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PROCEDURE FOR ROUTINE ANALYSES AND CLASSIFICATION OF SEISMIC EVENTS AT THE HAWAIIAN VOLCANO OBSERVATORY, PART I.

by

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INTRODUCTION

Earthquakes in Hawaii are ultimately related to volcanism. Numerous earthquakes occur episodically during vigorous magmatic intrusions in the shallow parts of the volcanoes, and in lesser numbers but persistently along feeding conduits deeper in the mantle beneath. Sustained harmonic tremor accompany volcanic eruptions and magmatic movement underground. Many crustal earthquakes occur along the unbuttressed flanks of the active volcanoes in response to stresses generated by repeated magmatic intrusions. Other earthquakes are caused by long-term gravitational adjustments in the lithosphere beneath the topographic highs of the Hawaiian Archipelago.

Here, I identify and classify seismic events in time and space relative to volcanism. Swarms of high frequency earthquakes less than 5 km in depth at the summit and along the rift zones of the volcanoes are associated with vigorous rock-fracturing during magmatic intrusions. These shallow earthquakes frequently precede eruptions and may be classified "volcano-tectonic" as suggested by Latter (1981). High frequency earthquakes deeper in the crust and mantle adjacent to the presumed conduit systems of the volcanoes may also be considered as a volcano-tectonic type. Sustained harmonic tremor and the frequently accompanying swarms of long-period earthquakes are "volcanic" events that occur within the magma storage or transport systems. The shallow events in this category coincide with volcanic eruptions, shallow magma movement, and post-intrusive adjustments within the magma storage complex. Normal high frequency earthquakes further from the volcanic centers usually result from long-term processes of volcanic growth. These earthquakes are more remotely connected in time and space to active volcanism and are "tectonic." They are numerous in the deep crustal regions about 5 to 10 km in depth along the unbuttressed flanks of the active volcanoes and scattered within the lithosphere beneath the archipelago. Some of these events due to long-term gravitational stresses are significantly large and damaging, and often accompanied by aftershock activity.

At the Hawaiian Volcano Observatory (HVO), earthquakes are routinely processed for locations and coded according to geographic designations that encompass various volcanic regimes on the island. Volcanic, volcano-tectonic, and tectonic events all occur in the summit and rift zone areas of the active volcanoes Kilauea and Mauna Loa. Magma intrusions and eruptions in these potentially eruptive zones are associated with swarms of volcanic microearthquakes and tremor. Alternatively, when magmatic activity becomes infrequent, the more gradually accumulating stresses tend to be relieved by earthquakes in a "tectonic" fashion, with occasional moderate-sized shocks and aftershocks. Only tectonic earthquakes occur in the geographic areas distant from the volcanic regions. In this report, characteristic recording differences for events located in these various areas are described. The purpose is to provide fundamental information for a preliminary assessment of location and relevance to volcanic activity in addition to later computer reduction of the data. Seismic data processing in Hawaii is an evolutionary development adapted to changes in instrumental technology and concepts in volcanology. The procedure described here was most applicable prior to 1979.

SEISMIC NETWORK AND PROCEDURES FOR SEISMIC ANALYSIS

Signals from an islandwide network of 47 stations are telemetered to the Hawaiian Volcano Observatory and recorded on six smoke drum recorders, three helicorders, two Develocorders, and a magnetic tape recorder. Detailed description of the seismic instrumentation is furnished in Hawaiian Volcano Observatory Summary 79 (Nakata and others, 1980). The records are routinely changed each morning at 0800 to 0900 and scanned. Thus, a preliminary assessment of the seismicity is made on a day-to-day basis primarily to evaluate the current state of the volcano. Secondarily, the seismograms are inspected for teleseisms, rockfalls, quarry blasts, instrumental problems, and a variety of less frequent events.

Smoke drum recorders and helicorders that continuously monitor seismicity in critical parts of the active volcanoes are in the central conference room at HVO where they are viewed frequently during the course of the day. When a staff member notices an unusual seismic disturbance, he immediately calls the seismic analysts to evaluate the activity. The entire staff is alerted when a seismic swarm starts, or a large earthquake occurs. A multi-speed 6-channel chart recorder is patched into six of the most critical stations from a bank of 36 stations being continuously recorded on the Develocorders. This chart recorder facilitates rapid evaluation of shallow earthquake swarms by enabling the analyst to accurately measure arrival times for the six most critical stations needed for hypocenter determinations. The rapid determination of many microearthquakes is important in outlining the location of magma intrusion, and following any migration of magma during the course of activity.

Optical drum seismographs are operated independently in locations at Uwekahuna, Hilo, and Haleakala. Because the optical system records a wide dynamic range in amplitude relatively accurately, the standard short-period Wood-Anderson and Sprengnether optical seismograms are used to measure amplitude for standard magnitude determinations. We sometimes measure P and S arrival times from the optical records, especially for earthquakes near the edge or outside the seismic network. Three components of long-period seismographs are operated at Uwekahuna to monitor teleseisms.

In times of volcanic quiescence and normal seismicity, visible drum records are first viewed for a preliminary appraisal of the seismicity. This is followed by a more accurate and detailed evaluation of more telemetered stations by scanning and reading the Develocorder microfilms. Amplitude and arrival time measurements from optical drum seismographs are then added to the data. Final processing of earthquakes includes phase picks from digitized tape records of the entire seismic network and computer determination of location and magnitude.

Smoke Drum Records and Types of Recorded Events

Smoke seismographs at HVO include drum recorders that revolve at a speed of 60 mm per minute with a 2-second downward deflection to mark the minute onset, and a 4-second downward deflection to mark the hour onset. Each revolution is 15 minutes long. The date, hour, minute, and station name are written at the top of the record when it is put on, and then again at the bottom when the record is taken off. Signal magnification is about 20 to 40 thousand peaking at 10 to 15 Hz. The smoke drums record seismicity from selected stations located in critical parts of Kilauea. These seismograms are observed each morning first for a rapid evaluation of the previous day's activity. Shallow microearthquakes from various localities are recognized on (1) station NPT in the summit caldera area, (2) station AHU in the south summit area and Koae faults, (3) station PAU in the upper east rift zone, (4) station HUL in the mid-and-lower east rift zone, (5) station DES in the southwest rift zone, and (6) station MLO in generally the central parts of the island.

A typical short-period earthquake very local to the station is recorded with a sharp P-wave arrival and trace amplitude relatively large compared to the signal duration (figure 2). P and S wave separation is generally too small to be measured. The signal frequency of nearby events is about 10 to 20 Hz, and attenuates rapidly to less than 5 Hz for distances over 5 km. The high frequency waves are better seen on the Develocorder film record viewed at 20X magnification. Similarly, trace amplitude decays conspicuously: at a station 5 km away the high frequency waves decay to more than half of the amplitude measured at the local station near the epicenter. Shallow earthquakes many tens of kilometers away typically show S-P intervals of more than several seconds at the summit stations, elongated signals, and amplitudes relatively small compared to the signal duration.

Deep earthquakes that originate at depths of 25 to 40 km beneath the summit region may be noticed by relatively slight differences of P-arrival times and S-P intervals. For large earthquakes, sharp P-arrivals display time differences of only a second or less across the stations MLO, AHU, and DES. Smaller deep earthquakes characteristically appear on MLO, AHU, or DES stations with sharp P and S waves separated at 3 to 4 seconds. For these events, signals at NPT often often appear weak and attenuated possibly because the seismic waves traveling to the station pass through magma zones and highly fractured rocks immediately beneath the summit caldera.

Teleseismic signals from distant earthquakes characteristically record with harmonic waves at a frequency of 1 Hz. Distant earthquakes recorded in Hawaii mostly originate from along the Pacific rim at distances of 4000 to 10,000 km, and the recording threshold is about M = 5.5. Many of the events that occur at shallow depths along the Pacific rim cause substantial underwater displacements. These often put energy in the SOFAR channel which is recorded as a T-phase. Since T-phase velocity averages 1.5 km per second as opposed to 8.2 km per second for teleseismic body waves, a typical lag time of 45 minutes to over an hour is expected. Near Hawaii, the waterborne T-phase penetrates the ground as a P-wave. The T-phase has a "cigar-shaped" harmonic signature 2 to 3 Hz in frequency. Stations along the coast closest to the earthquake epicenter record the signal earliest and strongest. Because the signal onset is poorly defined, the time of arrival is referenced to when the signal measures maximum amplitude and the phase reading is appropriately prefixed T-max.

Atmospheric and meteoric events such as wind, rain, snow, and electrical storms commonly interfere with ideal seismic operation. Wind and precipitation generally cause a continuous high frequency disturbance of 10-20 Hz that resemble harmonic tremor. These meteoric disturbances occur randomly across the network of stations without preference to those stations located near active volcanic regions with known sources of tremor. Lightning records as a sharp spike caused by the sudden electrical charge induced in the electromagnetic seismographs. Stations such as AHU and NPT which are telemetered over long cables are particularly susceptible to lightning strikes. This is because the surges picked up by the cable are readily transmitted to the sensitive seismometer components. Thunder generally follows the lightning by several seconds to a few minutes depending on the distance of the storm to the station. Disturbances from thunder show a tremor-like burst with irregular high-frequency waves about a half minute in duration.

Cultural noise caused by automobile traffic, aircraft, construction blasting, artillery firing and bombing frequently register on HVO seismograms. Kilauea stations near the main highway are subject to heavy traffic noise from 20-ton trucks that haul raw sugar from Kau to Hilo at 0400 to 1800 hours each day except Sundays and holidays, and tour buses that operate each day from about 0800 to 1600 hours. Heavy equipment noise due to occasional construction and land clearing activity may cause continuous noise during weekdays. Such surface disturbances generate locally strong signals that resemble tremor, but are strongly attenuated when recorded several kilometers away. The recorded frequency may range from 5 to 20 Hz.

Daily air tours conducted over Kilauea and Mauna Loa cause short, high frequency disturbances that generally last for a few minutes or less as the aircraft flies over the affected station. Weather permitting, an air tour in a fixed-wing aircraft goes over Kilauea summit at about 0900-1000 hours each morning, and if acoustical conditions permit, stations NPT and AHU may record a weak, half-minute long disturbance at a frequency of about 15 Hz. A helicopter tour carries passengers over the summit of Mauna Loa frequently at mid-morning hours causing our summit stations SWR, MOK, and WIL to independently record about a minute of very high frequency noise at about 30 Hz or more.

From time to time during daylight hours, construction blasting causes earthquake signals. The most regular and well-recorded signals are quarry blasts from James W. Glover Ltd. construction company's Leilani quarry in Hilo. Signals are characteristically a minute long, a centimeter in amplitude, and have a high frequency P-wave onset followed seconds later by a train of stronger low-frequency 2-3 Hz surface waves. Blasts are recorded at 1500-1600 hours on about a bimonthly schedule. Glover's blasting usually consists of numerous time-delayed charges totaling about 3500 pounds of explosives.

Military exercises at Pohakuloa that include heavy artillery firing and low-altitude bombing cause short, high frequency sonic bursts at about 15 Hz. These sonic interferences look similar to shallow microearthquakes, except that they show identical local characteristics on other stations and a long lag time due to the low 0.3 km per second velocity of sound waves in air. When high explosive 750-pound bombs are discharged, MLO station records weak seismic P-waves that precede the sonic component by over a minute. Strength of the sonic signal at any station depends on the acoustical quality dictated by atmospheric conditions that prevail over the station at the time of the event. Consequently similar patterns of artillery firing and bombing that occur on separate days at Pohakuloa are recorded differently at the seismic receivers around Kilauea. The signals are sometimes recorded strongly on all stations, and sometimes not at all. The stations that record the sonic bursts strongest one day may record the events weakest on another day.

Environmental and ground conditions that vary from place to place introduce microseismic background and cultural noise that characterize each station. MLO responds strongly to surf conditions where 1-second microseisms increase in amplitude by 2X or more during offshore storms. Located at the end of a scenic drive, the MLO station is plagued by automobile traffic during the day from about 0900 to 1700 hours. The DES station, situated about a kilometer from Highway 11, picks up truck noise from about 0400 to 1800 hours each day except Sundays and holidays. The NPT station operates with a high frequency seismometer that is relatively insensitive to normal low frequency microseisms. The station is situated at the edge of Halemaumau and frequently records rockfalls and weak disturbances from tour buses that travel around the caldera about a kilometer away. The AHU station is by far the most free from cultural noise, but is frequently subjected to high winds and electrical storms. PAU (located near the national park escape road) is subjected to heavy equipment operation and traffic noise from tour buses on the Chain of Craters-Kalapana road. The HUL station located in the lower part of the east rift zone at a privately owned vacation house is affected by passing vehicles about twice a day. Relatively weak disturbances are picked up at HUL by occasional heavy equipment operation within a few kilometers.

Certain instrumental problems are also characteristic of some stations. Due to cable telemetry, NPT and AHU are particularly susceptible to lightning storms and outages caused by cable discontinuity. MLO, PAU, DES, and HUL encounter radio telemetry malfunctions. HUL suffers an outage early each morning causing a half hour long oscillation at a high clipping level.

Helicorder Records

Helicorders display signals from three stations to supplement the six permanent smoke drum stations in areas where shallow seismic activity is concentrated. Magnification and recording format is similar to the smoke drums except the interval between revolutions is geared at half that of the usual drum traverse and one standard drum paper allows two days of recording. Since the Mauna Loa eruption in July 1975, the summit station MOK is occasionally monitored on helicorder to permit rapid and frequent assessment of seismicity there. A second area of interest is centered in the mid-east rift of Kilauea following the September 1977 eruption. Since the eruption, earthquakes continued to occur in the mid-east rift and south flank near Kalalua to warrant the operation of a second helicorder tapping the signal from station LUA. Still another area of interest has been the seismically active Kaoiki area on the southeast flank of Mauna Loa. The apparently tectonic region with persistent earthquakes called for the additional monitor of station AIN centered there.

Frequent inspections of the helicorder and smoke drum recorders enable members of the Observatory to recognize relative changes in seismicity at different parts of the volcano from day to day. Significant changes in activity, unusual events, or significantly large events are readily visible. Times of curious events are noted so that they may be evaluated in detail using more stations recorded on microfilm records.

Develocorder Films

Following a rapid examination of the smoke records, the Develocorder microfilms are read in more detail and higher precision. The film records are viewed at a magnification of nearly an order of magnitude higher than the smoke and helicorder records, at a time scale of 1 cm per second. Time marks are at 0.5- or 1.0-second intervals on the time signal. Minute marks are accompanied by the printed hour and minute. Significantly large or otherwise interesting events are generally treated first. Microfilm from the A-Develocorder is scanned starting from the take-off end so that the most current hours of the day's record are examined first. As the film is scanned hour-by-hour and backwards in time, the number of earthquakes are classified into geographical subdivisions. Discrimination is by P-wave arrival differences in the densely monitored active parts of Kilauea and Mauna Loa volcanoes. Some of the events are further classified according to their signature characteristics (i.e., long period, or short period).

To aid in rapid identification of earthquakes, stations critically located in active parts of the volcanoes are recorded on the A-Develocorder, and where possible, arranged on the film in order of geographically adjacent stations. Consequently, stations MOK, WIL, and SWR, used to identify microearthquakes at the summit of Mauna Loa, are placed on adjacent channels in the upper part of the format. Station PLA, examined with other upper Mauna Loa stations, identifies northeast rift events and is placed on a lower channel next to SWR. The traces even lower on the film distinguish earthquakes from various parts of Kilauea: (1) station NPT monitors summit earthquakes; (2) stations HUL and PUK monitor mid-east rift earthquakes; (3) stations AHU, ESR, PAU, and MPR monitor upper east rift earthquakes; (4) DES and PPL monitor southwest rift earthquakes; and (5) station PHO monitors lower east rift earthquakes. Other stations on the A-film such as HLP and KPN identify earthquakes originating from the Koae faults, and differentiates shallow summit-rift earthquakes from deeper south flank earthquakes. Also, station CAC is recorded on the A-film to identify and monitor Kona earthquakes on the west coast in a locality where damaging earthquakes have occurred.

As the events are classified on the microfilm, they are counted and totaled hourly using a manual 8-key counter. Hourly totals of the various type events are tabulated in an Hourly Earthquake Count sheet. The subdivision of microearthquakes for this preliminary classification consists essentially of Kilauea short-period caldera, Kilauea long-period caldera, Kilauea deep, Kilauea southwest rift-Kaoiki, Kilauea upper middle-lower east rift, Mauna Loa short-period, Mauna Loa long-period, and Mauna Loa northeast rift. Times/durations are noted for other events read such as harmonic tremor, teleseisms, quarry blasts, artillery firing, electrical storms, sustained equipment noise, atmospheric noise, instrumental problems, instrumental adjustments, etc. When the A-film is scanned entirely, the hourly counts are totaled, entered onto the Daily Earthquake Count sheet, and posted for review by interested staff members.

During the course of the hour-to-hour scan, earthquakes are selected for hypocenter determination if signals are well recorded and measure $\geq$ 40 seconds in duration of signal (which indicates a magnitude > 1.5). A dozen or more such events fall into this category each day and are selected for phase picks. Amplitude and durations are measured on selected stations. Times referenced on

0.5-second time codes recorded on the top and bottom of the microfilm strip are magnified to a scale of one centimeter per second and read to a relative accuracy of 0.05 second. The time code generator is periodically checked against WWVH radio time to maintain timing accuracy to within several milli-seconds of Hawaii Standard Time.

Where possible, the first motion of the P-phase is identified as up (U) or down (D). The first motion is further qualified as a sharp and impulsive (I) onset, or a weak and emergent (E) onset. Consequently, an IPU indicates a sharp impulsive P-phase with an up (or compressive) direction of first motion. To read onset times of P and S phases, the film viewer hairline is set at a convenient 0.5-second time break close to the first phase onset to be read, and the time is read with a millimeter scale using the hairline as the reference. Other phase arrivals within 1 second of the hairline are read, and then the film is advanced to another convenient 0.5-second time break for readings of later phases. The procedure is continued until all the stations are read. Because of irregularities in recording speed of the Develocorder film, reading wide time spans ($\geq$ 1 second) between the reference hairline and phase onset should be avoided. Also, to assure that the reading is taken from a true time reference compensated for any film drive irregularities, the reference hairline should be carefully aligned using both top and bottom time traces. Film magnification of 60 centimeters per minute should be checked using the reference arrows placed on the upper left and right corners of the viewer before reading each event with a standard millimeter scale. Focus and light intensity should be adjusted to maximize reading accuracy. The P and S times read are assigned weights according to the reader's confidence of the accuracy of his picks influenced by the quality of the phase arrivals and records. Weights range from a full weight (code 0) for the highest quality readings to no value (code 4) for times not to be used for hypocenter determination. Code 0 carries a full weight, 1 carries three fourths weight, 2 carries a half weight, 3 carries a fourth weight, and 4 carries no weight.

Amplitude and signal duration are read from selected stations for magnitude calculation. Peak-to-peak amplitude is read on the film viewer where the 0.2-second period seismic waves reach a maximum on relatively stable and calibrated stations such as KHU, PPL, KKU, and AHU. Magnitude (M) is individually calculated for each station and averaged for a final determination for the specific earthquake. Any abnormally high or low calculation of magnitude is omitted from the final averaged determination. Amplitudes read from standard Wood-Anderson type seismographs are additionally used for the magnitude calculation.

An alternate method of magnitude calculation uses the signal duration of the earthquake record. The coda length is measured in seconds from the P-wave onset to when the signal ends as it returns to microseismic background. Relatively stable and trouble-free stations such as AHU, PAU, and DES are chosen for coda length measurements from the A-Develocorder; AIN, HSS, KII, and KHU stations are used for the duration measurement from the B-Develocorder. Duration magnitude (M_{F-P}) is calculated for individual stations and averaged for the final magnitude. Similarly, any abnormally high or low calculation of magnitude is omitted from the final average.

Source areas, type of event, signature characteristics, or whether or not the event was felt, are generally coded in the remarks (RK) column of the earthquake reading sheet. The first three letters in capital generally describe the source areas (UER, MER, MOK, etc.) or signature characteristics of certain events (LPC, LPD). A fourth letter may further describe the event (F if the event was felt, T if the event was associated with tremor, L if the event showed long-period characteristics). These remarks are detailed in the HVO annual summaries.

To each completed reading sheet, event numbers are assigned in chronological order and entered in the upper right corner of the page following "sheet no. ____." The numbers run consecutively starting from number one at the beginning of each quarter of the year, and ending with the number of the final event of the quarter. Data sheets are kept in loose-leaf folders by quarters; for quarters where number of events are exceptionally many, several books are prepared and classified A, B, C, etc.

Teleseismic phases are read on a form called Distant Earthquake Reading Sheet. P-times and direction of first motion from Develocorder films are entered initially, and later, readings from optical records are entered. Teleseisms are filed chronologically in the quarterly reading books, but are numbered sequentially starting from 5000 to maintain a separation for computer filing.

Well-recorded artificial events are read and filed similar to natural seismic events. Local quarry blasts and refraction shots are treated as local earthquakes, but identified in the remarks column as blasts (BLS). Likewise nuclear blasts recorded from teleseismic distances are filed as distant earthquakes but noted as N-blasts.

Harmonic tremor is thought of as continuous ground oscillation caused by magmatic movement within the volcano. Such disturbances occur in bursts of several minutes to a few hours in duration during volcanic rest, and continuously during eruptive episodes. Harmonic tremor is classified as deep, intermediate depth, and shallow according to relative amplitude recorded across the seismic net. Deep tremor generally records evenly across most of the stations of the islandwide net; intermediate depth tremor shows amplitude decay at stations more than 10 km from the summit of the volcano; shallow tremor is very localized beneath eruptive areas such as at the summit and rift zones. If strong and sustained, tremor correlates with abrupt changes in ground tilt. Where possible, harmonic tremor is classified as Mauna Loa or Kilauea. Routinely, tremor is logged in the hourly and daily count sheet noting time in hour and minutes, duration in minutes, qualitative depth of origin, and location either Mauna Loa or Kilauea.

Cultural disturbances frequently recorded on seismograms include artillery firings and bombings from military exercises at Pohakuloa. Low-altitude bombings are made from two to three jet fighter-bombers usually in the mornings at 0900-1100 hours. Artillery firing is usually conducted during daylight, and occasionally at night. Seismic and sonic signals recorded from Pohakuloa exercises are usually strong at the nearby stations HSS, MOK, WIL, SWR, and HPU. Bombing events recorded on these stations appears as elongated seismic signals of low amplitude preceded by many seconds the sharp, high amplitude and high frequency sonic bursts. In addition, sonic signals from the artillery and bombs picked up on stations around Kilauea such as MLO, AHU, NPT, DES, and PAU are highly dependent on prevailing atmospheric conditions.

In addition to the usual meteoric and cultural disturbances that similarly plague stations on the smoke drum recorders, high altitude stations at the summit of Mauna Loa on the Develocorder register tremor-like noise during snowstorms and microshocks during freeze-thaw conditions particularly in the month of March. A number of the Develocorder stations suffer outage caused by radio telemetry interference for an hour or more near midnight.

Following a rigorous hour-to-hour scan of the A-film, the B-film is then examined and read. The large events of M $\geq$ 1.5 selected and timed on the A-film are likewise timed for stations on the B-film. The B-Develocorder includes stations that are mostly located in areas far from the active parts of the volcanoes. Readings from these remote stations are particularly important for earthquakes that are large, deep, or located near the edge or outside the islandwide seismic net. Direction of P-wave first motion read from stations that encompass the earthquake epicenter as completely as possible in azimuth and distance is necessary for focal mechanism reduction. P-first motion must be accurately read as up or down for large earthquakes of M $\geq$ 3.0 from as many stations as possible. For these large events, well-timed phase arrivals are useful to refine seismic velocity structure in addition to determining earthquake hypocenters. Hypocenter determination generally improves when the stations are completely around the epicenter and over a wide range of distances.

The timing of events using Develocorder films as described above was routine prior to 1979. Now, data processing includes computer-assisted measurements from digitized tape records.

Optical Drum Records

By the time the Develocorder records are thoroughly picked, optical records changed at Uwekahuna vault are developed and prepared for reading. The seismograms are from three short-period seismographs, and a three-component long-period seismograph. Instruments at Uwekahuna vault situated near the northeast edge of Kilauea Caldera are linked by a kilometer-long cable to the master timing system at HVO. Records are changed daily at about 0900. For all HVO optical records, the time and date on, station name, and component are written on the reverse side.

The Uwekahuna short-period seismographs consist of one high-gain horizontal component UWH, one low-gain Sprengnether vertical component USZ, and one low-gain Sprengnether horizontal USE. Drum speed is at 60 mm per minute, and timing format is similar to the smoke drum. Where signals from low intensity events at Uwekahuna are required, S-readings are made from the high amplification EV-17H. The S-times are especially helpful for depth control of Kilauea shallow earthquakes, and to constrain hypocentral distances for earthquakes offshore. The Sprengnethers operate at a magnification nearly comparable to the standard Wood-Anderson seismographs. USE records are read for S-times and trace amplitude in mm, USZ records are read for P-times, direction of first motion, and trace amplitude.

Teleseismic phases are read from the Uwekahuna long-period records. The long-periods are Press-Ewing seismographs recorded on standard drums at 15 mm per minute with a minute deflection downward for 1 second and an hour deflection downward for 2 seconds. Moderate to large earthquakes of M $\geq$ 5.5 recorded at

HVO mainly occur 4,000 to 10,000 kilometers from Hawaii especially along the outer margins of the Pacific. P and S arrivals only are typically read for $\geq$ 100 km deep events. P, S, L, and R phases are usually read for shallow earthquakes focused at < 100 km depth. Arrival times are estimated to the nearest second. Also catalogued are direction of first motion, and trace amplitude from R-waves for determination of surface wave magnitude (Ms).

