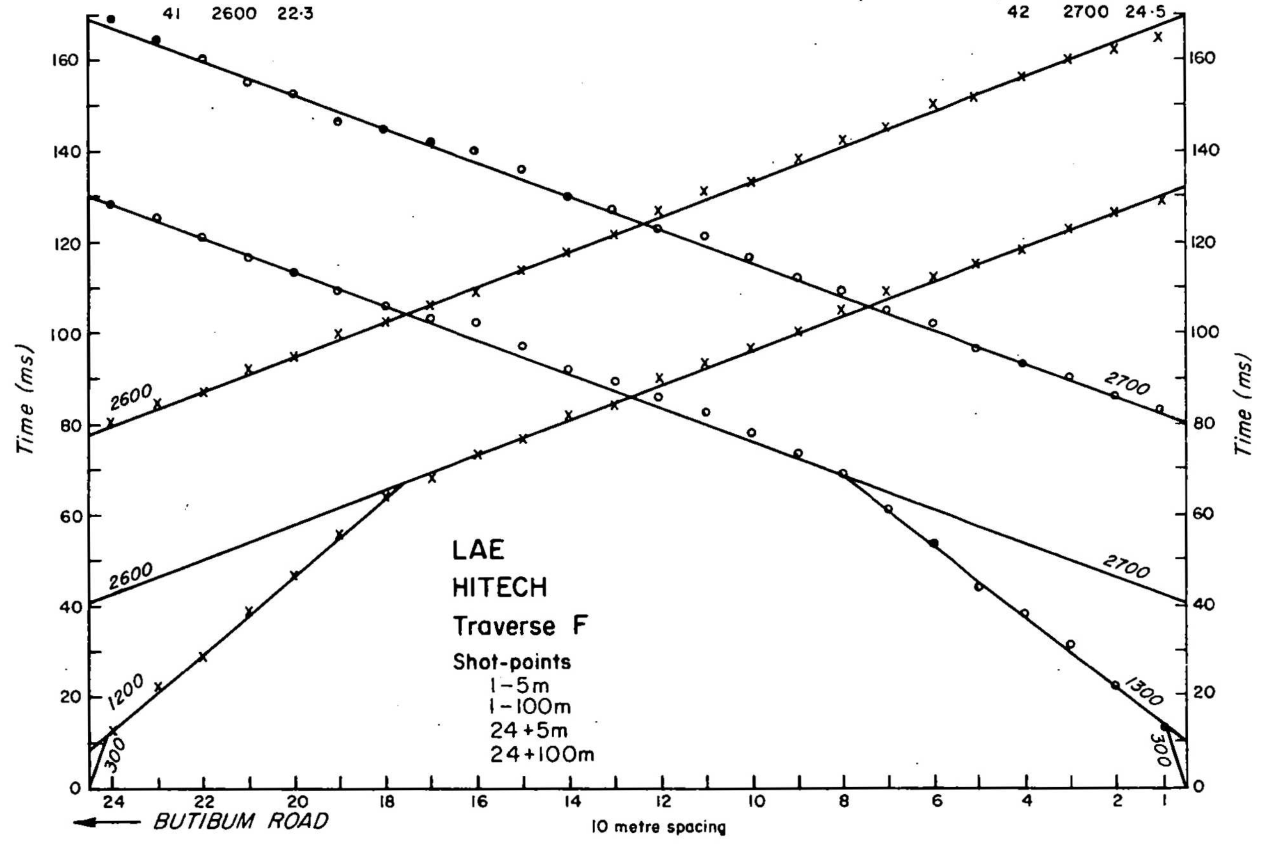
T	V	Depth (metres)
0	300	
9	1100	1·4
29	2000	14·4
51	2900	41·8