From two independent stations at Hilo and Haleakala National Park, unprocessed photographic records are mailed to HVO in sealed mailing tubes about two times a week. Both stations operate short-period seismographs including a high-gain EV-17 vertical component and standard magnification Wood-Anderson east-west and north-south components. Seismograms from the vertical components are read for P-times, direction of first motion, and trace amplitude. The Wood-Anderson horizontals are read for S-times and trace amplitude. These two stations are independently timed by crystal chronometers, and for time correction, WWVH radio time signals are recorded onto each seismogram daily. Due to varying quality of radio reception from the WWVH transmitter on Kauai, signals from day-to-day may be poor or good. Because of limitations in clock correction and record distortion, timing inaccuracy up to several tenths of a second should be expected. P and S times read from the independent stations consequently should be down-weighted as a standard procedure. Readings from these stations are important for deep events, or on occasional events that occur northeast of Hawaii or near Maui. Haleakala station also serves as a volcanic monitor with a capability of detecting any microearthquake activity that might occur at Haleakala. A separate log is kept listing all seismic events recorded locally at Haleakala station. At Hilo, records are usually changed in the early evening between 1700-1900 hours, and WWVH radio signals are poor. At Haleakala, records are consistently changed at 0700-0800 hours, and there the WWVH radio signal and overall record quality are good.

In addition to the optical records obtained from Hilo and Haleakala, daily records from a short-period vertical component Sprengnether seismograph at Kipapa, Oahu, (KIP) is furnished to HVO by the Pacific Tsunami Warning Center. Kipapa comprises the third outstation and its readings are important for earthquakes offshore from Hawaii and especially those that sometimes occur along the northwestern parts of the Hawaiian Archipelago. The Kipapa record format is standard with 60 mm per minute recording speed, 2-second down deflection each minute, and 4-second down deflection each hour. Independent station records are read into pre-designated spaces in the reading sheets as they are received and processed at HVO.

Magnetic Tape Records

Signals from the entire seismic network are recorded on 1-inch magnetic tape from a continuously operating Bell and Howell VR-3700B recorder. Selected records of local earthquakes, teleseisms, and volcanic tremor are digitized from the analog tape using reference times read from Develocorder films. The digitized phase data for the local earthquakes are routinely picked and processed for final locations and magnitude using the Data General Eclipse minicomputer system at HVO.

The tape records are preferentially used over the Develocorder films for the final processing of local earthquakes since they include all the stations of the network and more accurate picks are possible. The nearly simultaneous picking and locating procedure that is programmed provides the analyst with the advantage to readily check and correct for picking errors. The earthquake locating procedure utilizes a computer program called HYPOINVERSE (Klein, 1978). Phase and summarized data are compiled on computer files. Tape records that contain the selected events on the original 1-inch analog tape are also dubbed and copied onto a master library tape filed under Hawaii at the USGS Office of Earthquake Studies at Menlo Park, California.

SUMMARY

A series of figures and tables are sequentially included for graphical and tabulated summarizations of instrumental information and the various seismic recordings in Hawaii. Position, recording format, and other station data are outlined in figure 1 and table 1 (from Nakata and others, 1980). Seismic signatures from various natural or human causes commonly observed on the HVO smoke drums are illustrated in figure 2 (from Tilling and others, 1975). Copies of smoke records to display patterns of shallow earthquake swarms and harmonic tremor activity are provided in figure 3. To show more detail and short-term signature characteristics of eruption related activity and individual events recorded across a network of stations, a series of Develocorder film sections are compiled in figures 4 and 5. Cultural and meteoric disturbances recorded on the Develocorder films are reproduced in figure 6. Develocorder samples of well-recorded earthquakes from the various geographic designations are selected to show differences in P-wave arrival times and direction of first motion (figure 7). As a supplement to figure 7, differences in P-wave arrivals, direction of first motion, and calculated S-P intervals are listed in table 2. Finally, the various recording characteristics and the mode of occurrence for the earthquakes in the various localities beneath Hawaii are summarized in entirety in table 3.

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FIGURES AND TABLES

Figure 1.--Map of the island of Hawaii showing seismic stations (three-letter codes inside circles) and geographic regions (three-letter codes inside heavy line boxes). See tables 1, 2, and 3 for coordinates of latitude and longitude pertaining to seismic stations and geographic regions. Codes assigned to the various geographic regions relate to an appropriate volcanic/tectonic structure, cultural landmark, or description of seismic events typical of the region (Nakata and others, 1980):

Kilauea

SPC (Short-period caldera)
LPC (Long-period caldera)
DEP (Deep)
UER (Upper east rift)
KOA (Koae fault system)
SWR (Southwest rift)
MER (Middle east rift)
LER (Lower east rift)
POL (Poliokeawe fault system)
LSW (Lower southwest rift)
PPL (Puu Pili)
HLP (Hilina Pali)
GLN (Glenwood)

Mauna Loa

MOK (Mokuaweoweo)
UKF (Upper Kaoiki fault system)
HEA (Hilea)
KON (Kona)
NER (Northeast rift)

Others

KOH (Kohala)
HIL (Hilo)
KKU (Keanakolu)
DIS (Distant source)

Figure 2.--A schematic comparison of various seismic traces of natural and man-induced events. These sketches portray seismic disturbances often observed on 60 mm/min smoke drum recordings from the stations located around the summit of Kilauea (Tilling and others, 1975).

Figure 3a.--Smoke drum seismograms from stations at the summit of Kilauea showing (1-A) microearthquake activity preceding the onset of a swarm of high frequency or short-period earthquakes accompanying shallow magma intrusion, and (1-B) harmonic tremor and high frequency earthquakes from shallow movement of magma and summit collapse.

Figure 3b.--Smoke drum seismograms showing (2-A) flurry of low frequency or long-period earthquakes from post-collapse adjustments of the summit storage system at Kilauea, and (2-B) high frequency earthquakes related to late stage intrusion of magma on the southwest rift of Kilauea.

Figure 3c.--Smoke drum seismograms from stations at the summit of Kilauea showing (3-A) post-intrusion harmonic tremor related to low level magma movement in the summit storage system, and (3-B) gradual decay of the post-intrusion harmonic tremor and occasional earthquakes accommodating structural adjustments.

Figure 4.--Pre-eruption seismic sequence for the September 1977 eruption of Kilauea viewed on half minute sections for 18 stations on the Develocorder strip film:

(a) 2104 HST, September 12. Onset of small earthquakes in the east rift zone of Kilauea.

(b) 2124 HST, September 12. Increase in the size and number of earthquakes, and start of weak harmonic tremor.

(c) 2126 HST, September 12. Continued increase in the size and number of earthquakes, and higher intensity harmonic tremor.

(d) 2155 HST, September 12. High level seismicity recorded on stations at epicentral distances within 20 kilometers. Earthquake swarm and harmonic tremor continue at fluctuating amplitude until outbreak of eruption at 1912 HST, September 13, about 22 hours after the beginning of the seismic swarm. Thousands of earthquakes were recorded at M < 4 and depths < 5 km (Moore and others, 1980).

Figure 5.--Small seismic events from common sources at Kilauea and Mauna Loa volcanoes viewed on half minute sections for 18 stations on the Develocorder strip film:

(a) 0315 HST, August 13, 1979. Shallow high frequency earthquake at the summit of Kilauea (SPC). This type normally increases in number during times of sustained inflation of the summit.

(b) 1754 HST, November 3, 1979. Halemaumau rockfall. Localized high frequency signals with weak onset caused by rock slabs dropping to the crater floor after breaking loose from the unstable walls. These events are most frequent after an intrusion-related collapse of the summit, large earthquake, and heavy rainfall.

(c) 0917 HST, October 2, 1977. Shallow low frequency or long-period earthquake (LPC) in post intrusion swarm of small earthquakes at the summit of Kilauea.

(d) 2048 HST, November 9, 1974. Intermediate depth long-period earthquake at the summit of Kilauea (LPC). Such an earthquake often occurs in flurries associated with volcanic tremor during advanced stages of the inflation period.

(e) 2012 HST, September 26, 1979. Deep summit earthquake at Kilauea (DEP) characteristically recorded with about 3-4 seconds S-P interval and small P-arrival differences less than 1 second on the summit stations. These events outline the stress distribution along the deep magma conduit system beneath Kilauea.

(f) 2116 HST, September 12, 1977. High frequency Kilauea east rift earthquake (UER) in an intrusion-related swarm of shallow earthquakes preceding the 1977 Kilauea eruption.

(g) 2027 HST, November 9, 1974. Shallow high frequency earthquake at the summit of Mauna Loa (MOK). Analogous to the SPC earthquake at Kilauea, the MOK type accompanies inflation at the summit of Mauna Loa. Earthquakes of this category occurred at an increased rate for a year leading to the Mauna Loa eruption in July 1975.

(h) 0355 HST, November 21, 1976. Intermediate depth long-period earthquake at the summit of Mauna Loa. Analogous to the Kilauea LPC earthquake, Mauna Loa earthquakes of this type occur in flurries often related to bursts of tremor during periods of sustained inflation.

(i) 2101 HST, September 12, 1977. High frequency earthquake at intermediate depth beneath the upper Kaoiki faults on the southeast flank of Mauna Loa (UKF). Tectonic earthquakes of this group occur persistently in the stress region between Mauna Loa and Kilauea volcanoes.

(j) 1938 HST, September 28, 1979. Low frequency or long-period earthquake deep within the mantle beneath Kilauea and Mauna Loa volcanoes (sometimes called LPD earthquakes). Events of this type are frequently associated with deep tremor bursts an hour or two in duration.

(k) 0017 HST, January 14, 1978. Monochromatic low frequency or long-period earthquakes deep within the mantle beneath Kilauea and Mauna Loa (sometimes called LPD also). Events of this type are often associated with deep tremor bursts an hour or two in duration.

Figure 6.--Cultural (man-induced) and meteoric seismic signals viewed on half minute sections for 18 stations on the Develocorder strip film:

(a) 0908 HST, November 2, 1978. High altitude winds recorded locally as continuous high frequency noise (15-20 Hz) superimposed on erratic low frequency disturbance (about 1-2 Hz) on Mauna Loa summit stations MOK and SWR. The third summit station WIL was out of operation. Cultural noise with a predominant frequency of 5 Hz and erratic amplitude caused by heavy ground-moving equipment recorded at a distance of about 1 kilometer on station PAU. Surface waves are sometimes picked up at stations a couple of kilometers away. High frequency disturbance of low amplitude such as seen on stations PHO and CAC, or intermittently erratic signals as seen on station PPL are due to instrumental malfunctions and radio telemetry interferences. Certain coastal and high elevation stations are prone to changes in microseism level caused by ocean surf. Background level of the 1-second period microseism such as that on station KPN may increase in amplitude by several times during high surf activity on the south coast of Hawaii.

(b) 1549 HST, October 1, 1979. Lightning recorded essentially simultaneously on stations WIL, SWR, PLA, NPT, AHU, ESR, MPR, and KPN. The signal is typically a sharp, high frequency (15-20 Hz) spike, and when sufficiently strong, destroys various components of the seismograph and telemetry system, such as in the case of AHU station. The subsequent sound waves heard as thunder is recorded as an erratic burst of high frequency (5-10 Hz) noise about a minute in duration. Here, moderate signals from thunder is recorded first on PLA at minus 6 seconds, and later on MLO at minus 13 seconds indicating the source of the electrical storm to be about 2 kilometers from station PLA, assuming sound wave velocity in air at 0.34 kilometers per second.

(c) 1107 HST, September 29, 1979. Passing automobiles and buses recorded on station ESR at a half kilometer distance. The signal is typically several minutes in duration, erratically peaking in amplitude near the middle with a predominant frequency of about 8 Hz.

(d) 0858 HST, September 30, 1979. Helicopter flying within a hundred meters above station SWR. The signal is typically about a minute in duration peaking in amplitude near the middle with high, monochromatic frequency close to 15 Hz.

(e) 1430 HST, September 28, 1979. Footsteps from a person walking by within 10 meters of station HUL. The signal is several minutes in duration with sharp, high frequency (15 Hz) spikes at about half second intervals, and erratically peaking in amplitude near the middle.

(f) 1532 HST, February 7, 1979. Initial phases of a quarry blast recorded at distances 20 to 50 kilometers away. Time-delayed explosives totaling 3000 to 5000 pounds of explosives are routinely discharged at a construction rock quarry in Hilo. A well-recorded signal is characterized by a compressional (up) first motion, high frequency onset (5 Hz) followed by about a minute of low frequency (1 Hz) surface waves.

Figure 7 (a-zz).--Fifteen-second seismogram sections from the Hawaiian Volcano Observatory A (upper) and B (lower) Develocorders each with 18 stations and time marks top and bottom showing the P-wave onsets of moderate earthquakes from the various regions. The three-letter earthquake code, and determination of origin time, location, and magnitude are printed on the upper right corner. To clearly outline the arrival pattern, the seismograms were blocked and whitened out 1.0 second after the P-wave onset at each station. Stations with early arrivals blocked out furthest to the left are closest to the earthquake epicenter. For earthquakes within the island network, large differences in arrivals imply a shallow source as opposed to a tight arrival pattern indicative of deeper events.

Table 1.--Seismometer stations in Hawaii operated by the U.S. Geological Survey, 1979. All stations are equipped with standard 1-second period geophones with the exception of a 3-component long-period seismograph at Uwekahuna. Instrumental specifications are detailed in Hawaiian Volcano Observatory Summary 79 (Nakata and others, 1980).

Table 2.--Identifying signatures for sharp earthquakes from the various regions as recorded on Develocorder film and illustrated in figure 7:

(a) P-wave arrival differences in tenths of seconds using a reference time of 0.0 second for the station(s) of earliest arrival, and relative times in seconds thereafter for later stations.

(b) Direction of P-wave first motion up (compression) and down (dilation) at each station dependent on the earthquake focal mechanism and location.

(c) P- and S-phase intervals in tenths of seconds (S-P) calculated for each station. S-P times to estimate distances are measurable for small events where the signal amplitude is below saturation levels.

Table 3.--Identification of earthquakes from the various geographic regions:

(1) Volcanic Regime. Volcanic systems and structures related to the various pre-designated geographic subdivisions.

(2) Earthquake Type Code. Earthquakes are separated in general according to geographic locations identified by three-letter codes. Numbers in parentheses are additional identification codes used to relate to the various classifications in the other figures and tables.

(3) Epicentral Area by Geographic Coordinates. Boundaries of the geographic subdivisions of earthquake types in degrees and minutes of latitude North and longitude West.

(4) Typical Focal Depth (km). Depth in kilometers for earthquakes in the various groups.

(5) Common Mode of Occurrence. Recurrence pattern of earthquake types.

a. Swarm--Intense rate of high frequency earthquakes often associated with harmonic tremor and magma intrusion as a prelude to eruption. Earthquake repetition is extremely high where individual earthquakes overlap creating a continuous signal that is locally high in amplitude.

b. Flurry--Conspicuous increase in earthquake rate but normal background level is retained at standard recording speed so that onset time and the entire coda for each earthquake is usually discernable.

c. Burst--Concentration of earthquakes within a relatively short interval of time often several hours or less. This mode is common in intermediate and deep earthquakes coinciding with volcanic tremor that signify incremental movement of magma deep within the crust or mantle under south Hawaii.

d. Intermittent--Earthquakes that tend to occur in a wide interval in time, space, and magnitude. Such isolated events are apparently due to long-term stresses and do not consistently correlate with volcanic events.

e. Aftershocks--When intermittent earthquakes occur at a magnitude of $M \geq 4$, an aftershock sequence may be generated. Unlike earthquakes in swarms, flurries, and bursts that are sequentially random in magnitude and time, aftershocks decay hyperbolically following a principal shock usually more than one magnitude larger than the largest aftershock. The size and duration of the sequence is proportional to the size of the main shock. An apparently systematic decay pattern is prescribed in aftershock sequences, as opposed to more random time-space-magnitude distributions in swarms, flurries, and bursts.

(6) Classification. Earthquake classification adapted from Latter, 1981. Volcanic (V) earthquakes are referred to as tremor-like events with predominance of low or monochromatic frequencies that occur in magma storage and transport systems. Tectonic (T) earthquakes are typical high frequency shocks caused by sudden displacements in solid bodies of rock. Volcano-tectonic (VT) events are tectonic earthquakes that relate closely in time and location to volcanic activity. Many are shallow shocks caused by brittle fracture of wall and roof rocks that accomodate magma movement often accompanied by ground swelling.

(7) Range of Earthquake Magnitude in Typical Year. Based on the standard Richter local magnitude (M), most earthquakes in Hawaii are $M < 4$. Magnitude-frequency statistics generally indicate that volcanic earthquakes are lowest in magnitude, volcano-tectonic earthquakes are intermediate, and tectonic earthquakes are highest. For the largest earthquakes averaged over the years, $M > 5$ earthquakes occur once a year, $M > 6$ earthquakes occur once a decade, and $M > 7$ earthquakes occur once a century.

(8) Number of Earthquakes $M \geq 2.0$ in Typical Year. Generally for the $M \geq 2.0$ category, tectonic earthquakes are emphasized in number, whereas for the $M < 2.0$ category, volcanic and volcano-tectonic earthquakes are numerous. Volcanic and volcano-tectonic earthquakes of $0 < M < 2$ at Kilauea number many thousands per year. The seismic network configuration is more sensitive to small volcanic events than to small tectonic earthquakes.

(9) Stations of First Arrivals. The station(s) to first record the earthquake is usually 1 to 20 kilometers away depending on the depth and epicenter of the event relative to the station location.

(10) Relative Signal Attenuation Rate with Distance. Rate of amplitude decay or signal loss is described as high, moderate, or low. The attenuation rate across the seismic net is typically high for shallow high frequency events, and relatively low for deep and low frequency events.

(11) S-P in Seconds at Nearest Station. Time intervals in seconds for the onset of P and S phases (S-P) approximated for the nearest recording station.

(12) Signature Characteristics at Various Epicentral Distances. Recording characteristics of amplitude, duration, and frequency are distinguished for near and far epicentral distances. The ratio of maximum peak-to-peak amplitude in millimeters and duration in seconds as read from the Develocorder film on the standard viewer with 20X magnification is used as a numerical description of the signal form, and the predominant frequency in cycles per second differentiates high and low frequency events. Shallow high-frequency events normally show high frequencies and high amplitude/duration ratios at near stations, and contrastingly, low frequencies and low amplitude/duration ratios at far stations. Long-period and deep earthquakes show relatively slight changes in frequency and amplitude/duration ratio with changes in epicentral distance.

Figure 1

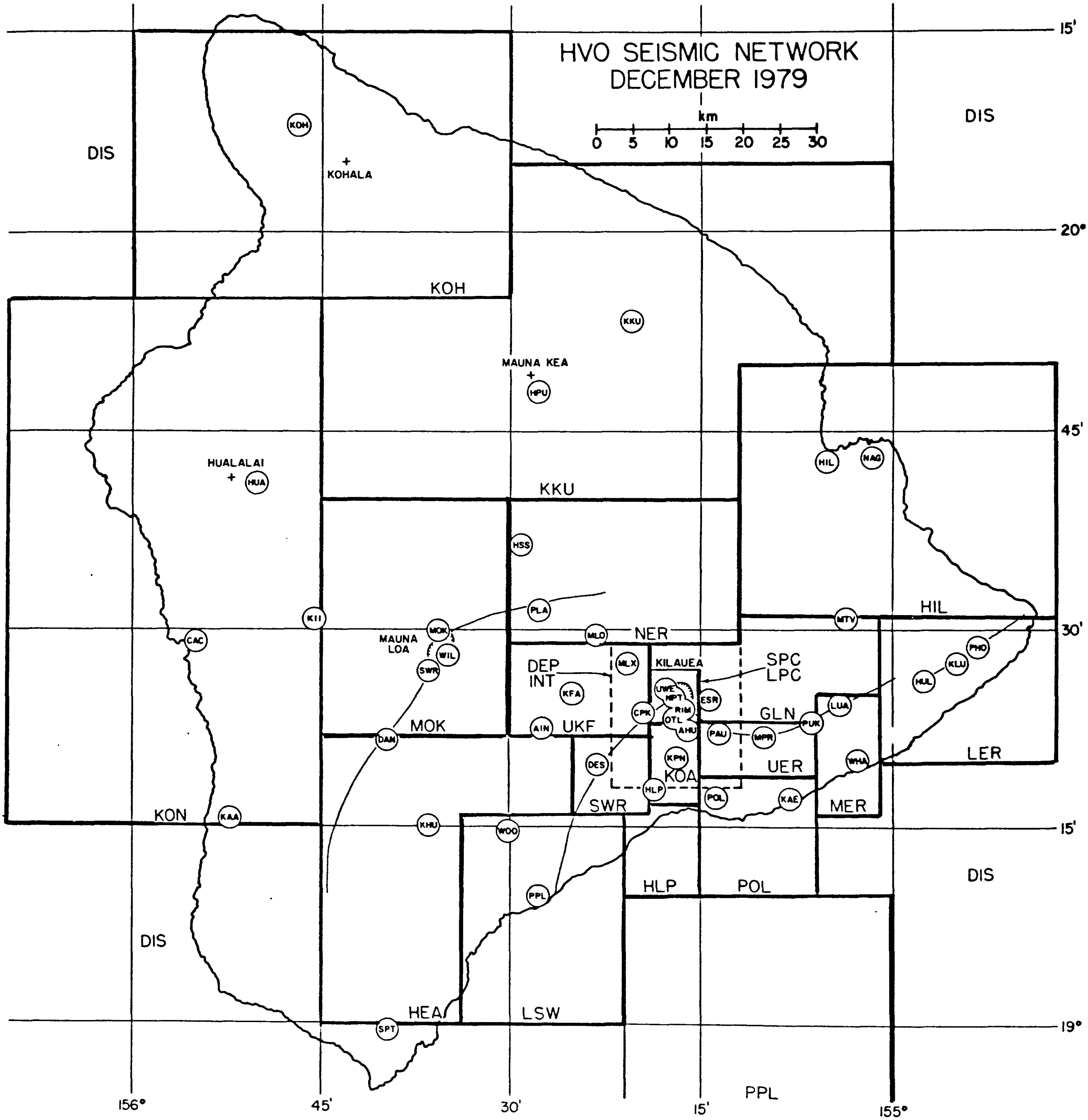
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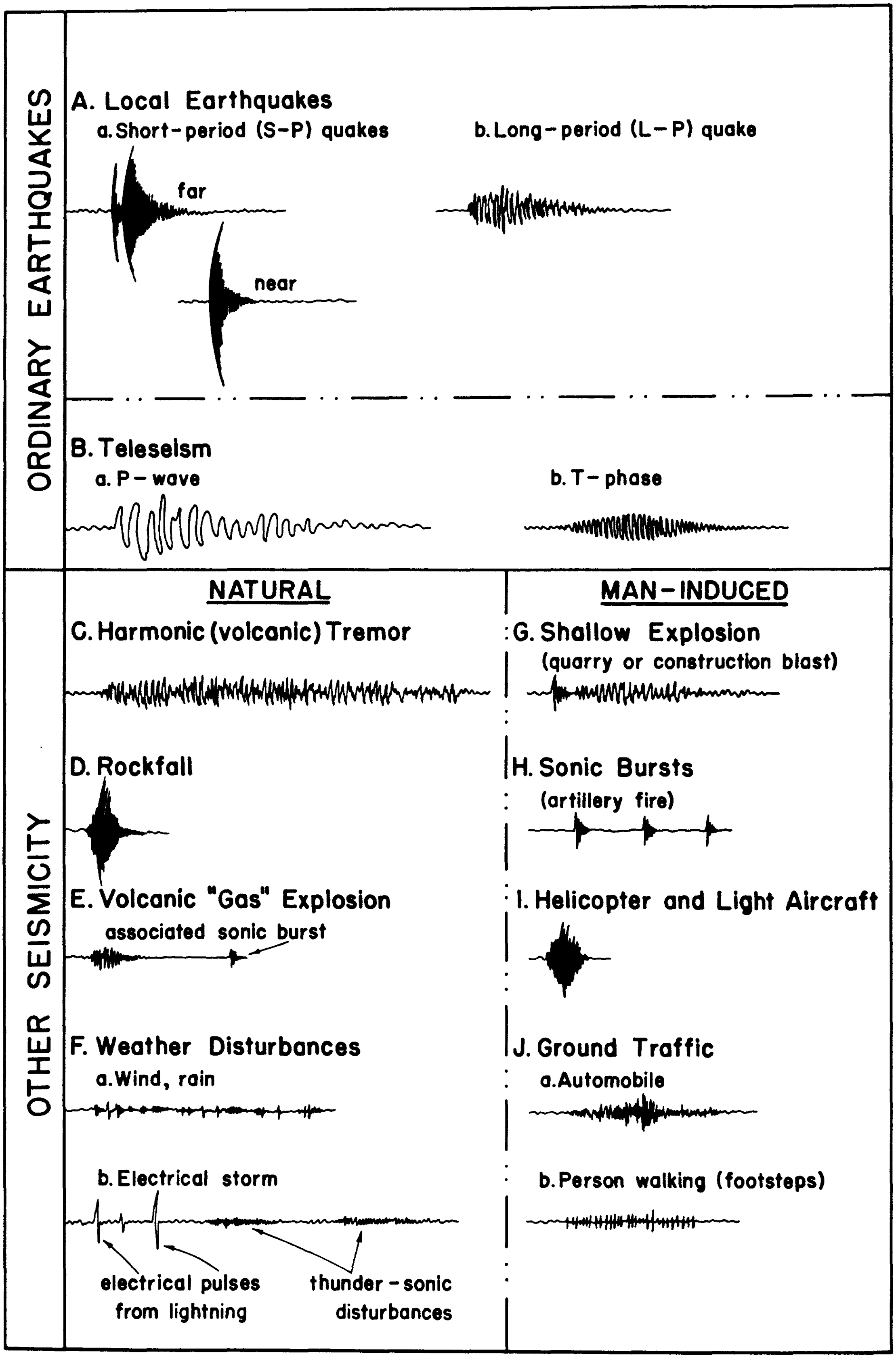
Figure 2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a. Short-period (S-P) quakes
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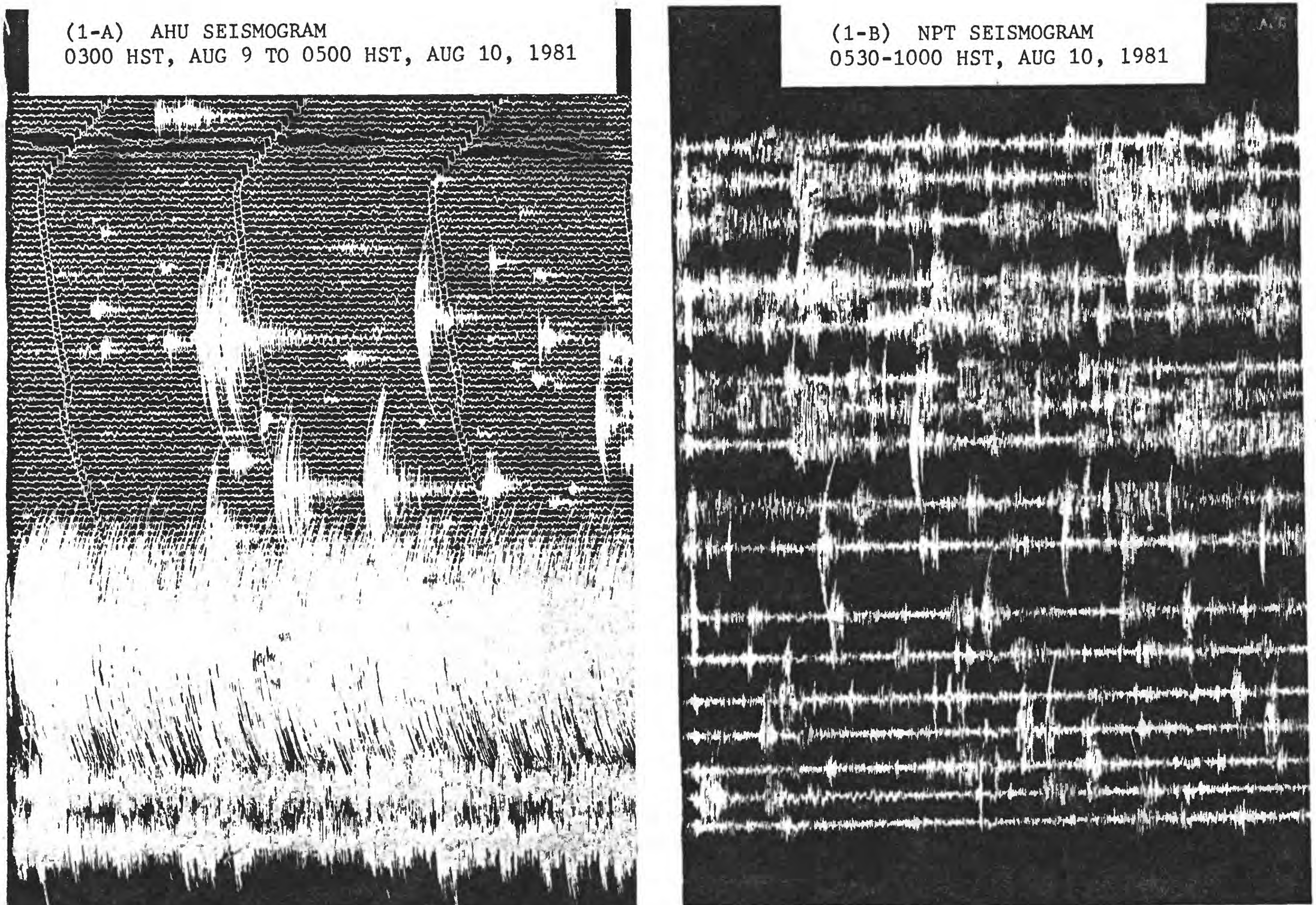
b. Long-period (L-P) quake
B. Teleseism
a. P-wave
b. T-phase
OTHER SEISMICITY
NATURAL
C. Harmonic (volcanic) Tremor
D. Rockfall
E. Volcanic "Gas" Explosion
associated sonic burst
F. Weather Disturbances
a. Wind, rain
b. Electrical storm
electrical pulses
from lightning
thunder-sonic
disturbances
MAN-INDUCED
G. Shallow Explosion
(quarry or construction blast)
H. Sonic Bursts
(artillery fire)
I. Helicopter and Light Aircraft
J. Ground Traffic
a. Automobile
b. Person walking (footsteps)

Figure 3a.

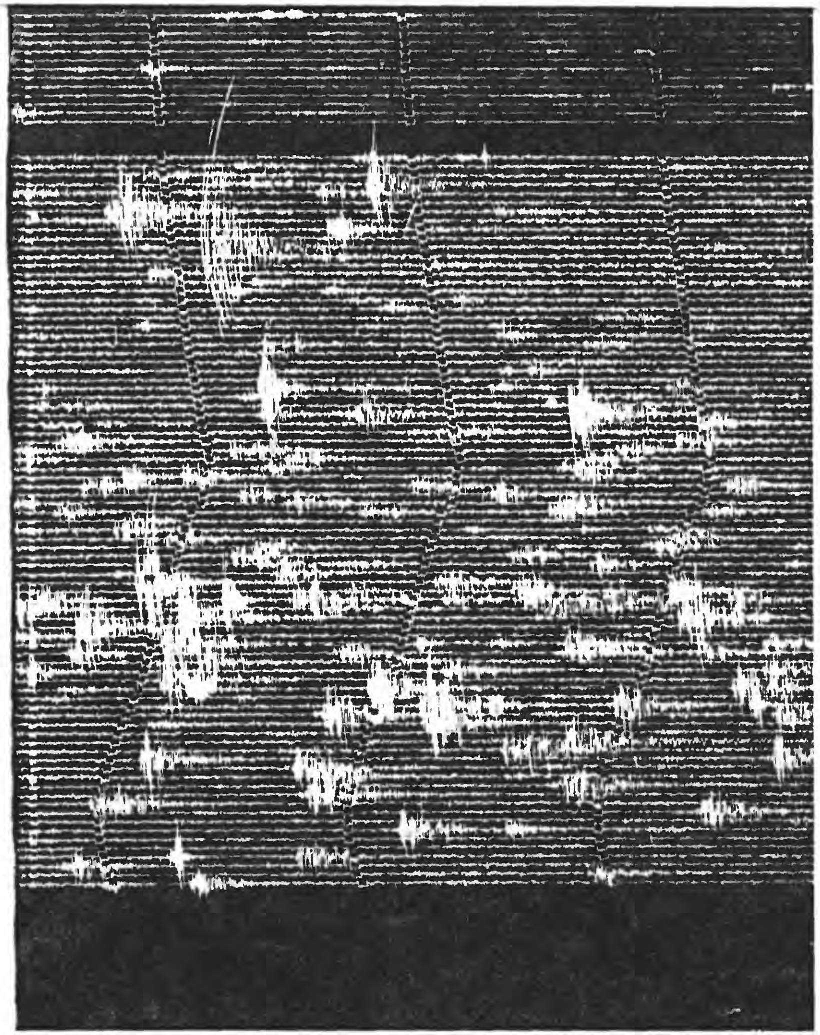


(1-A) AHU SEISMOGRAM
0300 HST, AUG 9 TO 0500 HST, AUG 10, 1981

(1-B) NPT SEISMOGRAM
0530-1000 HST, AUG 10, 1981

Figure 3b.

(2-A) NPT SEISMOGRAM
0900 HST, AUG 13 TO 0900 HST, AUGUST 14, 1981



(2-B) DES SEISMOGRAM
0900 HST, AUG 13 TO 0900 HST, AUG 14

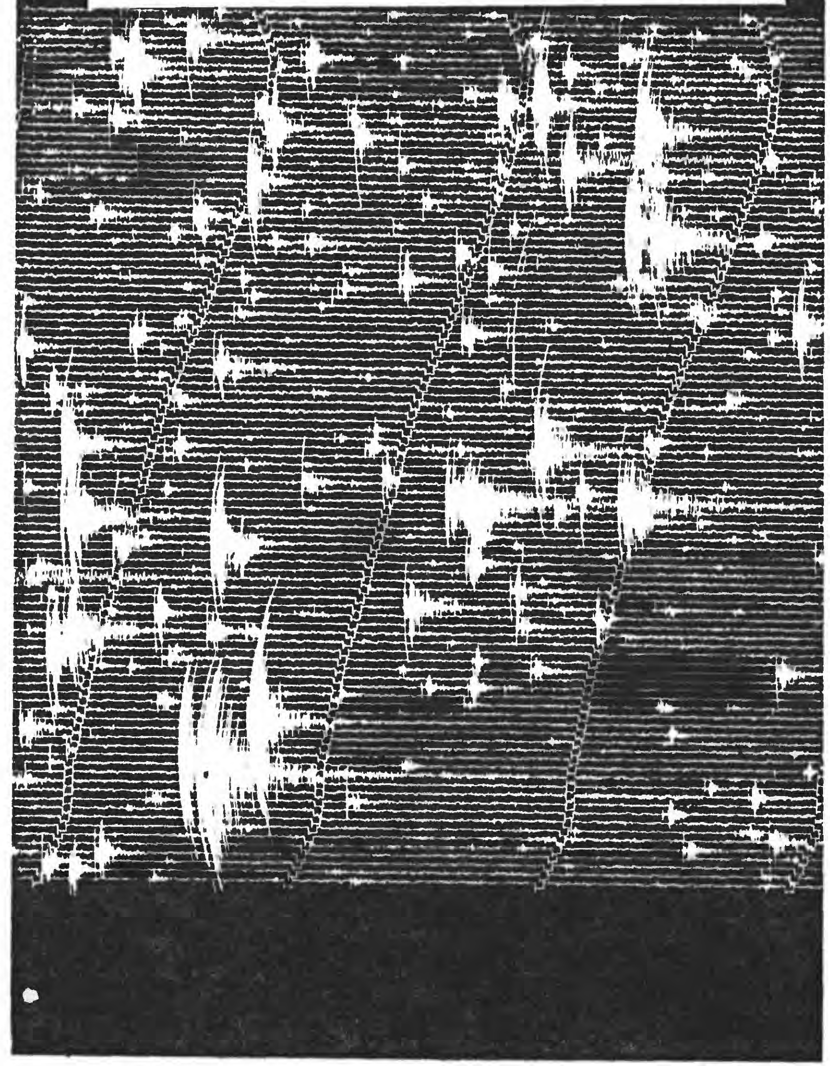
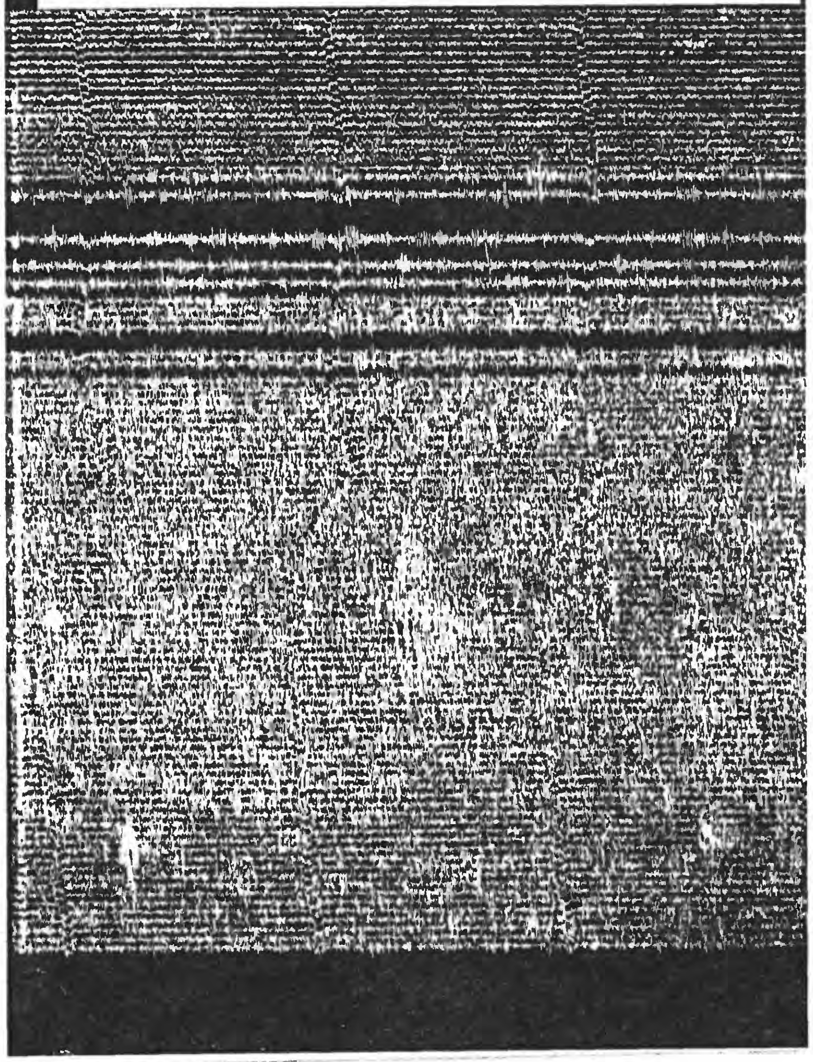
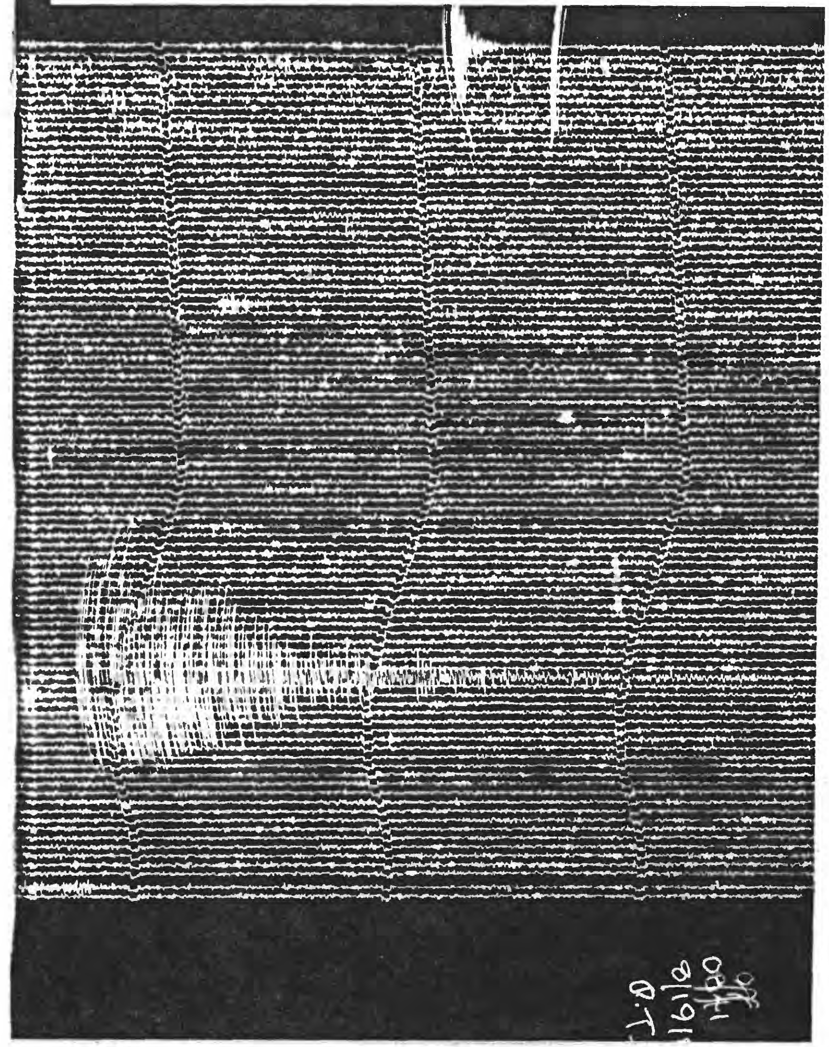


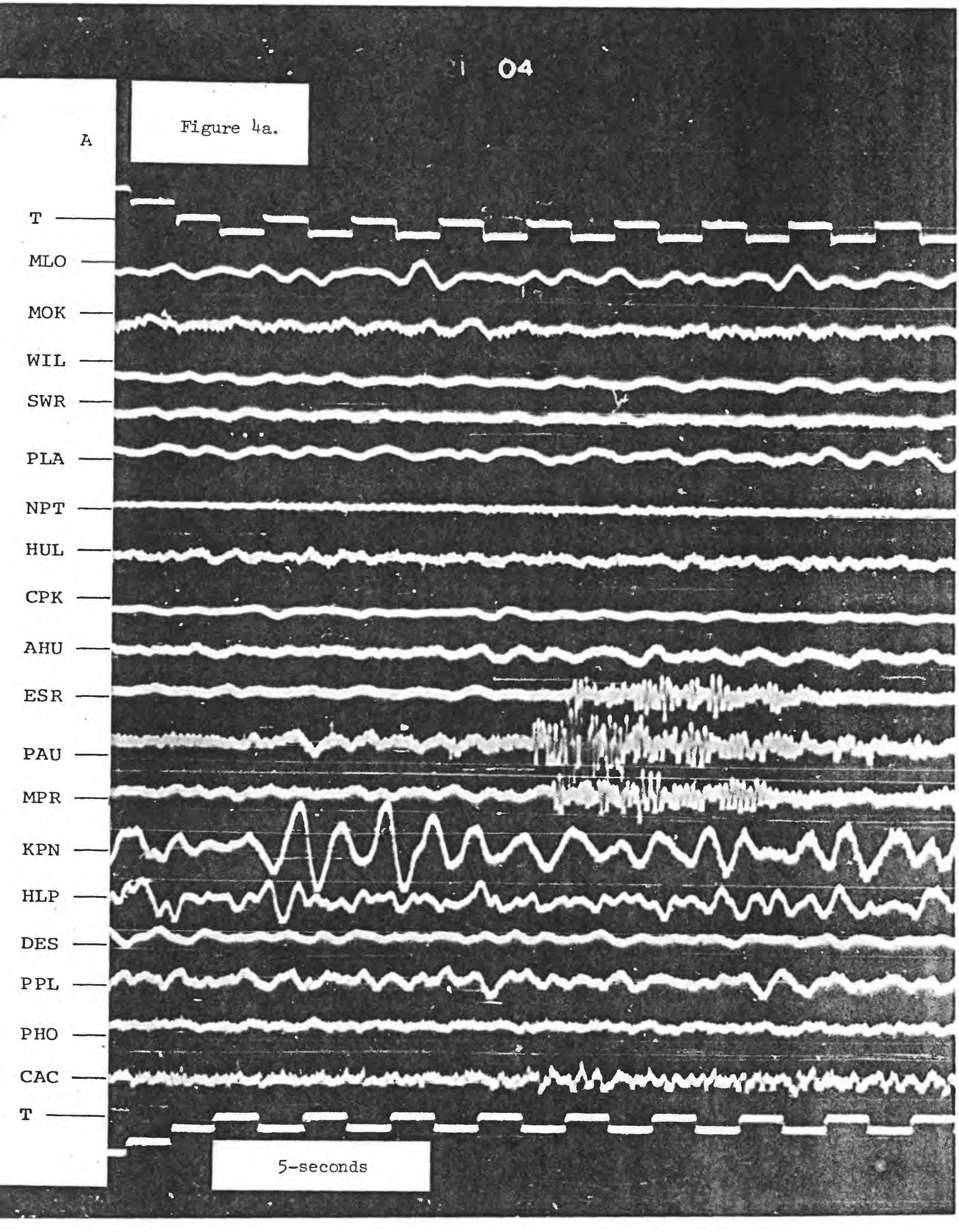
Figure 3c.