T	V	Depth (metres)
0	300	
8	1000	1·3
26	2000	11·5
60	3200	52·8

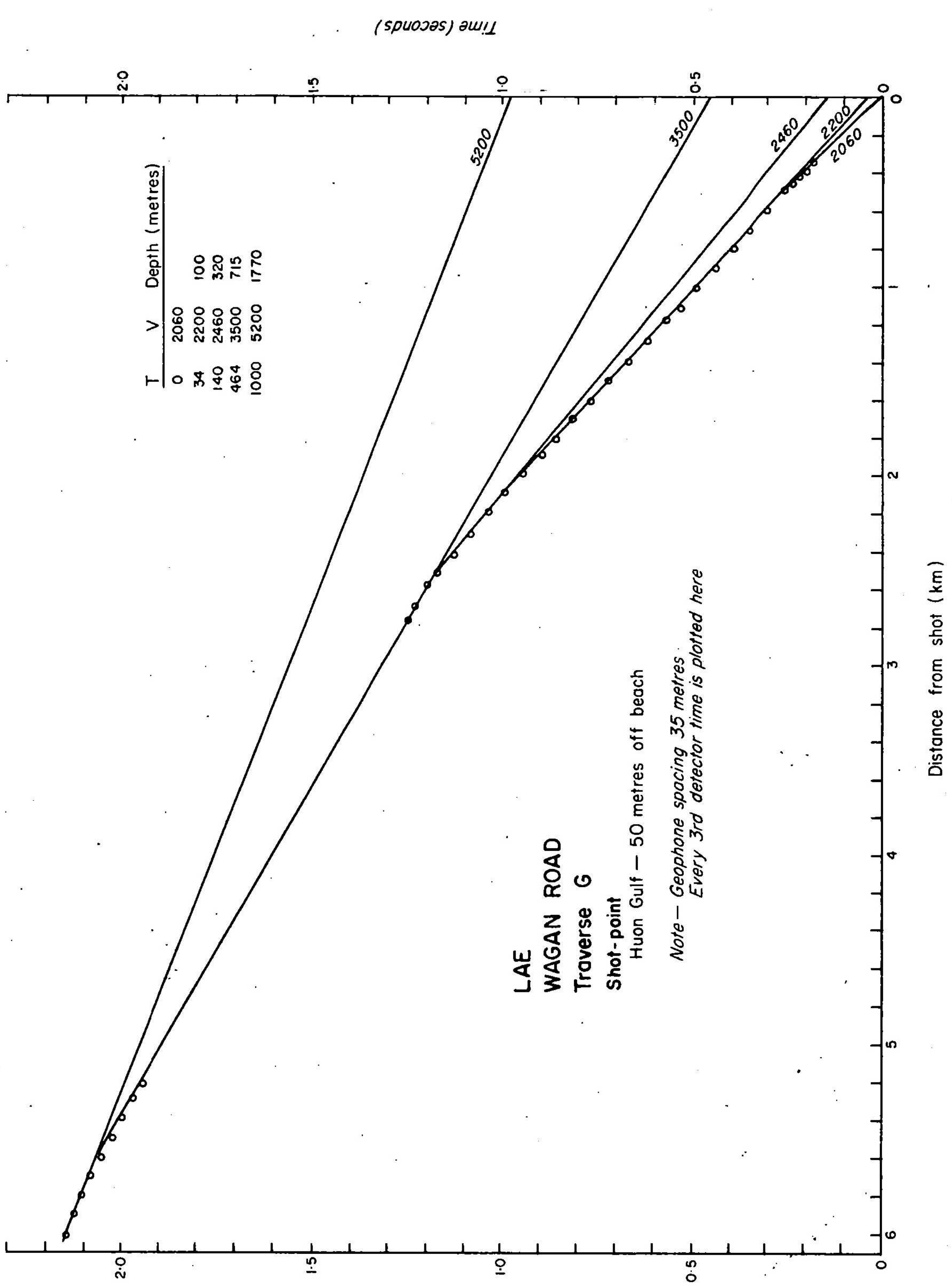


T	V	Depth (metres)