(3-A) NPT SEISMOGRAM
0900 HST, AUG 15 to 0900 HST, AUG 16, 1981



(3-B) NPT SEISMOGRAM
0900 HST, AUG 18 TO 0900 HST, AUG 19, 1981





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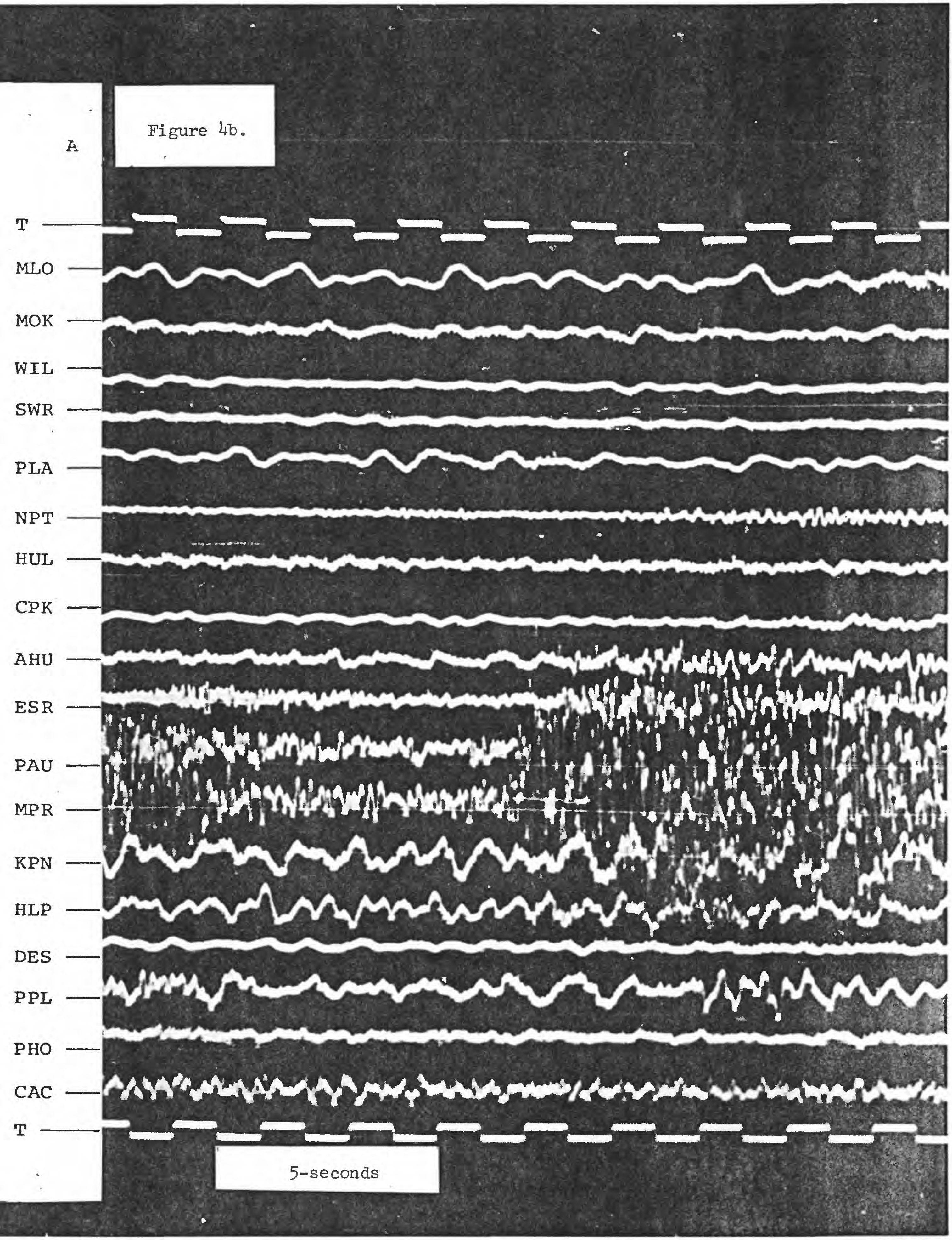
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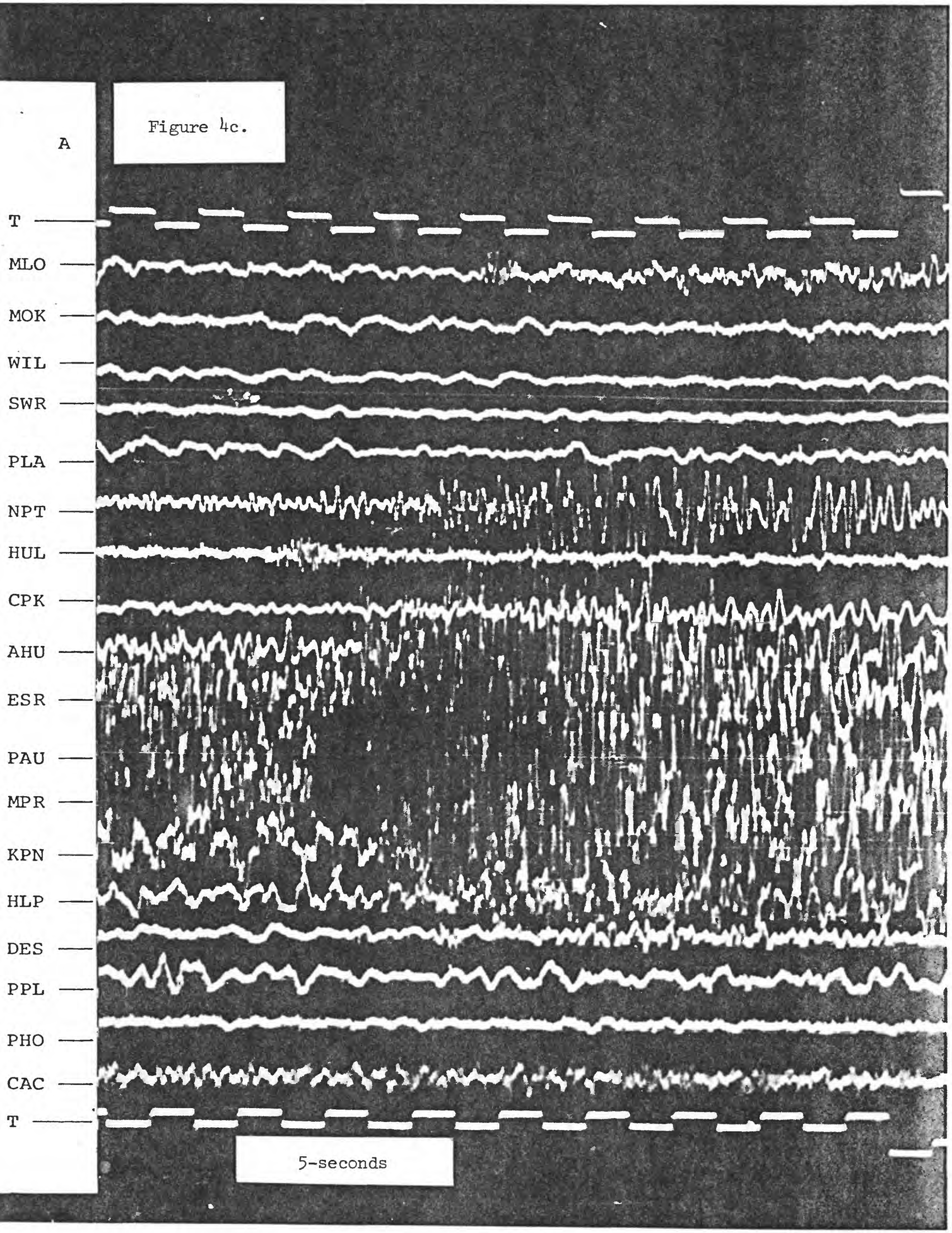
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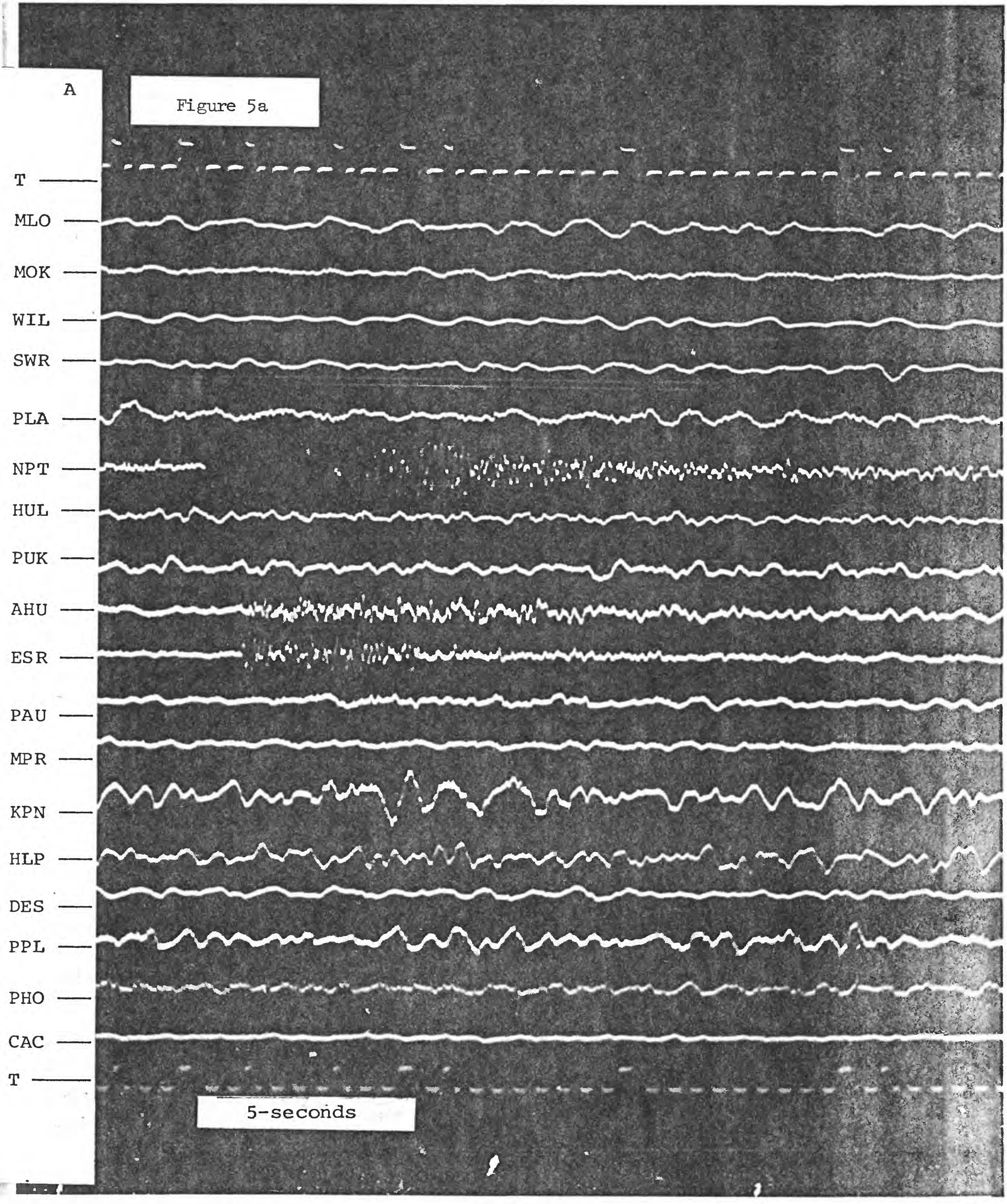
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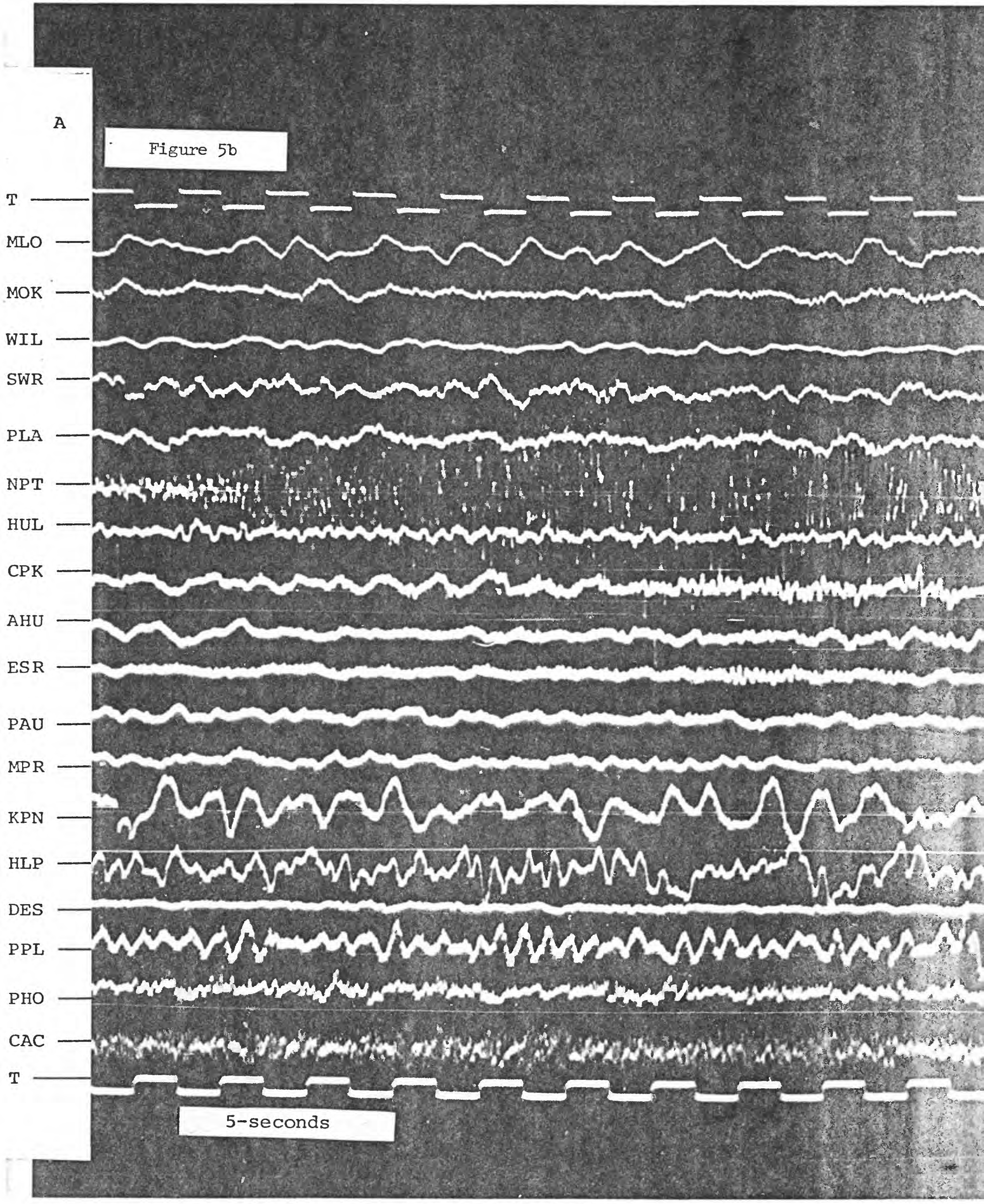
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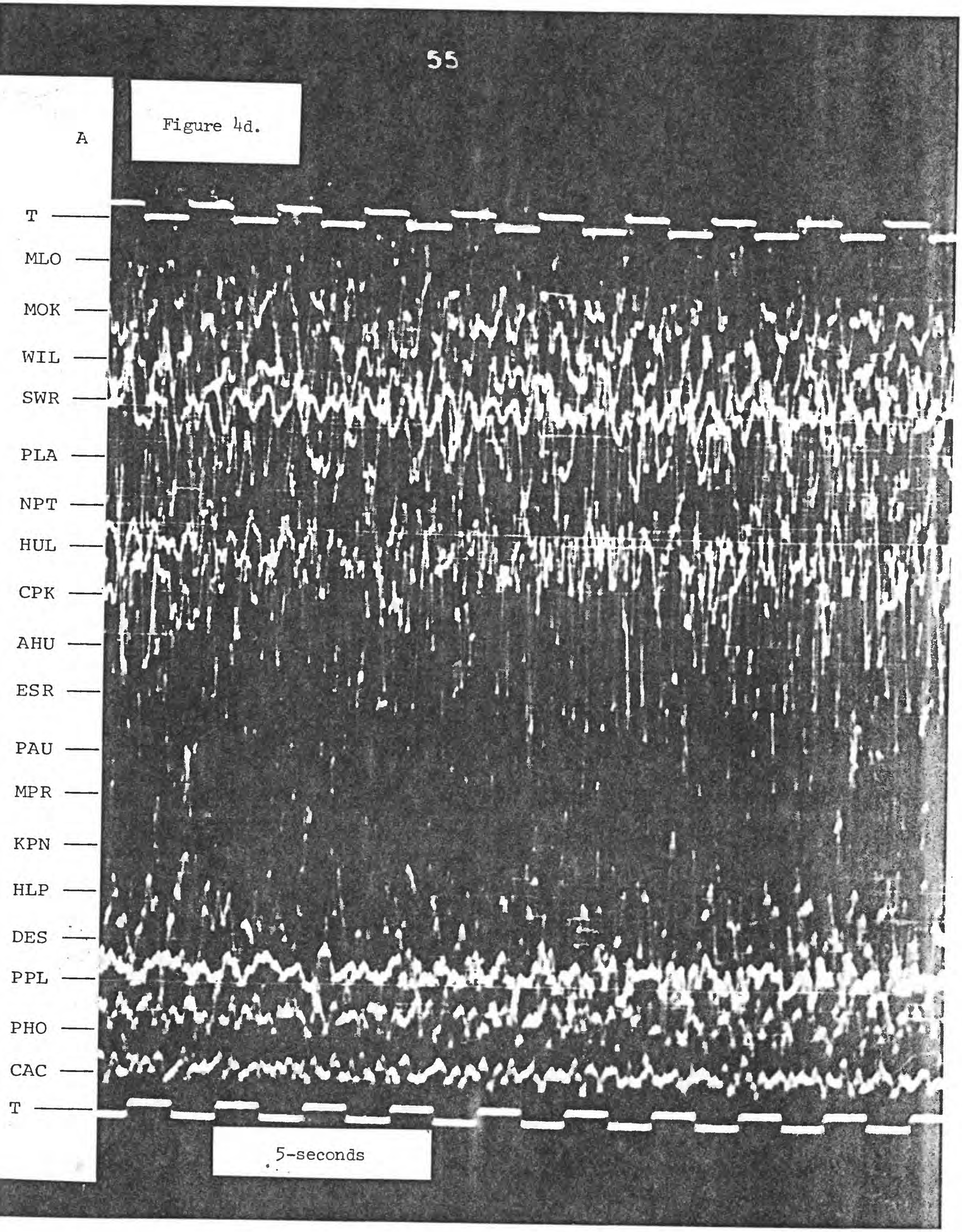
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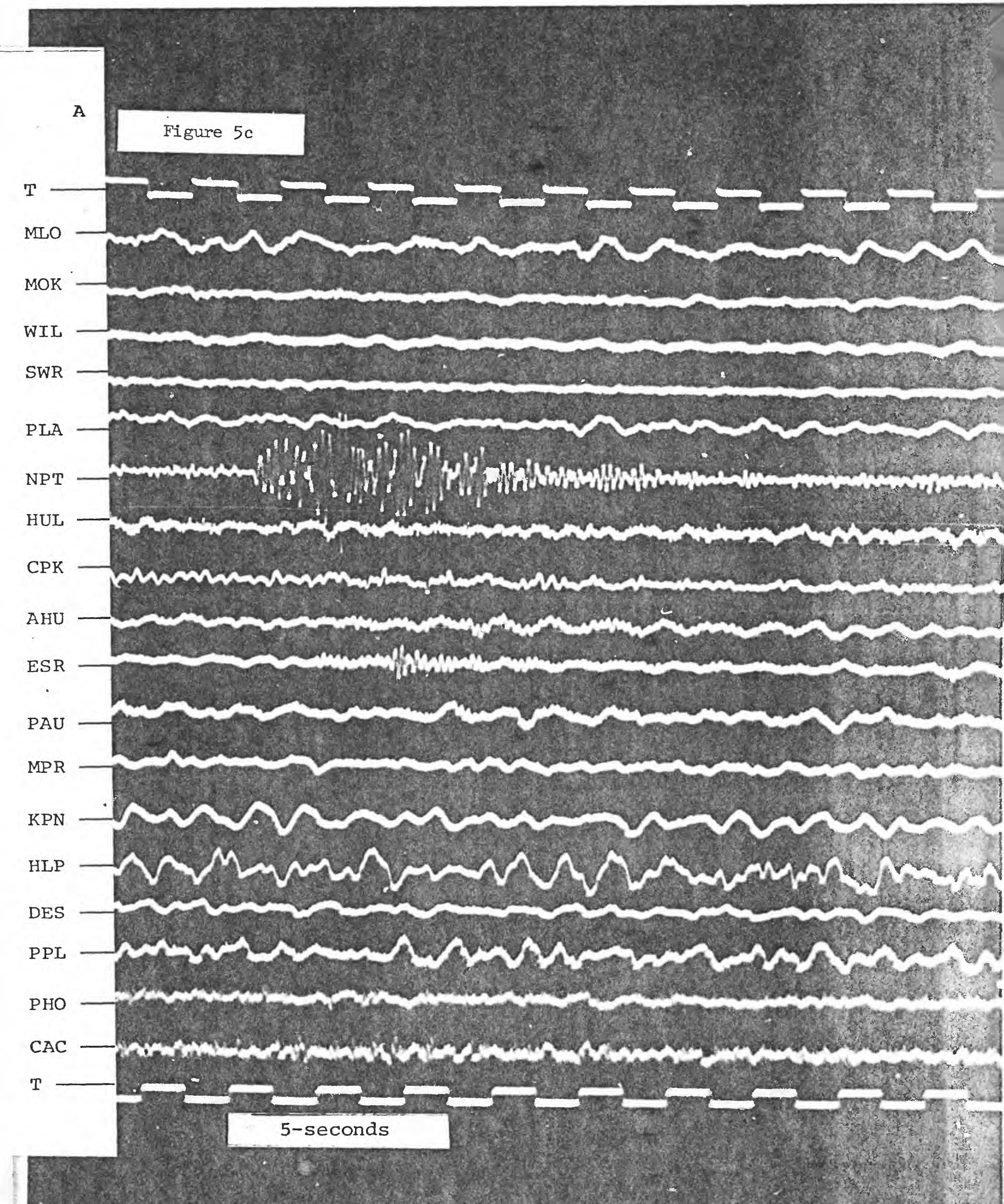
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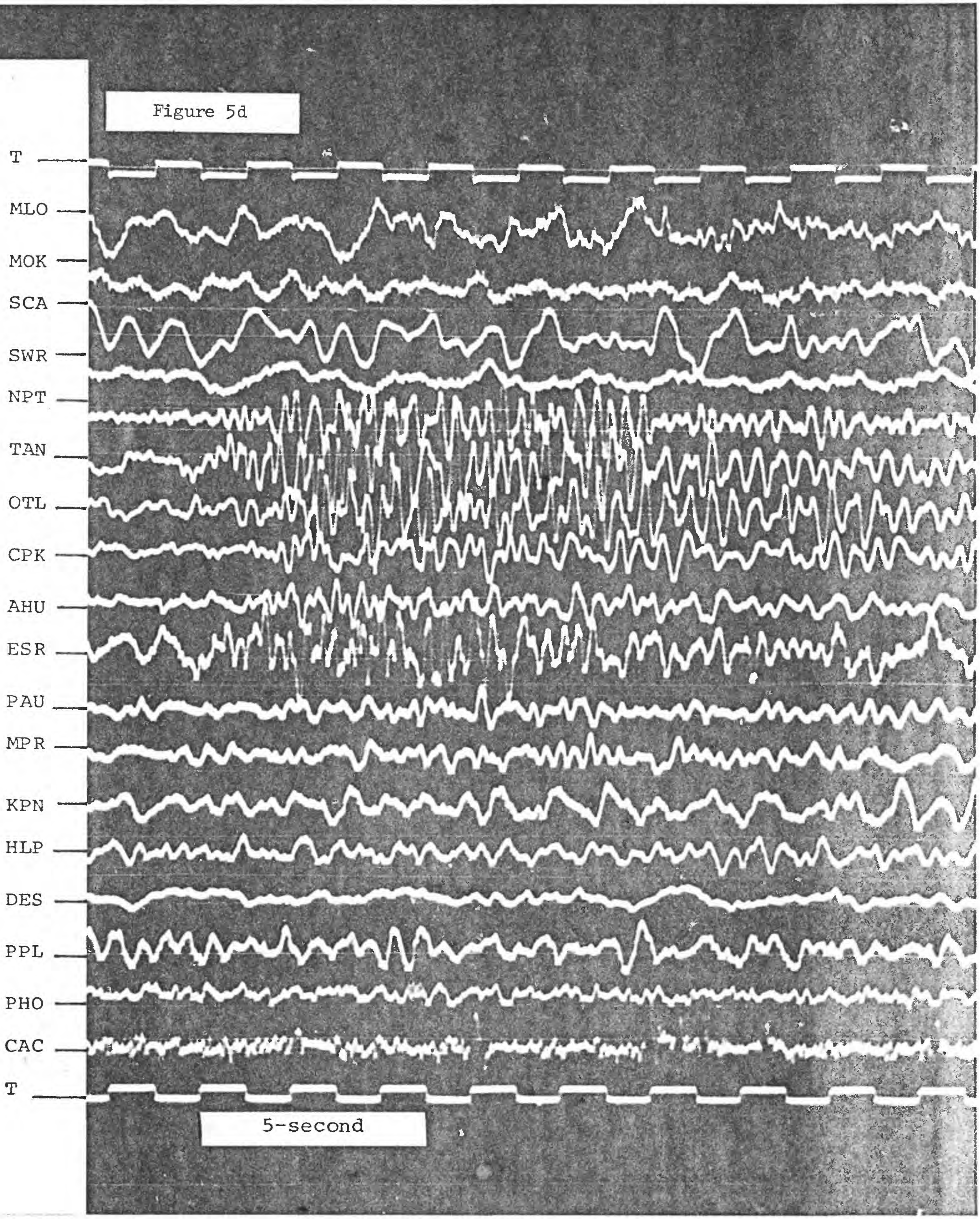
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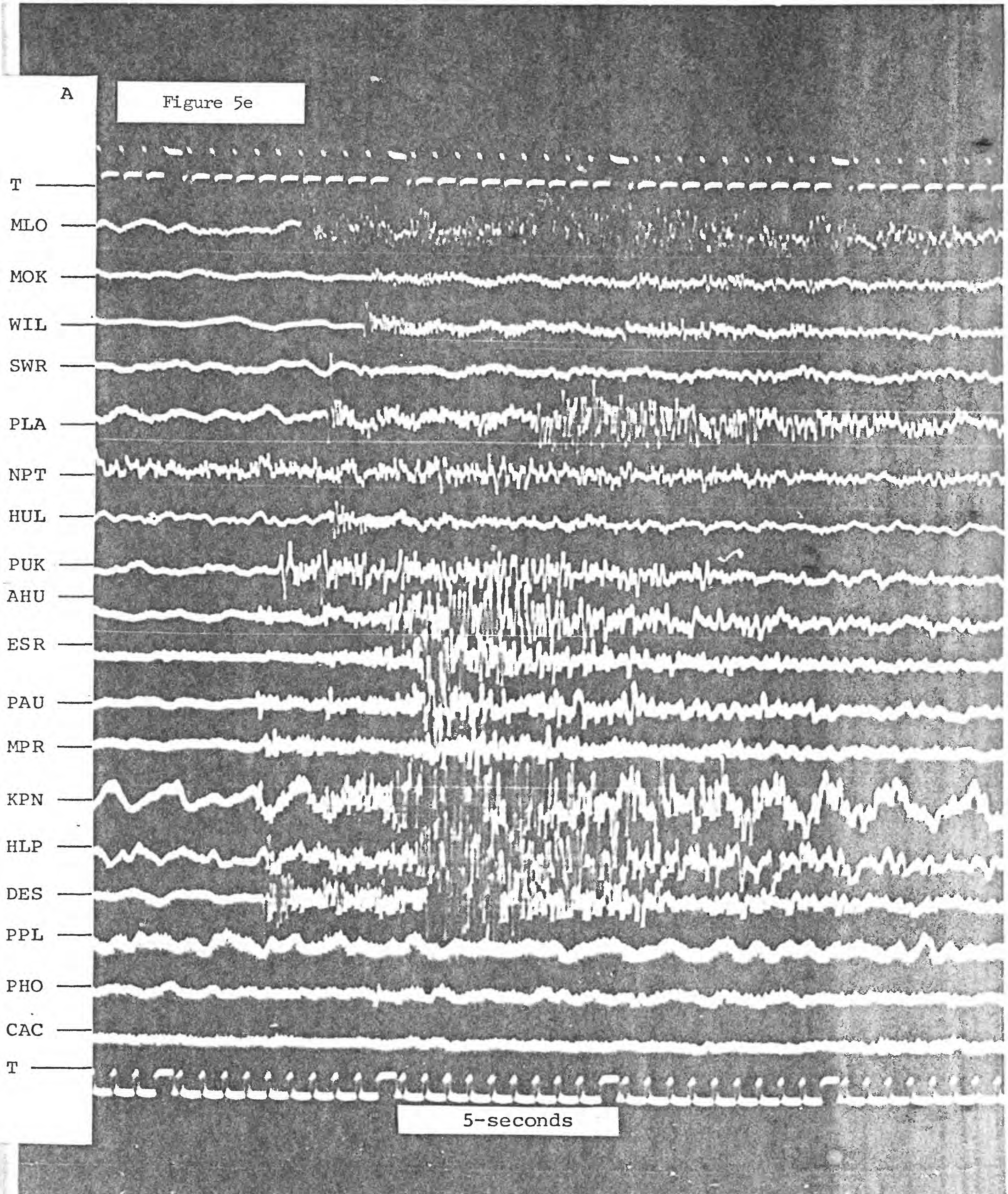
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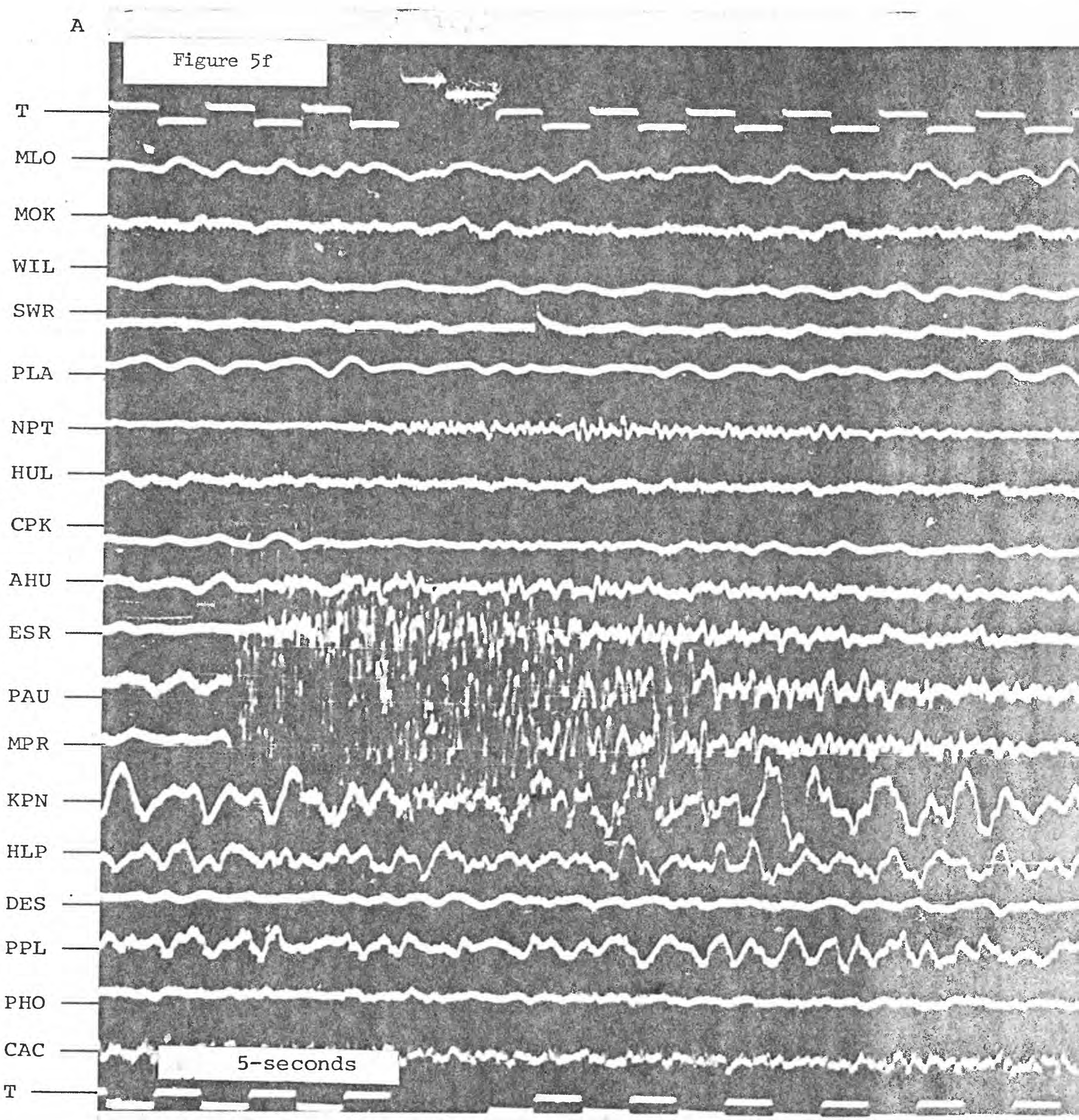
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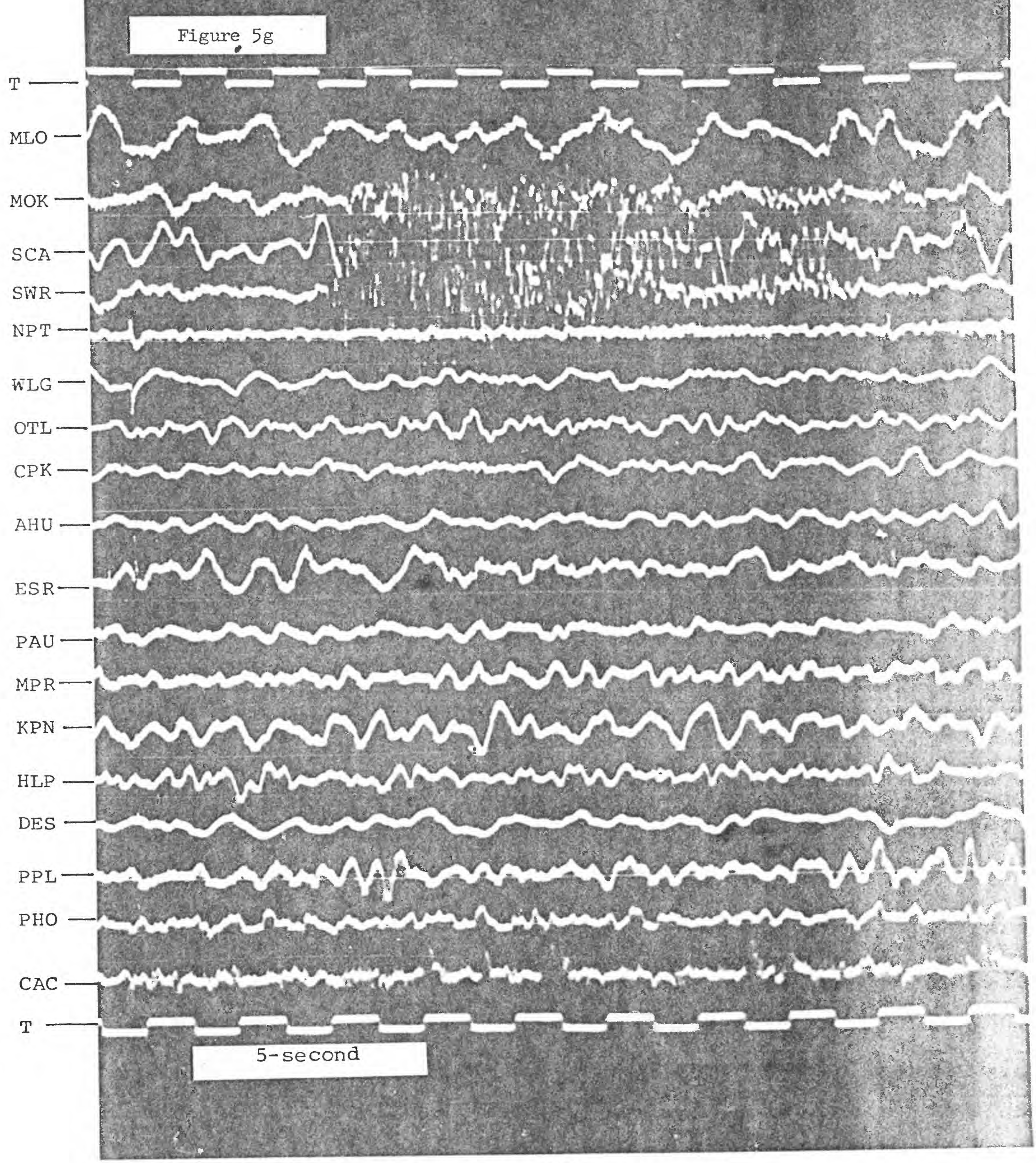
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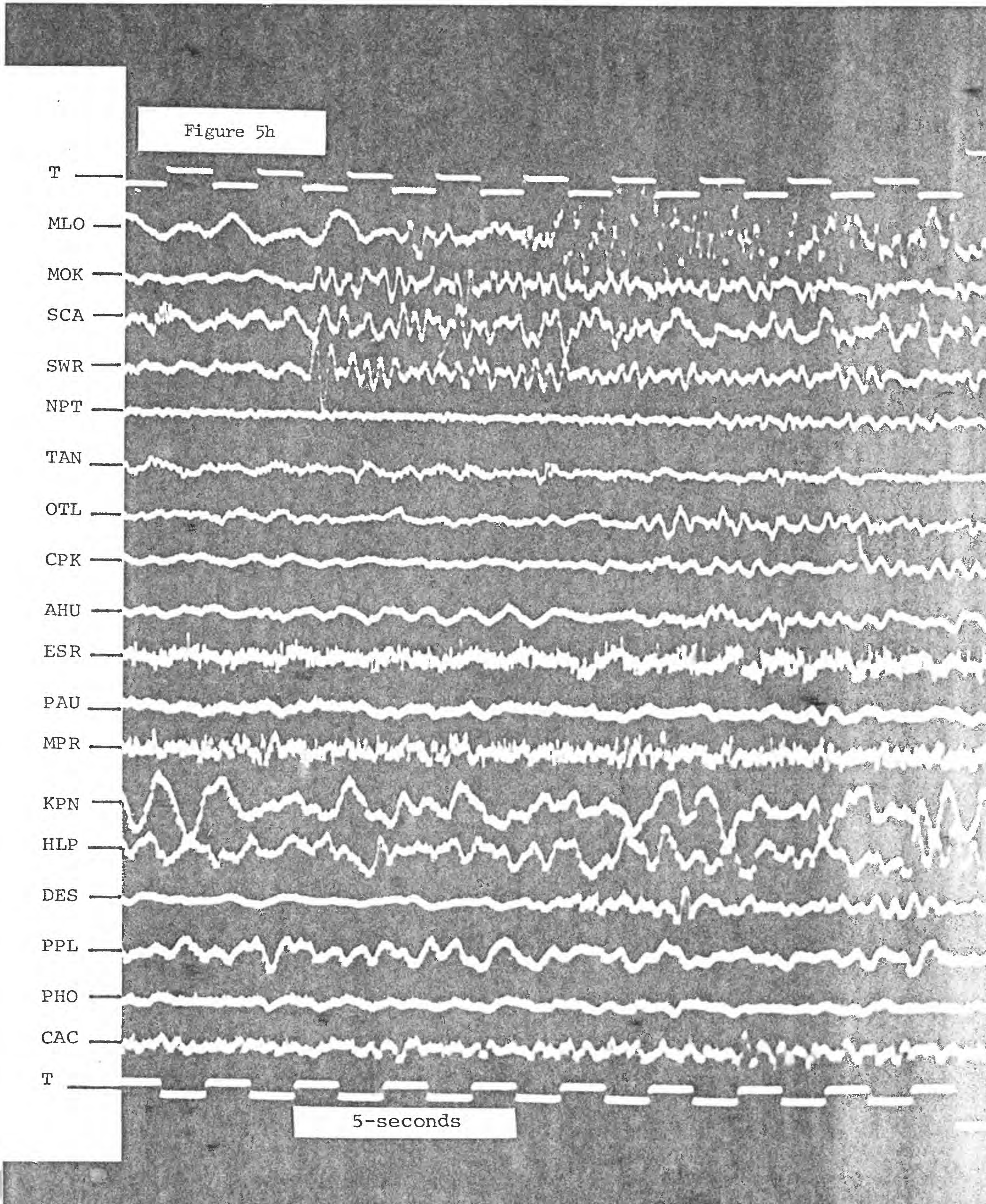

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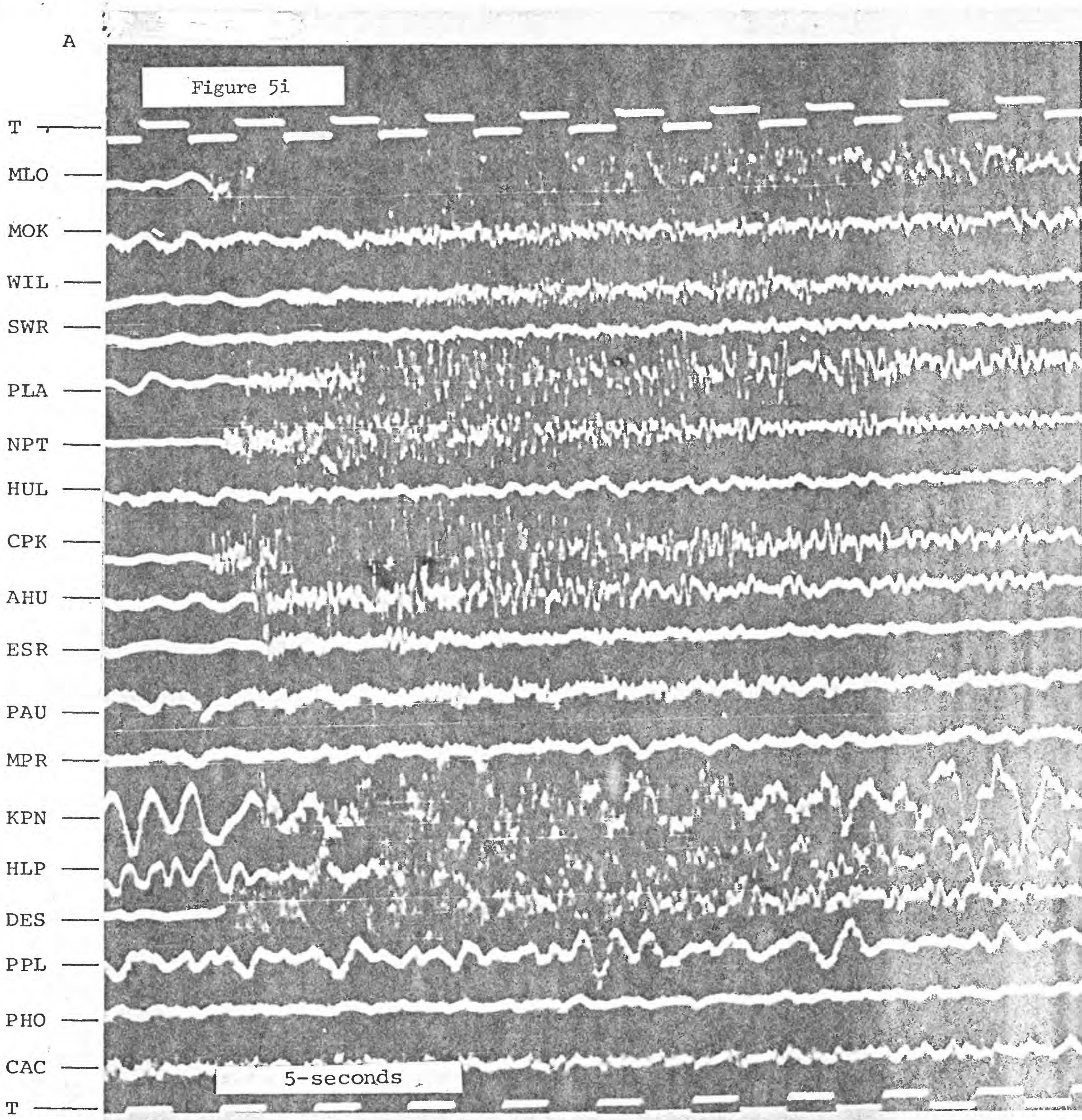
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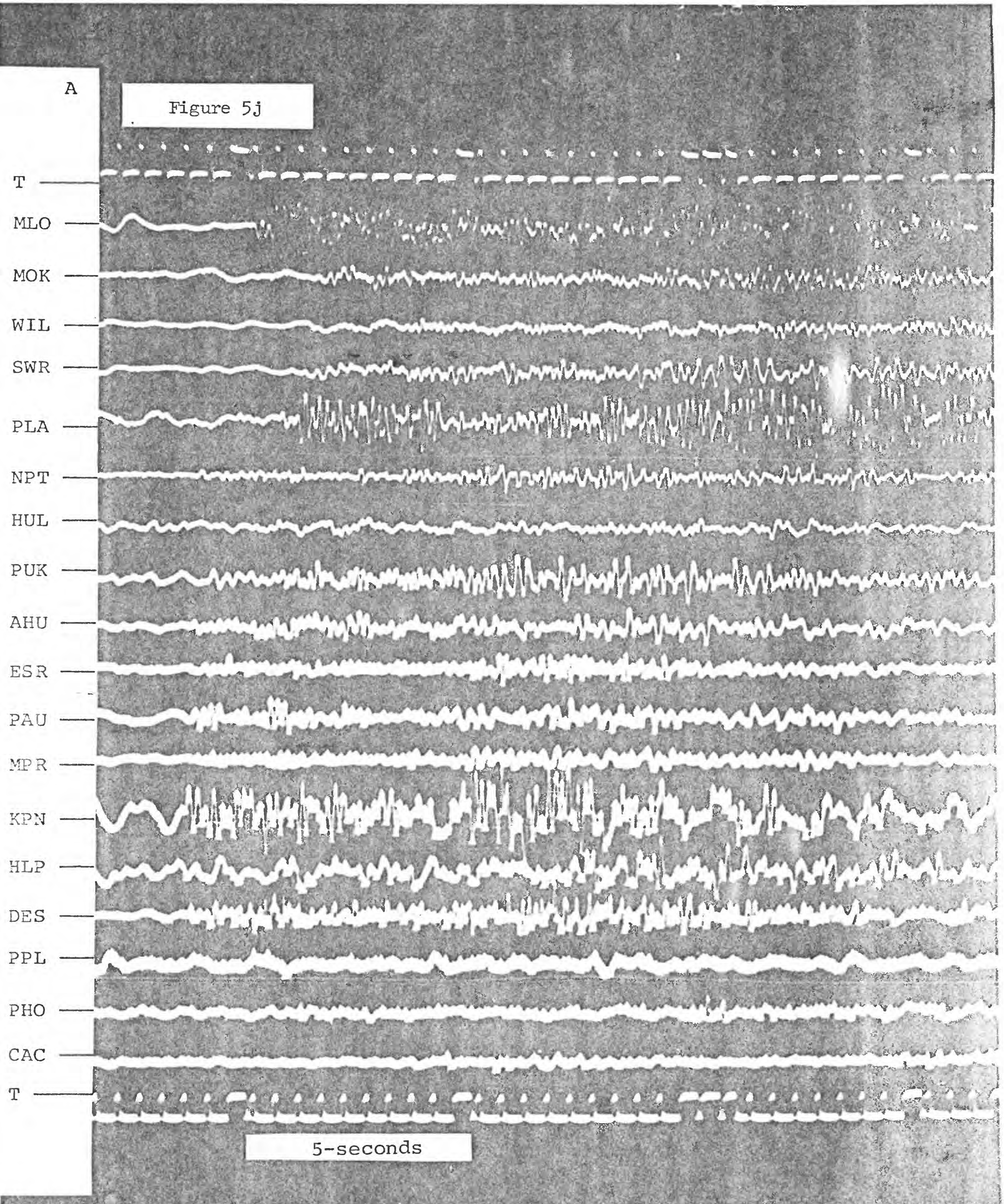
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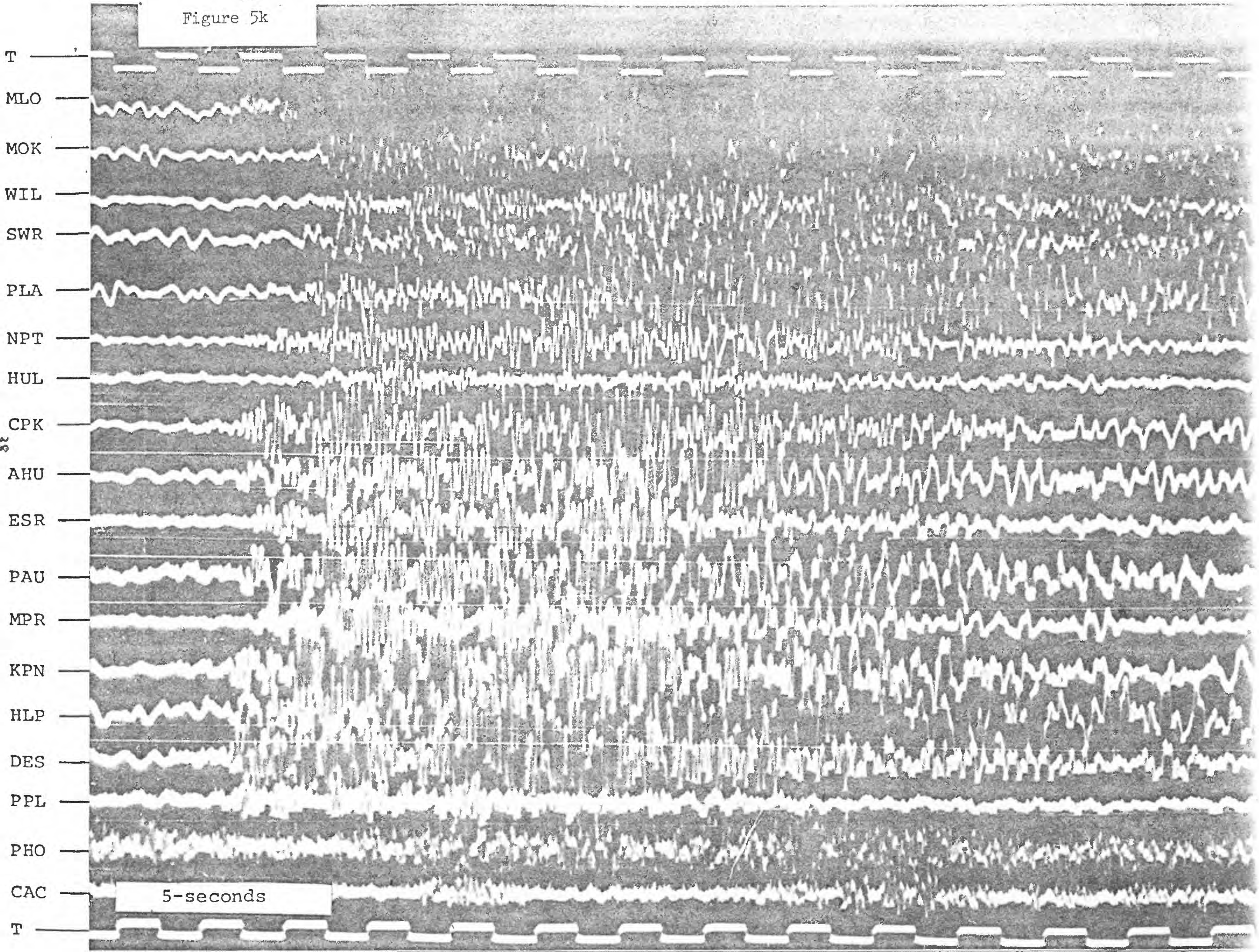
Figure 5j
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5-seconds

Figure 5k


T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
CPK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5-seconds