0	300	
10	1200	1·5
41	2600	22·3

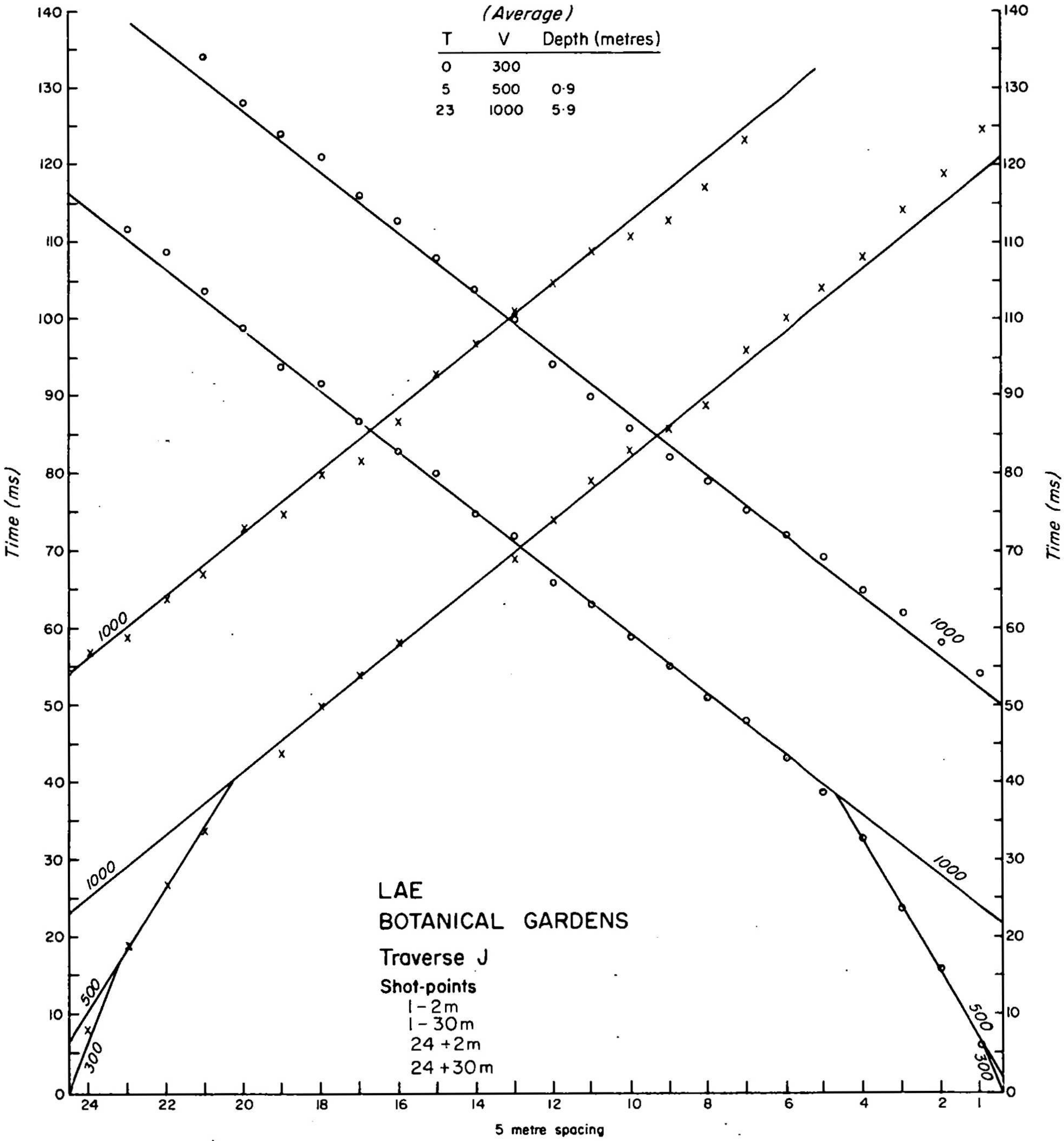
T	V	Depth (metres)
0	300	
11	1300	1·7
42	2700	24·5