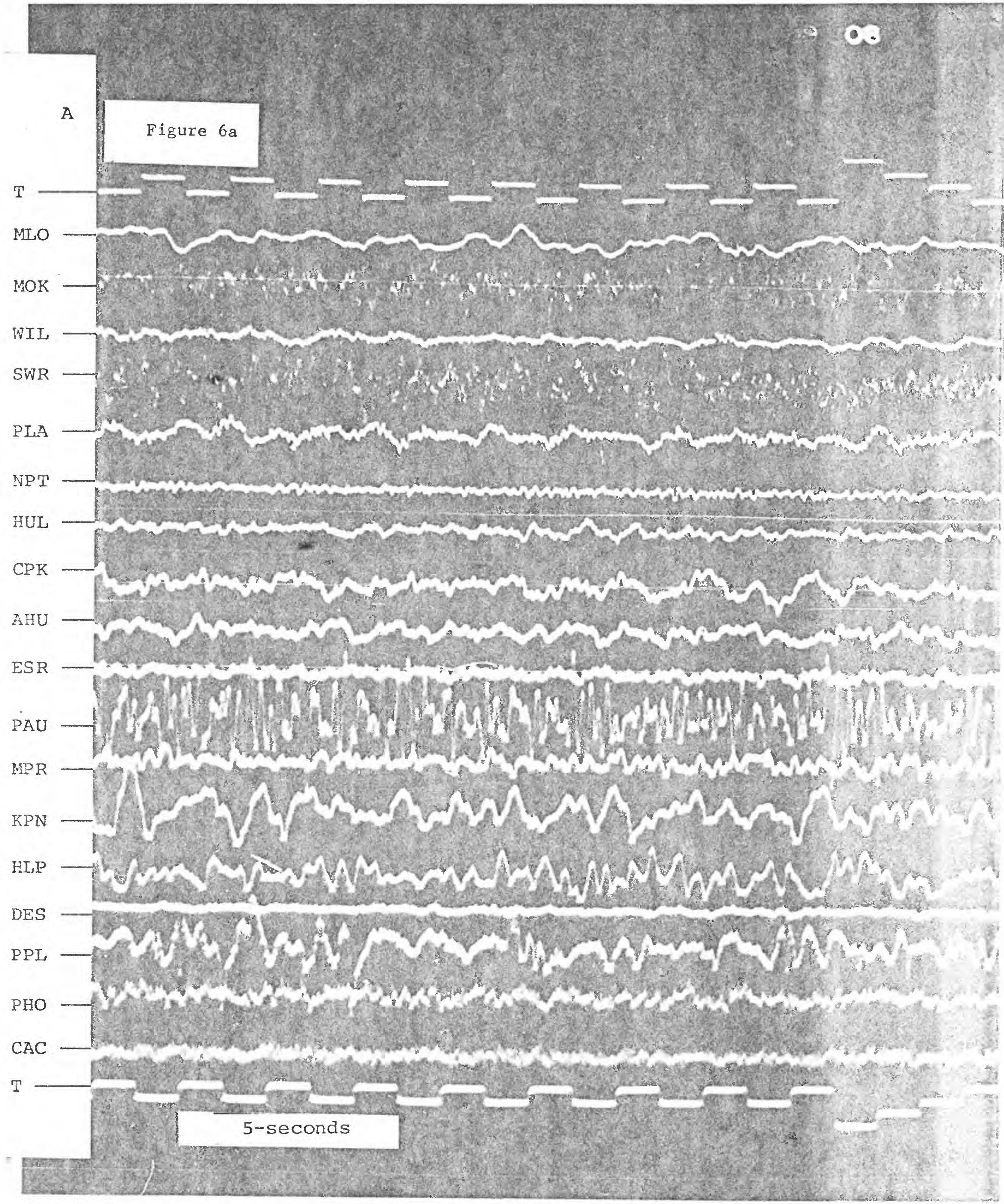
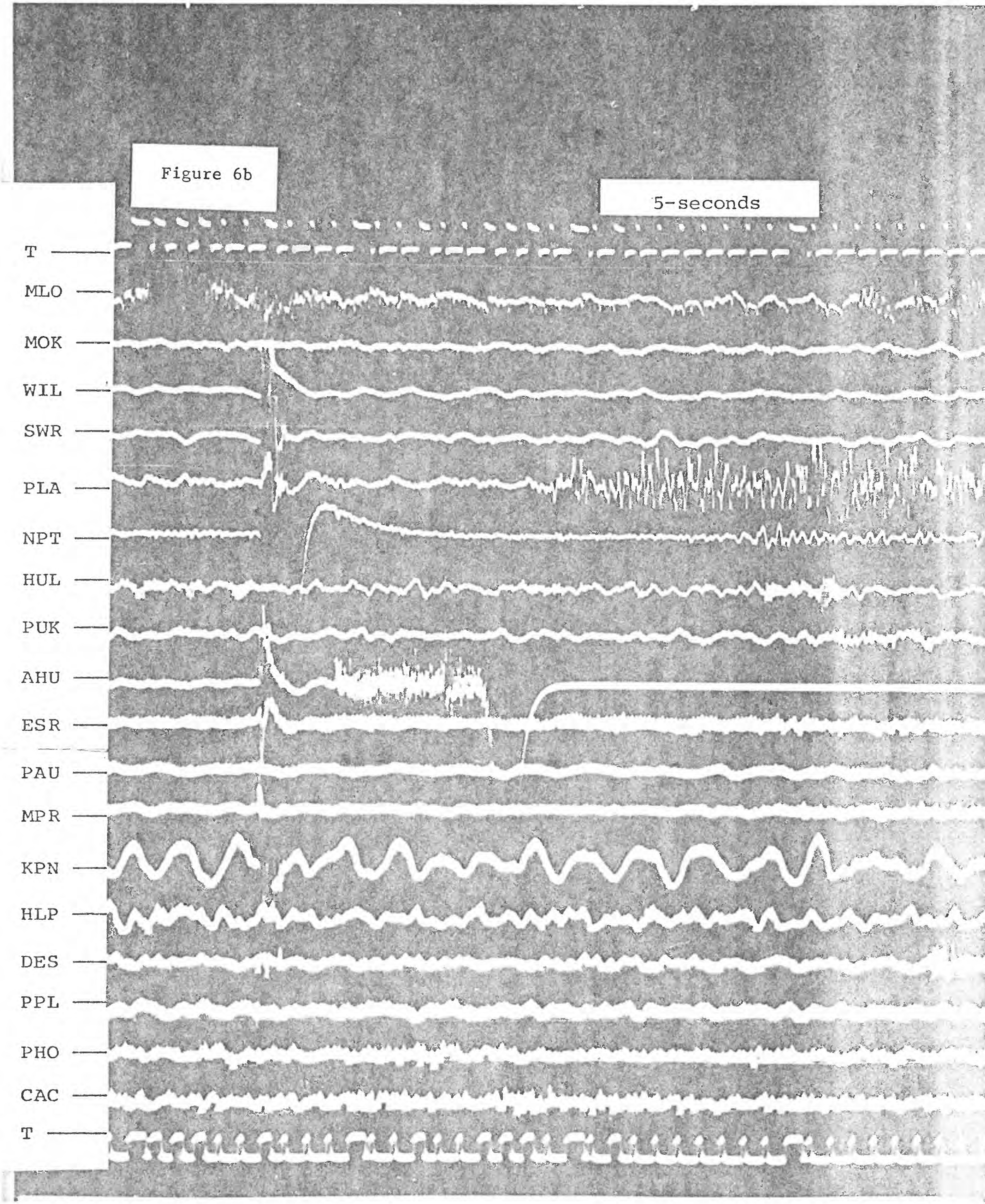

A
Figure 6a
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
CPK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5-seconds

Figure 6b


5-seconds
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T

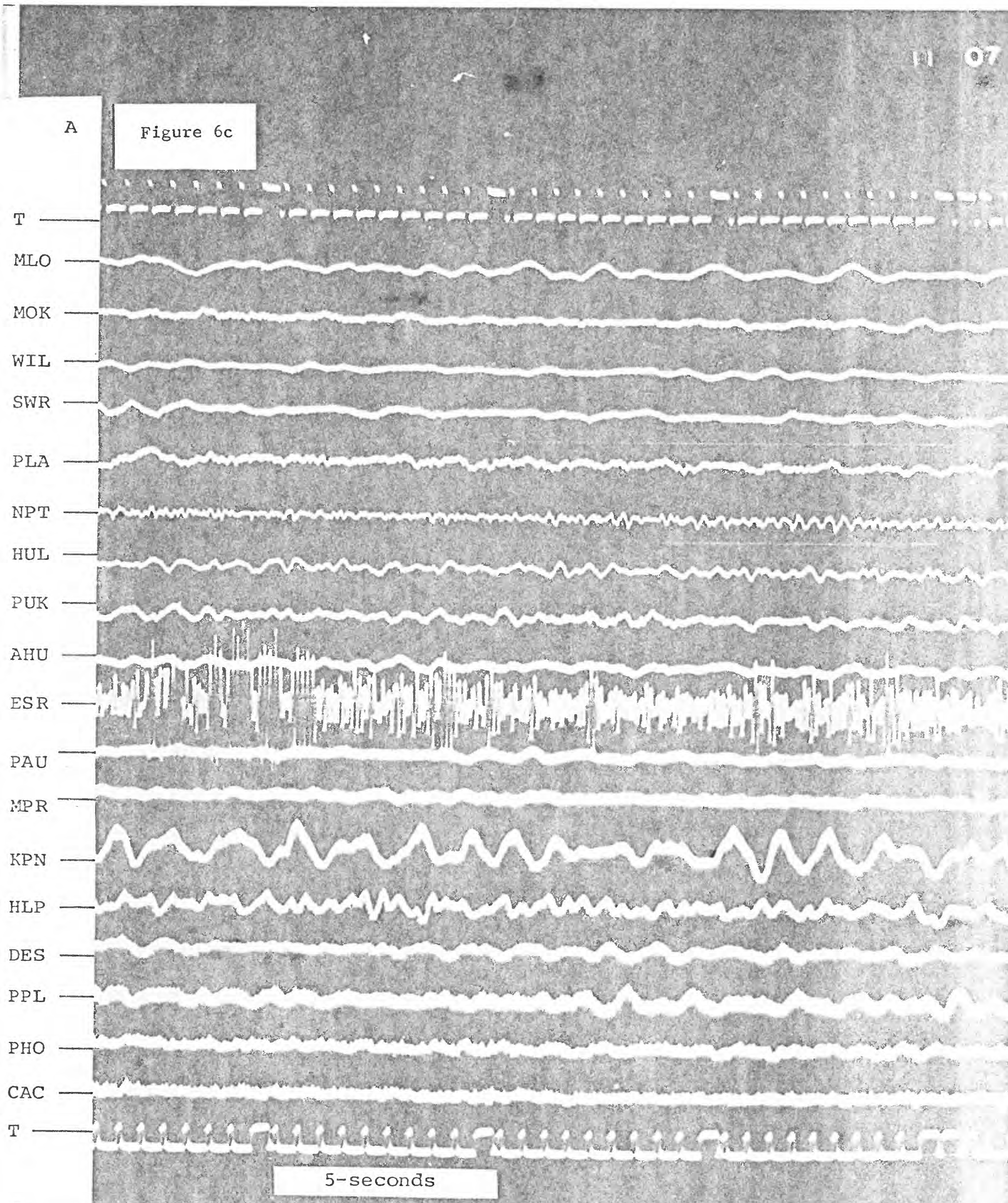
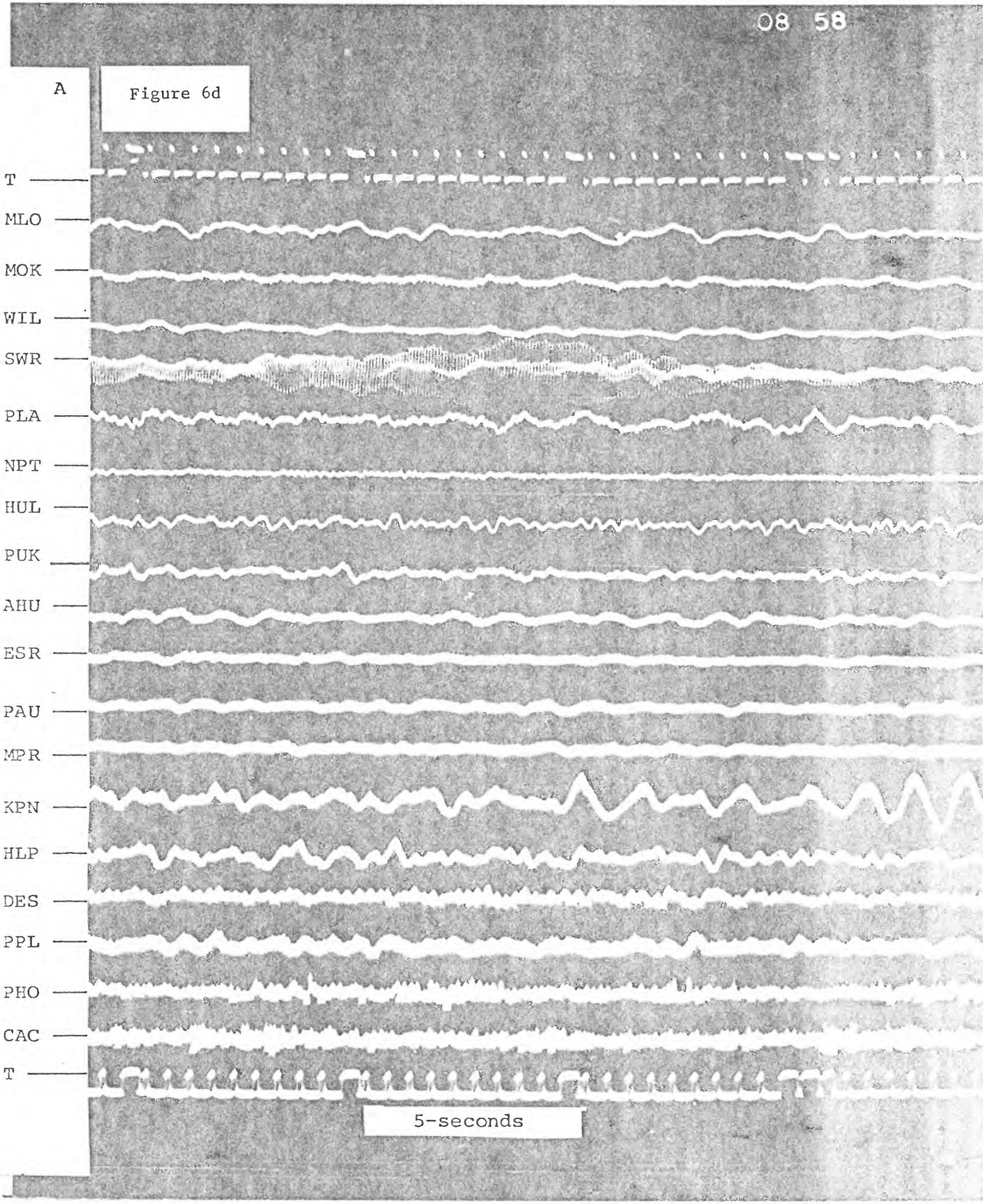
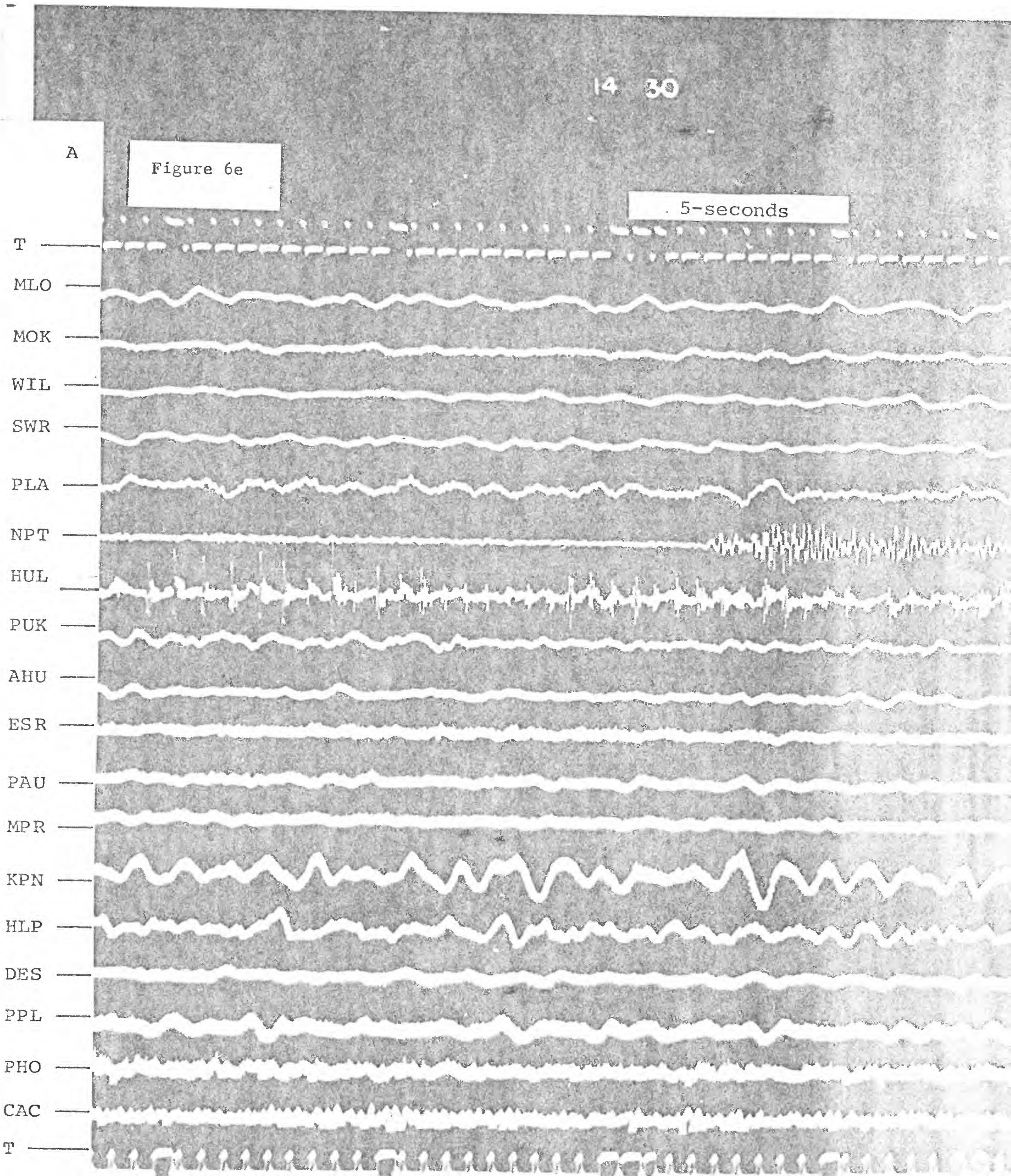

A
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5-seconds

Figure 6c


08 58
A
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5-seconds
Figure 6d


14 30
A
Figure 6e
5-seconds
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T

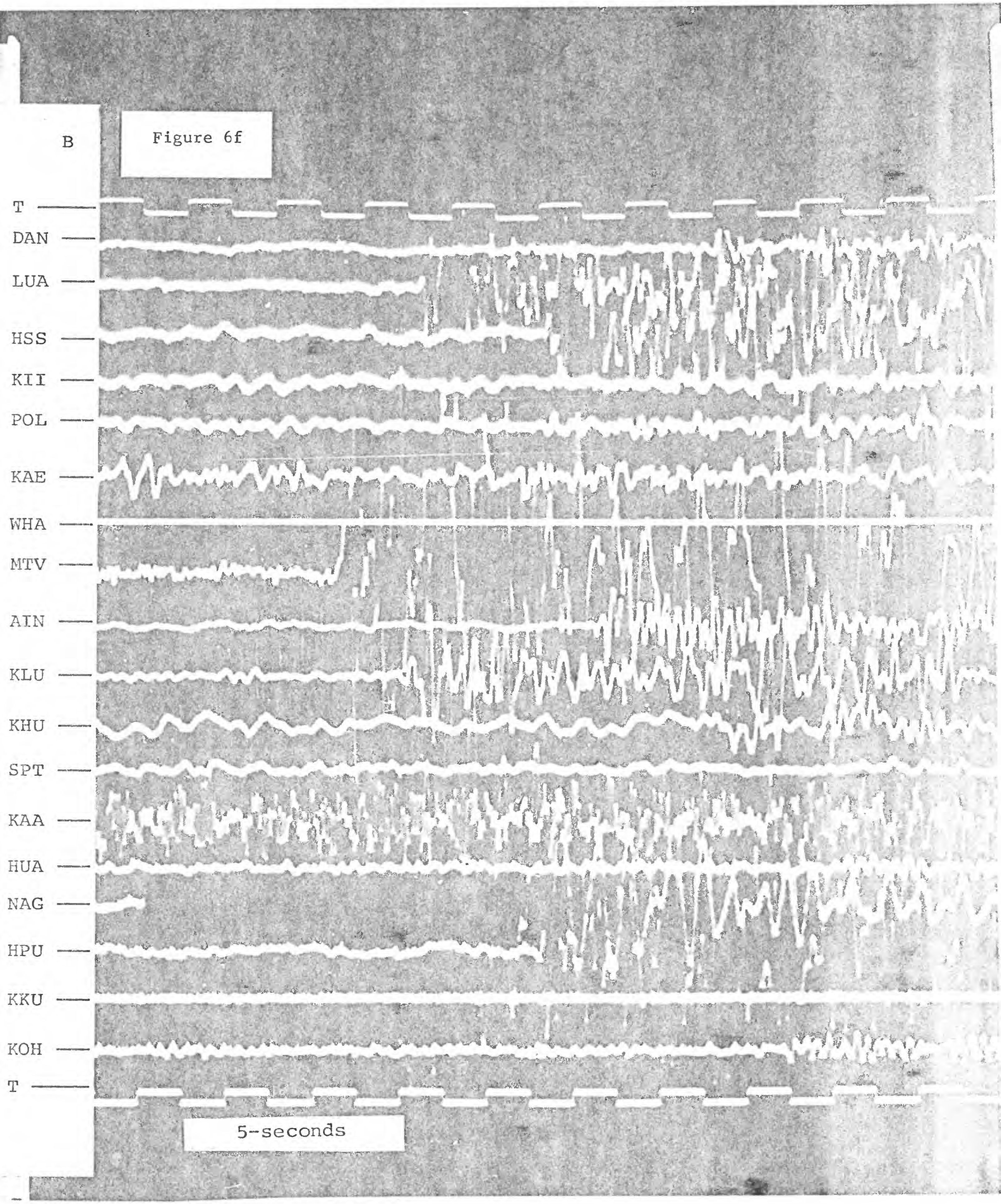
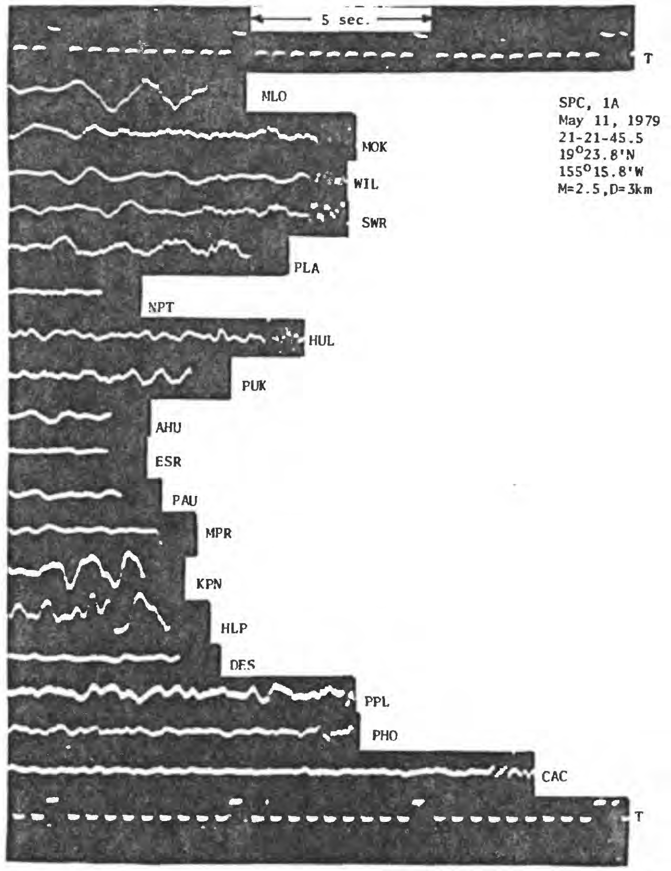
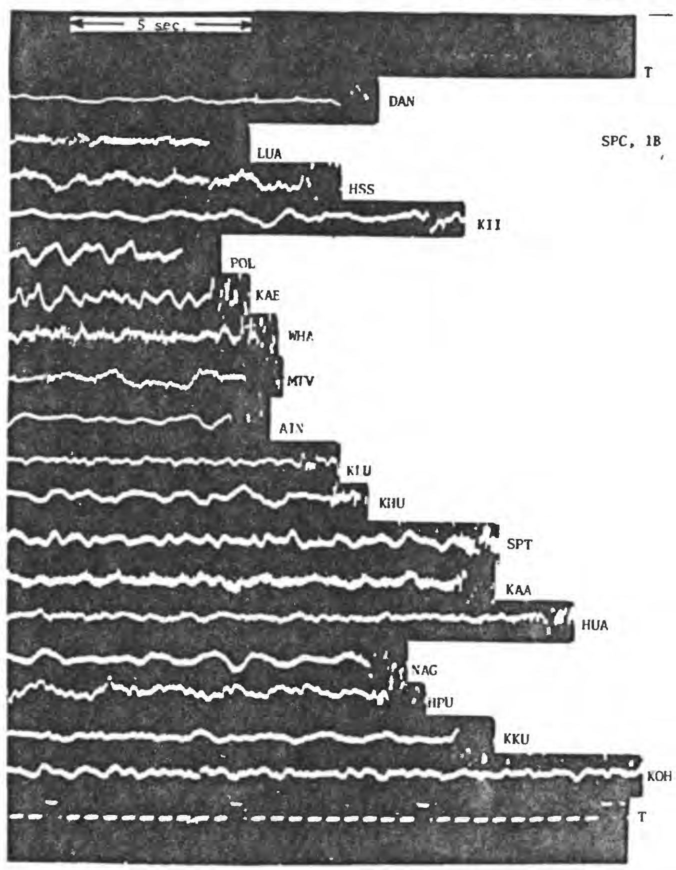

B
Figure 6f
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
5-seconds

Figure 7a


5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
SPC, 1A
May 11, 1979
21-21-45.5
19°23.8'N
155°15.8'W
M=2.5,D=3km


5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KIU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
SPC, 1B

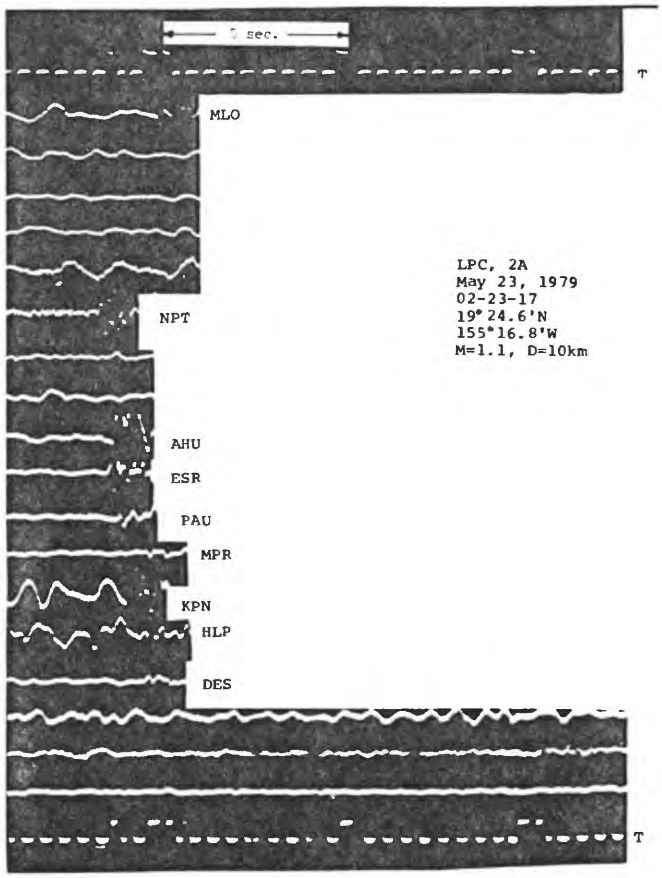
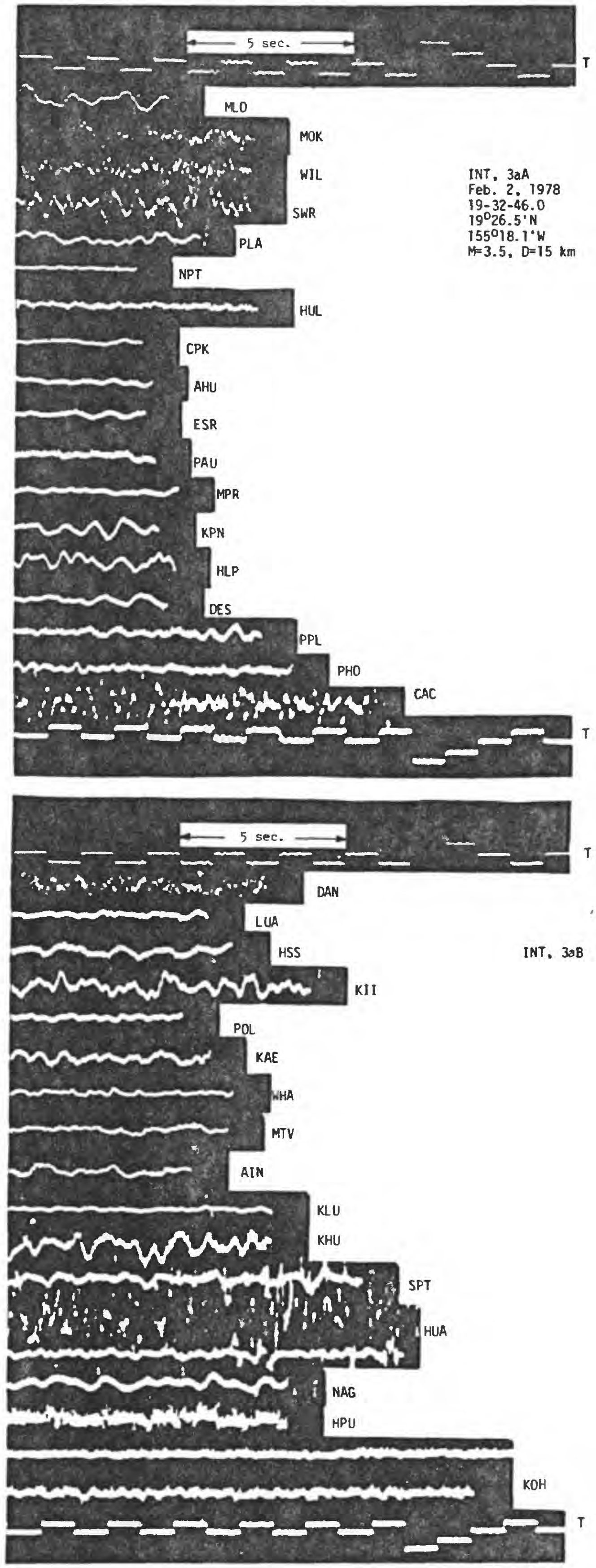

5 sec.
T
MLO
NPT
AHU
ESR
PAU
MPR
KPN
HLP
DES
T
LPC, 2A
May 23, 1979
02-23-17
19°24.6'N
155°16.8'W
M=1.1, D=10km

Figure 7b

Figure 7c



5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
CPK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
INT, 3aA
Feb. 2, 1978
19-32-46.0
19°26.5'N
155°18.1'W
M=3.5, D=15 km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
HUA
NAG
HPU
KOH
T
INT, 3aB

Figure 7d

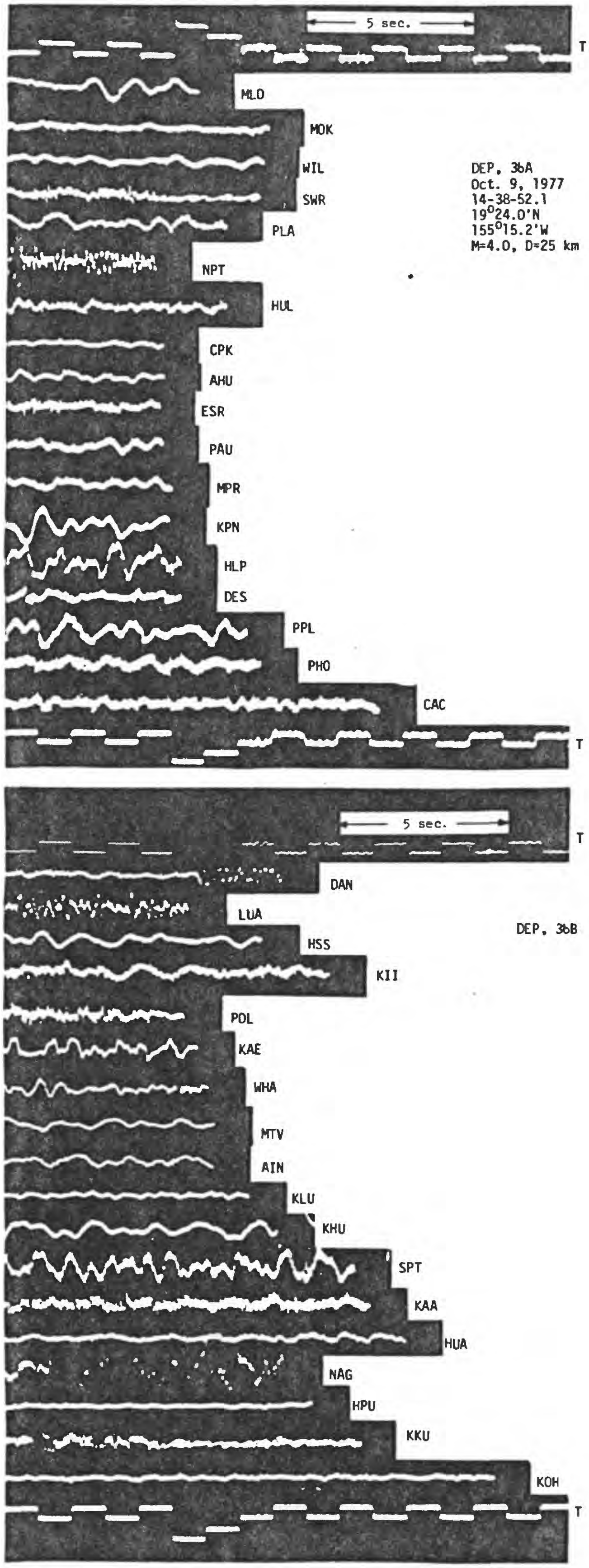

5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
CPK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
DEP, 36A
Oct. 9, 1977
14-38-52.1
19°24.0'N
155°15.2'W
M=4.0, D=25 km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
DEP, 36B

Figure 7e

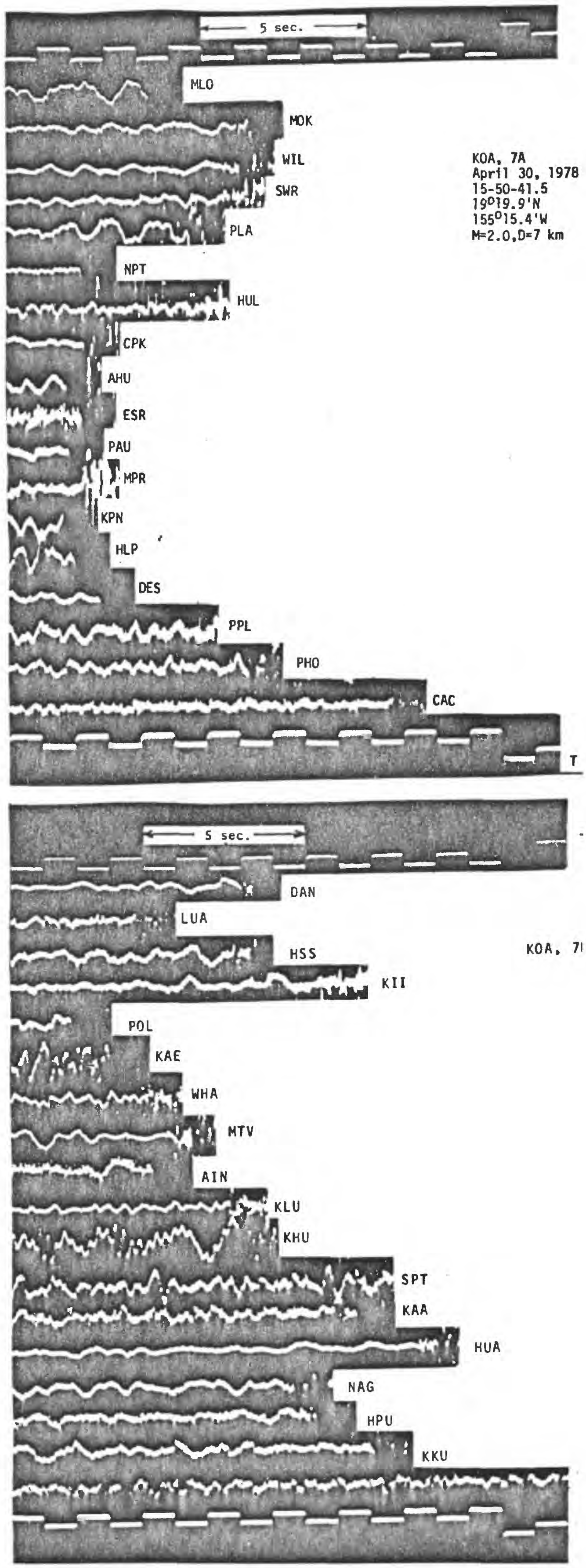
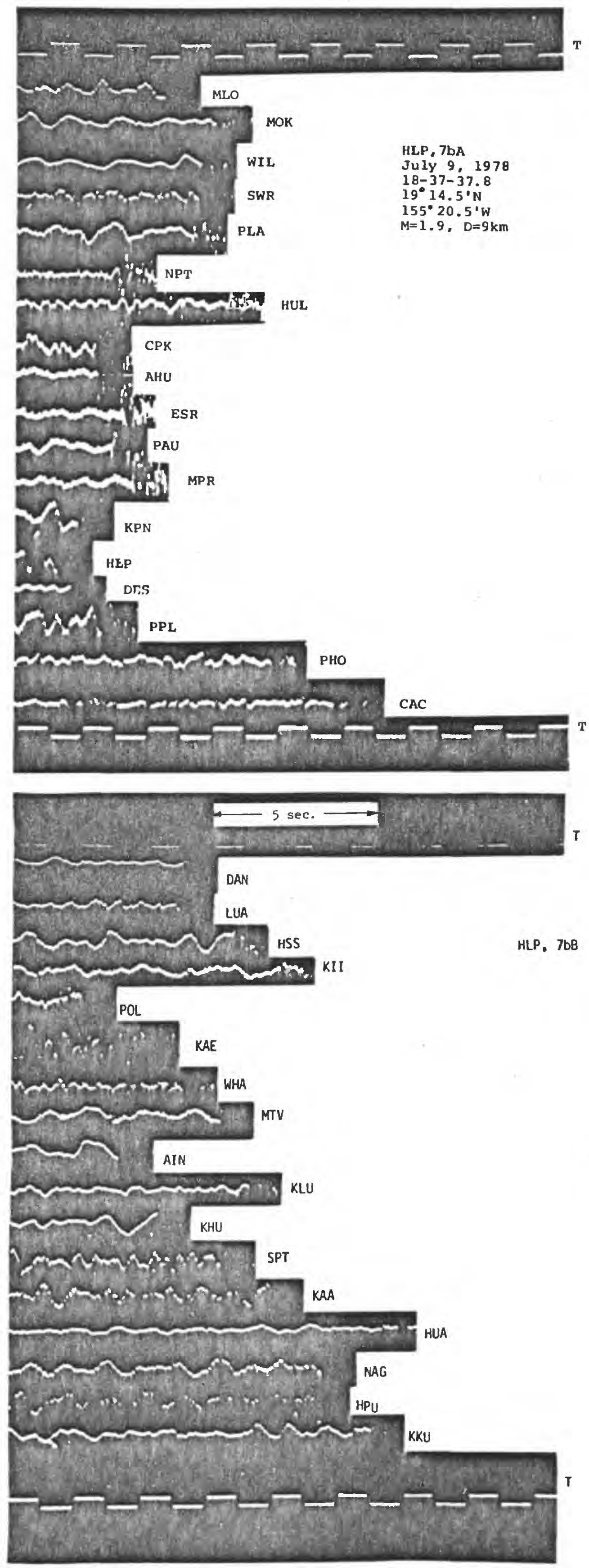

5 sec.
MLO
MOK
WIL
SWR
PLA
NPT
HUL
CPK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
KOA, 7A
April 30, 1978
15-50-41.5
19°19.9'N
155°15.4'W
M=2.0,D=7 km
5 sec.
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU

Figure 7f


T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
CPK
AHU
ESR
PAU
MPR
KPN
HLP
PPL
PHO
CAC
T
HLP,7bA
July 9, 1978
18-37-37.8
19°14.5'N
155°20.5'W
M=1.9, D=9km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
T
HLP, 7bB

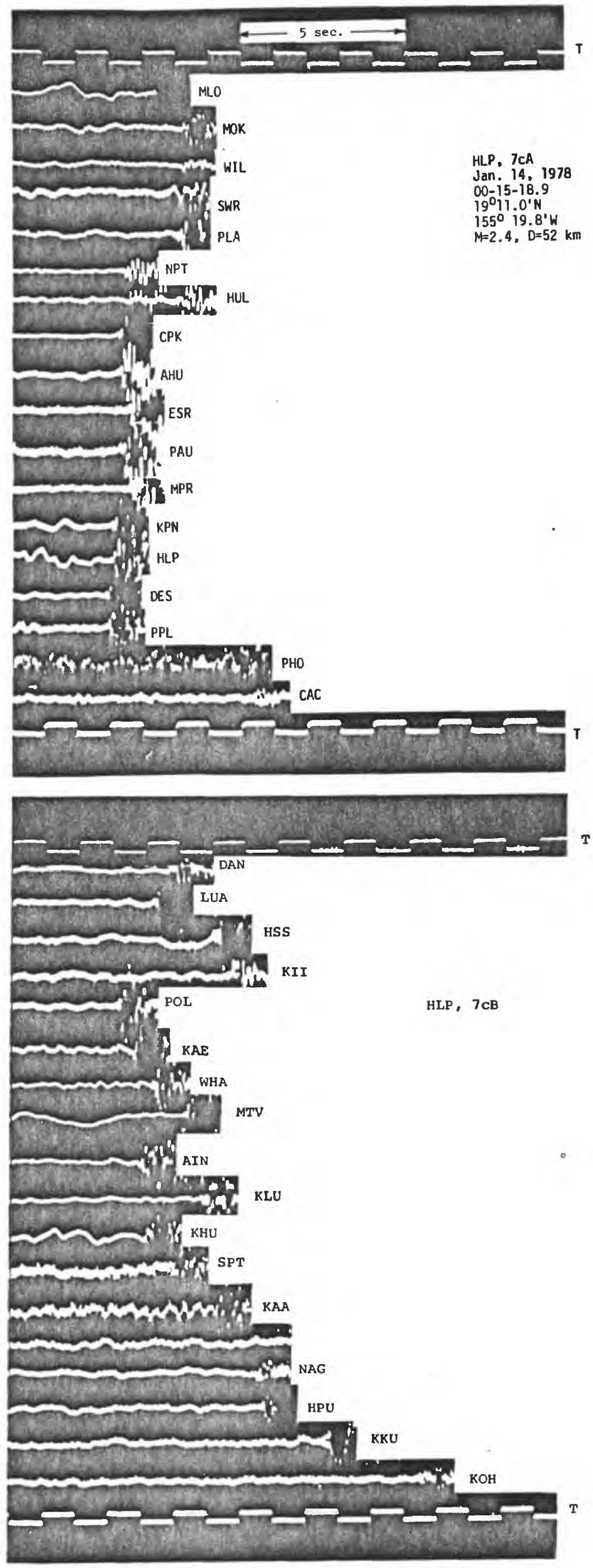
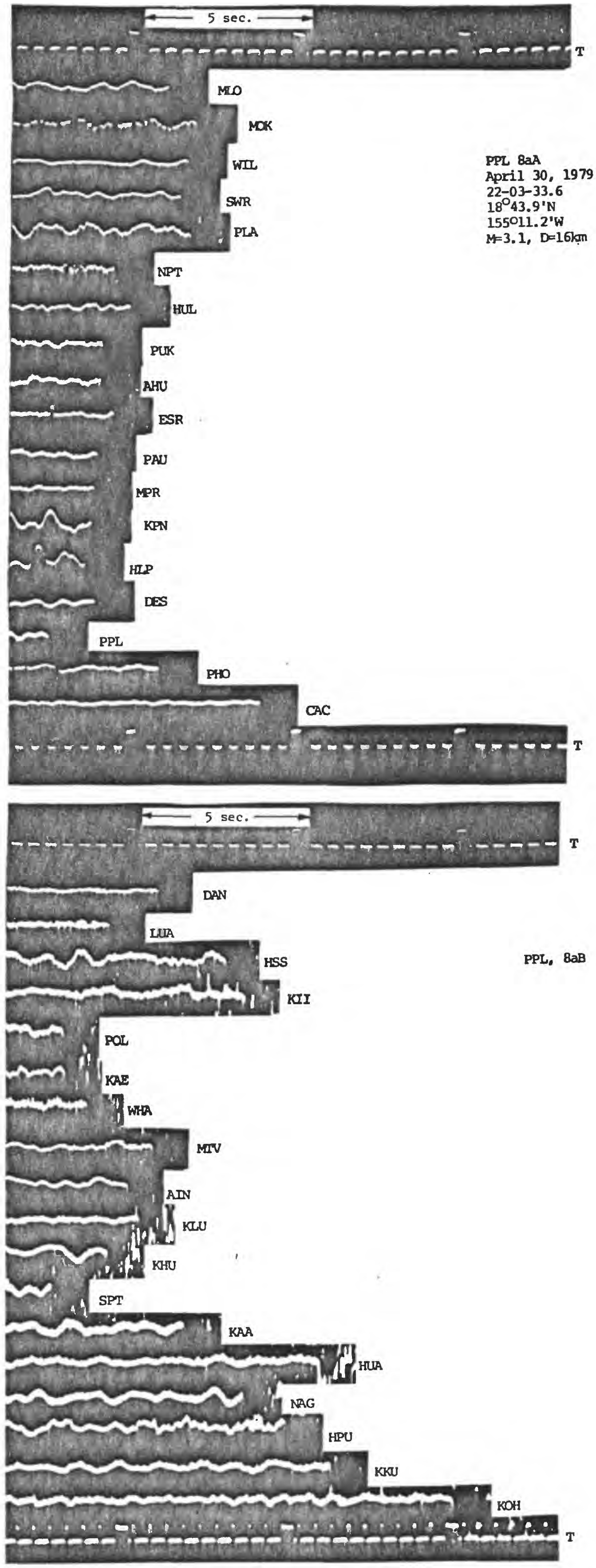

5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
CPK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
HLP, 7cA
Jan. 14, 1978
00-15-18.9
19°11.0'N
155° 19.8'W
M=2.4, D=52 km
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
NAG
HPU
KKU
KOH
T
HLP, 7cB

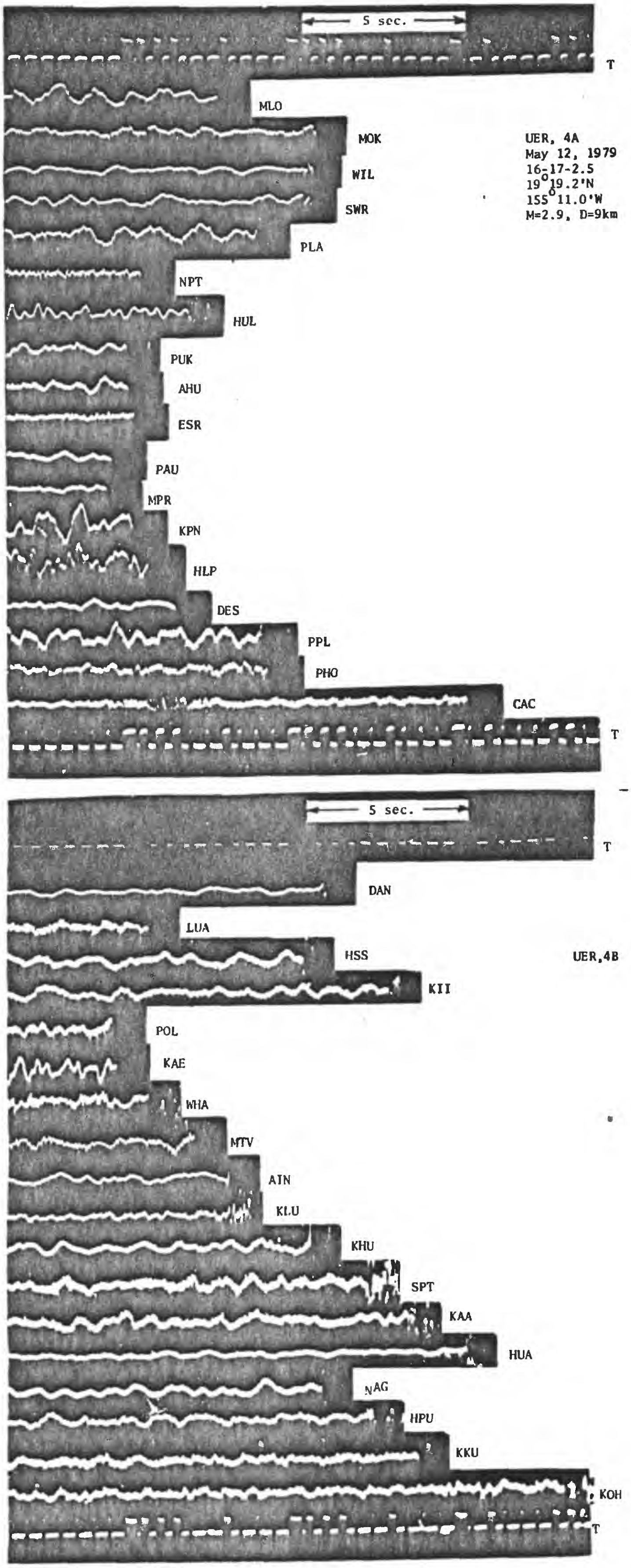
Figure 7g

Figure 7h



5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
PPL 8aA
April 30, 1979
22-03-33.6
18°43.9'N
155°11.2'W
M=3.1, D=16km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
PPL, 8aB

Figure 7i


5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
UER, 4A
May 12, 1979
16-17-2.5
19°19.2'N
155°11.0'W
M=2.9, D=9km
5 sec.
T
DAN
LUA
HSS
KII
UER,4B
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T

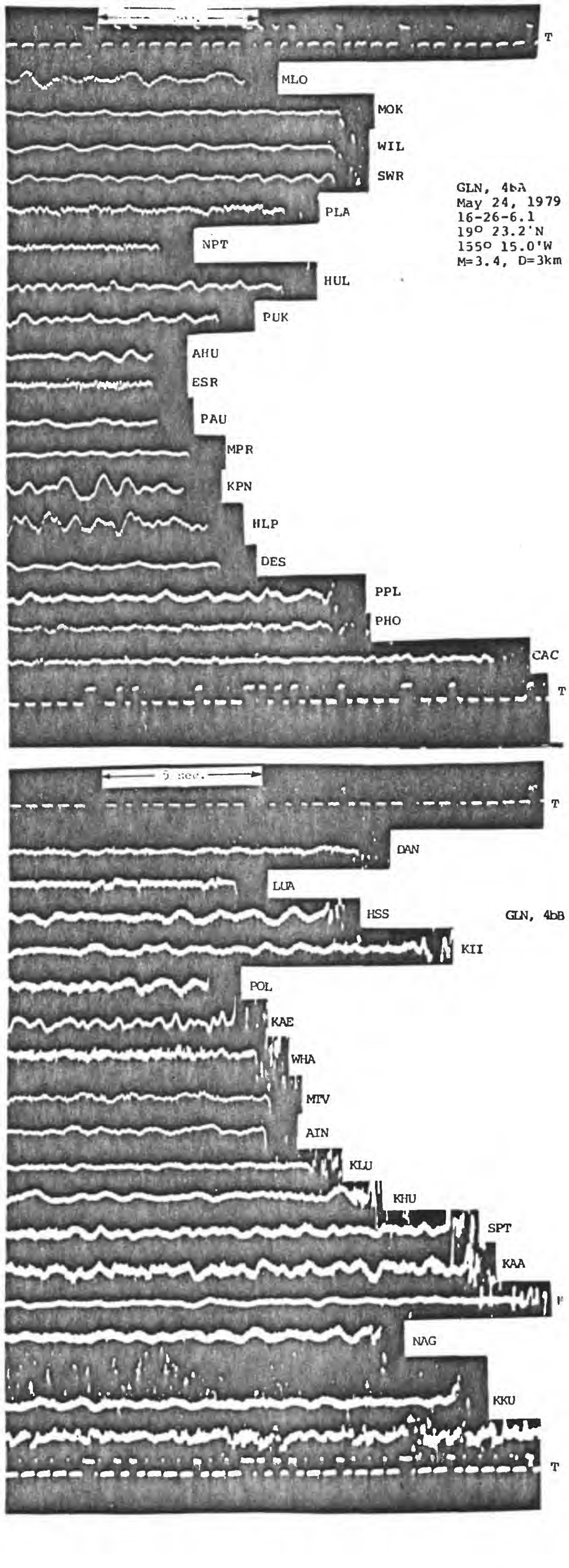

T
MLO
MOK
WIL
SWR
GLN, 4bA
May 24, 1979
16-26-6.1
19° 23.2'N
155° 15.0'W
M=3.4, D=3km
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5 sec.
T
DAN
LUA
HSS
GLN, 4bB
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
NAG
KKU
T