SEISMIC TRAVERSES E AND F



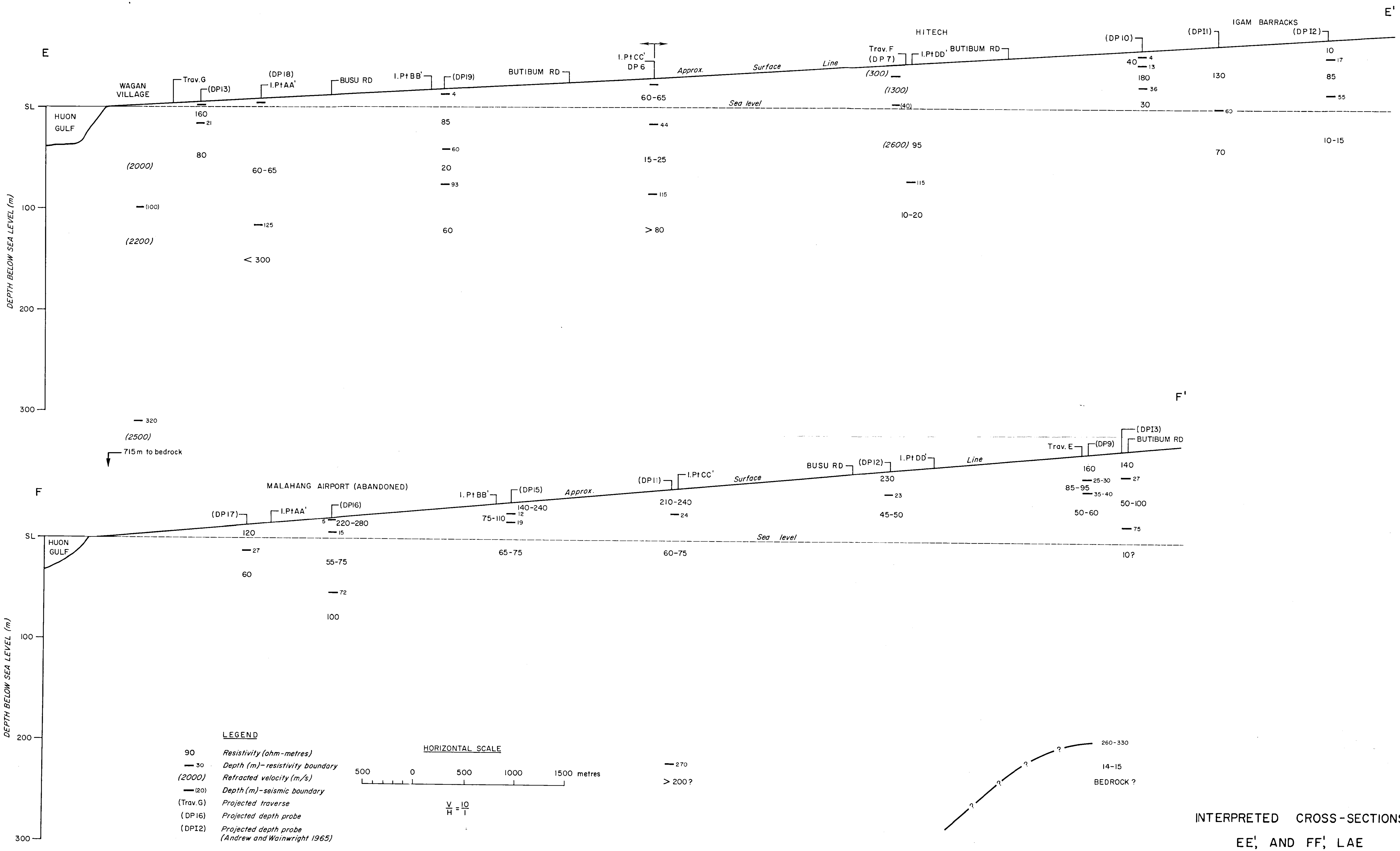
SEISMIC TRAVERSE G



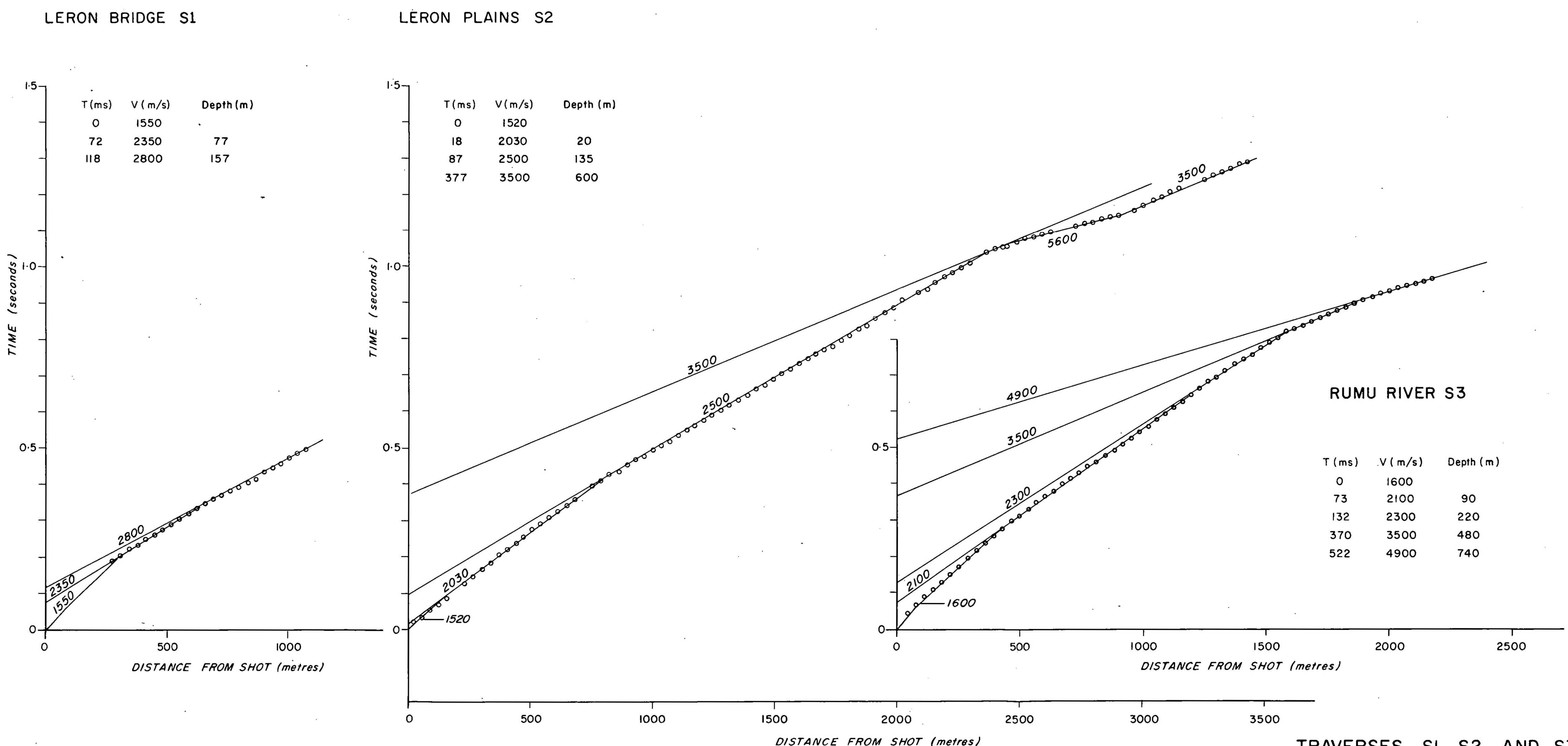
SEISMIC TRAVERSE J

INTERPRETED CROSS-SECTIONS

AA', BB', CC', AND DD', LAE



INTERPRETED CROSS-SECTIONS EE', AND FF', LAE



LERON BRIDGE S1

T(ms)	V(m/s)	Depth (m)
0	1550	
72	2350	77
118	2800	157

LERON PLAINS S2

T(ms)	V(m/s)	Depth (m)
0	1520	
18	2030	20
87	2500	135
377	3500	600

RUMU RIVER S3

T (ms)	V (m/s)	Depth (m)
0	1600	
73	2100	90
132	2300	220
370	3500	480
522	4900	740

TRAVERSES S1, S2, AND S3, MARKHAM VALLEY

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