Figure 7j

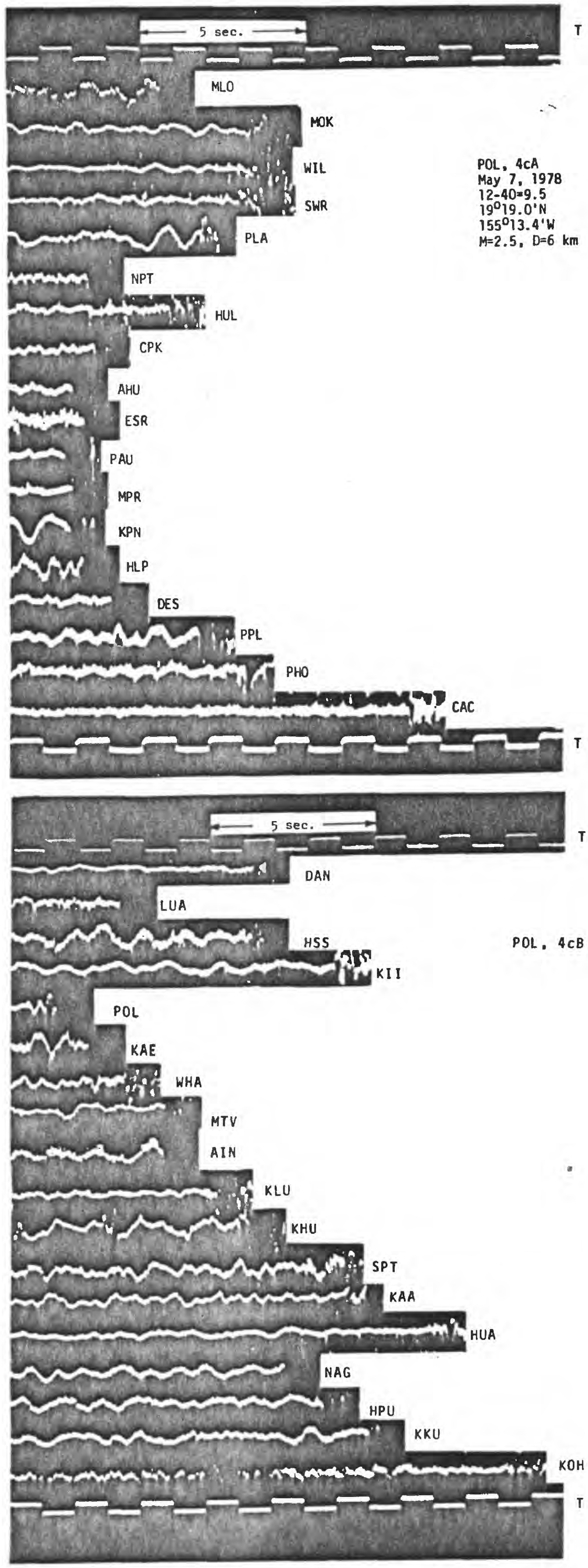

5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
CPK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
POL, 4cA
May 7, 1978
12-40=9.5
19°19.0'N
155°13.4'W
M=2.5, D=6 km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
POL, 4cB

Figure 7k

Figure 71

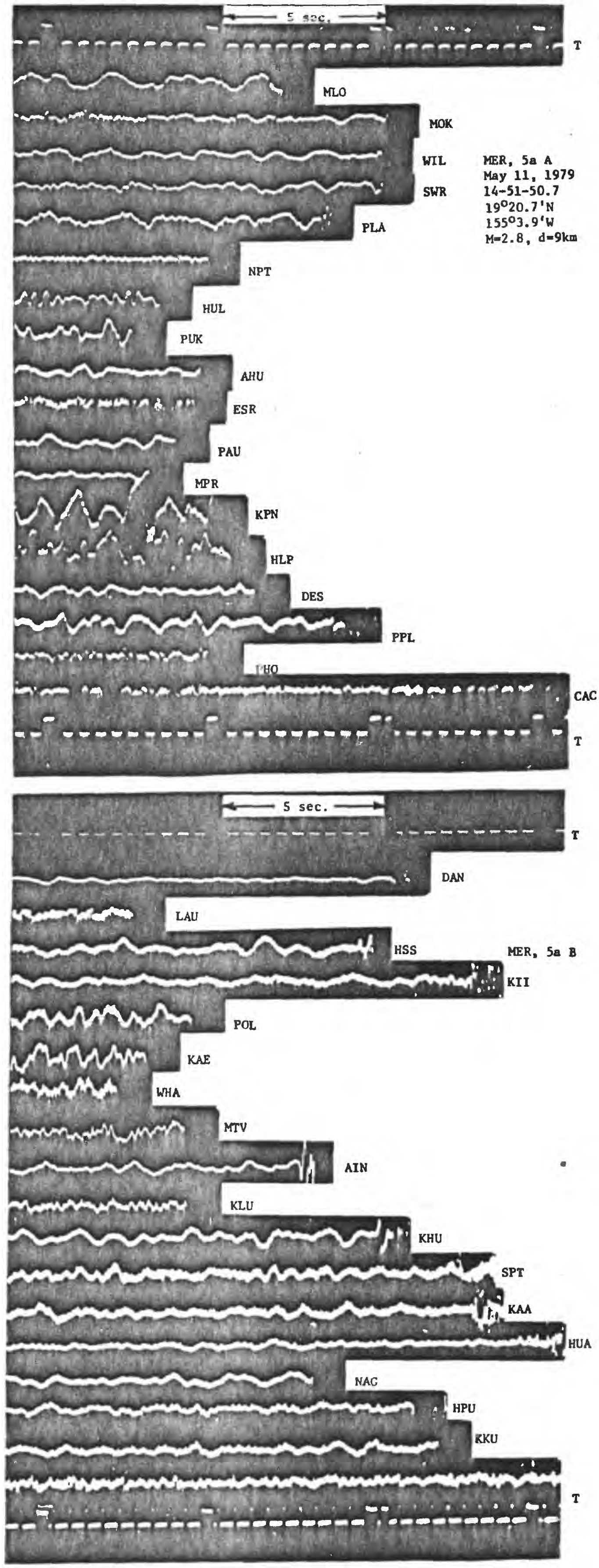

5 sec.
T
MLO
MOK
WIL
SWR
MER, 5a A
May 11, 1979
14-51-50.7
19°20.7'N
155°3.9'W
M=2.8, d=9km
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5 sec.
T
DAN
LAU
HSS
MER, 5a B
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAC
HPU
KKU
T

Figure 7m

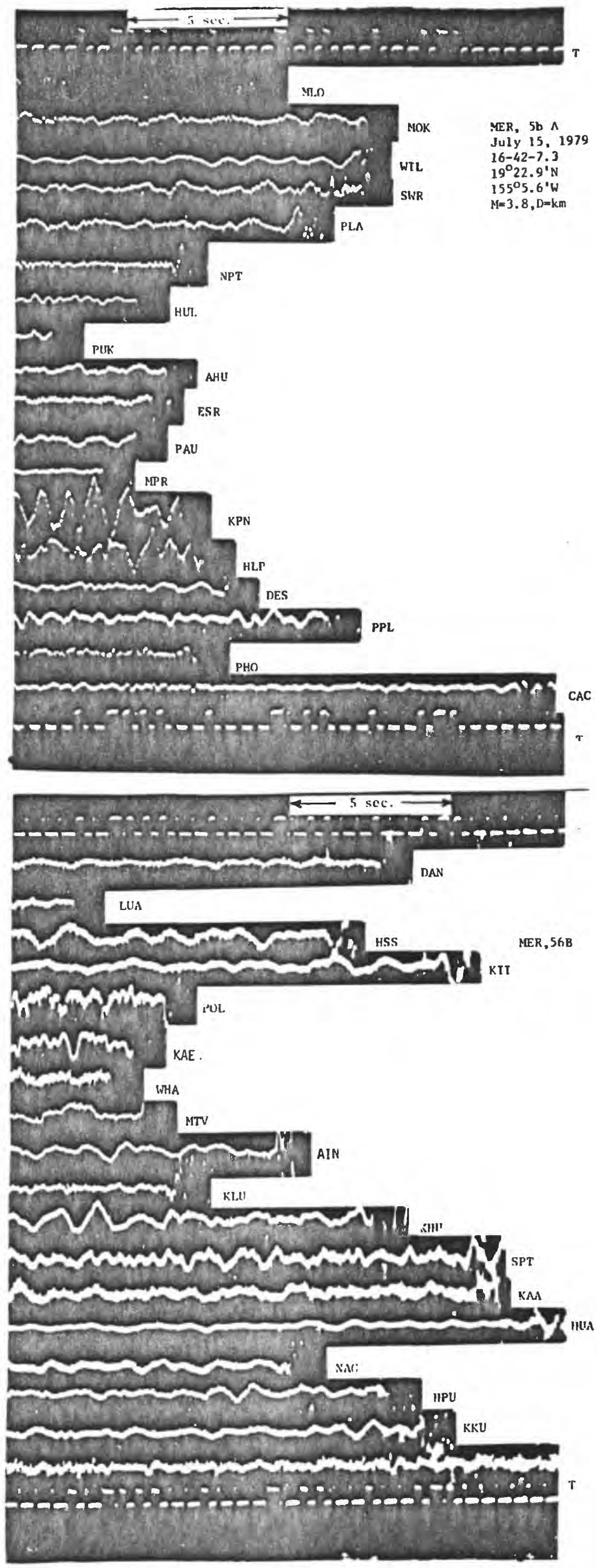
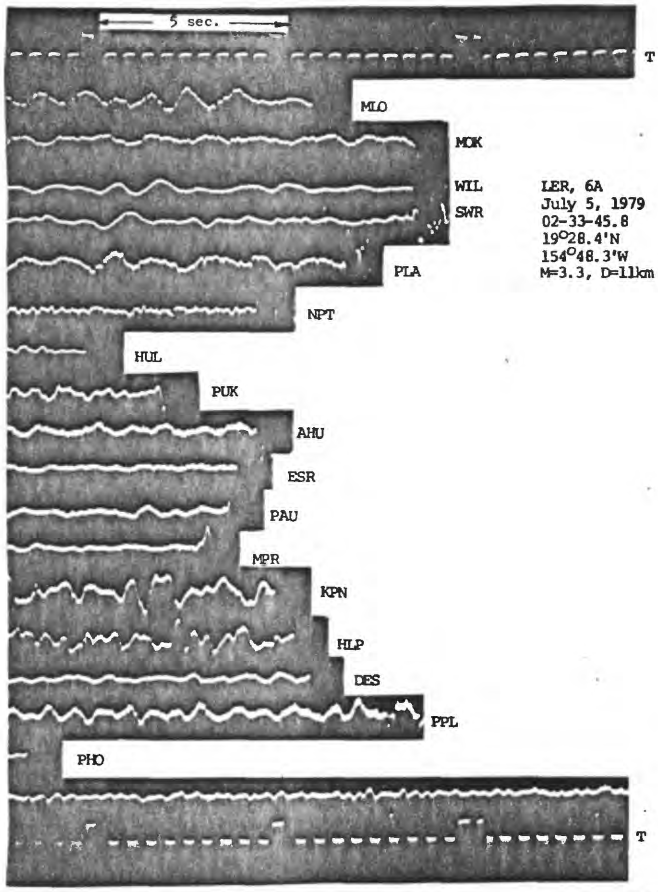

5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
MER, 5b A
July 15, 1979
16-42-7.3
19°22.9'N
155°5.6'W
M=3.8,D=km
5 sec.
DAN
LUA
HSS
MER,56B
KII
POL
KAE
WHA
MTV
AIN
KLU
SPT
KAA
HUA
NAG
HPU
KKU
T

Figure 7n


5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
T
LER, 6A
July 5, 1979
02-33-45.8
19°28.4'N
154°48.3'W
M=3.3, D=11km

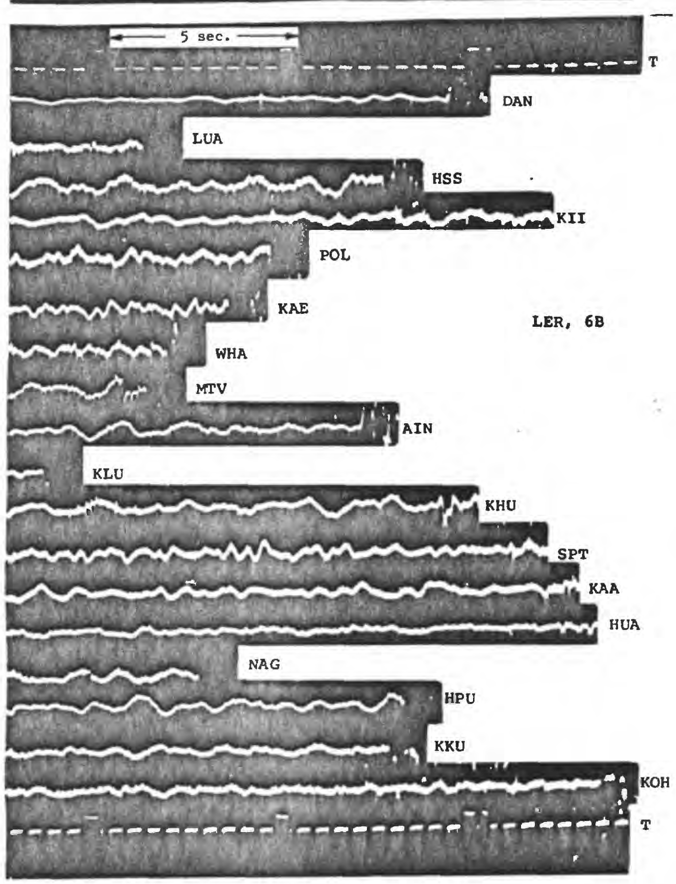
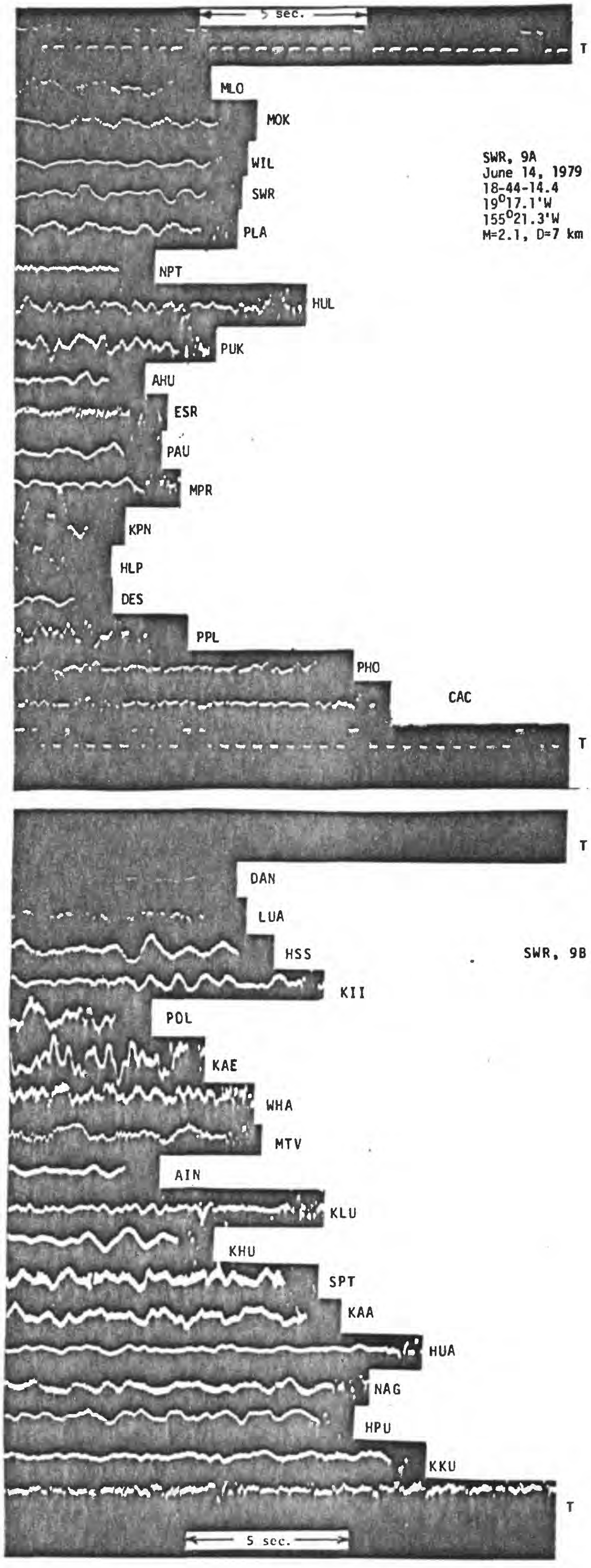

5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
LER, 6B
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T

Figure 7o



5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
SWR, 9A
June 14, 1979
18-44-14.4
19°17.1'W
155°21.3'W
M=2.1, D=7 km
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
T
5 sec.
SWR, 9B

Figure 7p

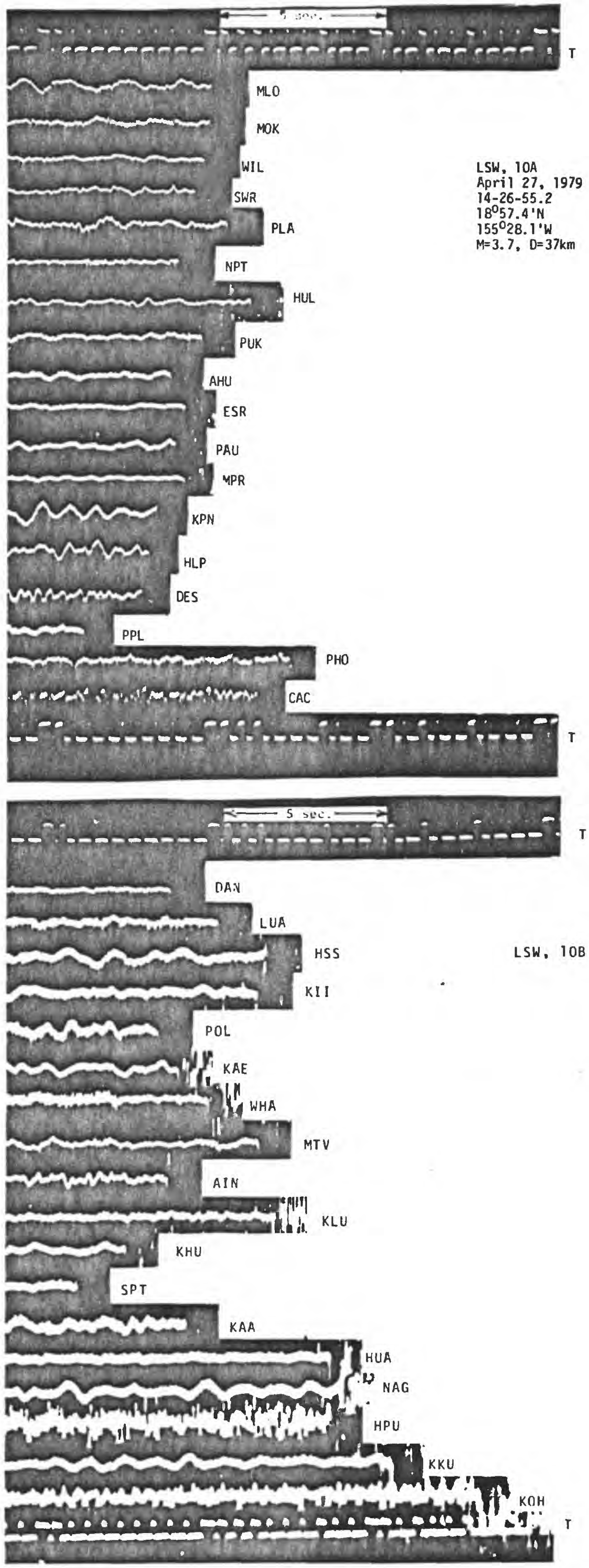

5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
LSW, 10A
April 27, 1979
14-26-55.2
18°57.4'N
155°28.1'W
M=3.7, D=37km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
LSW, 10B

Figure 7q

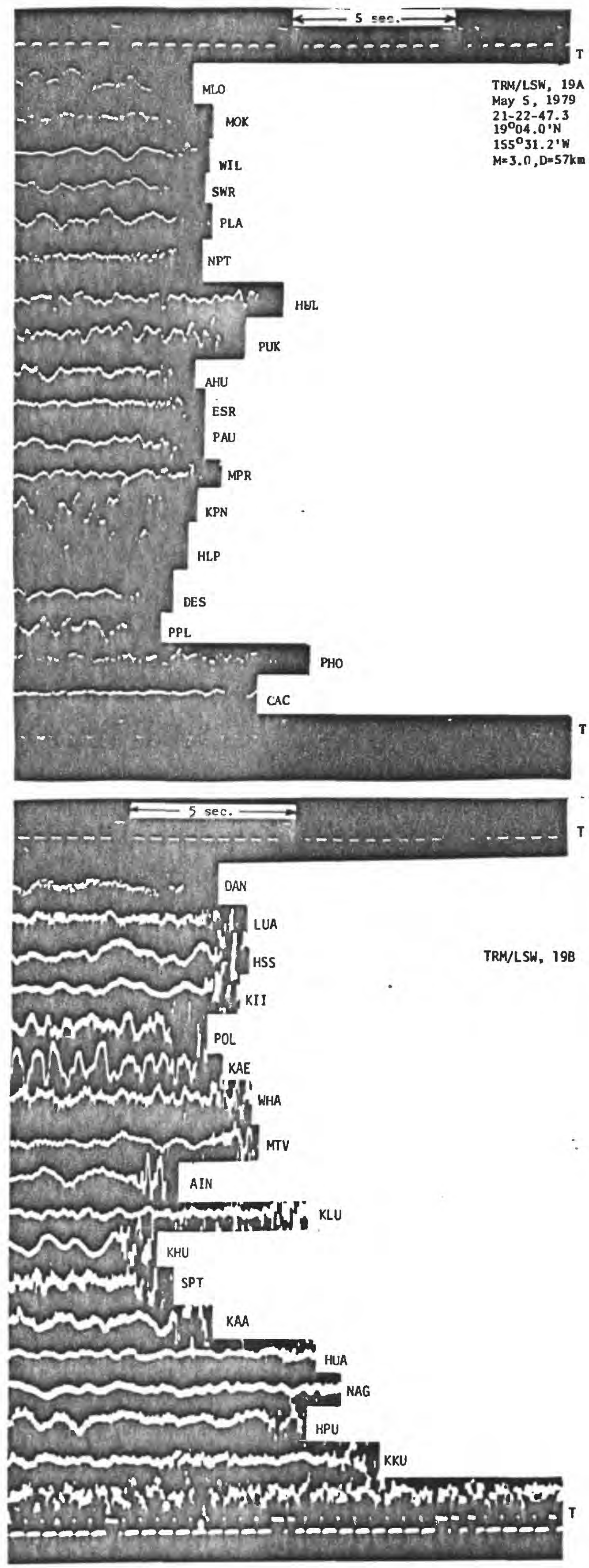
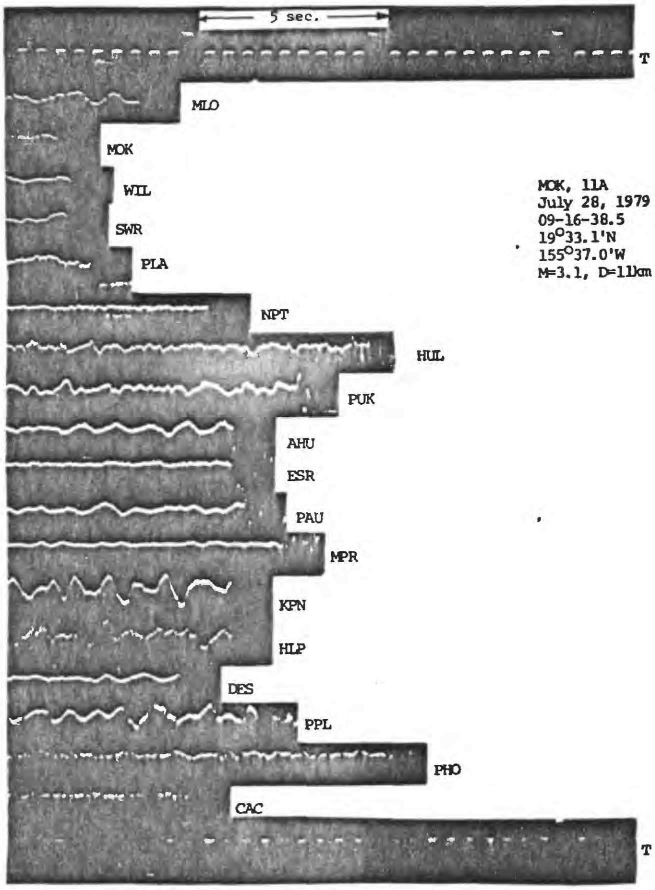

5 sec.
T
TRM/LSW, 19A
May 5, 1979
21-22-47.3
19°04.0'N
155°31.2'W
M=3.0,D=57km
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5 sec.
T
TRM/LSW, 19B
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
T

Figure 7r


5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
MOK, 11A
July 28, 1979
09-16-38.5
19°33.1'N
155°37.0'W
M=3.1, D=11km

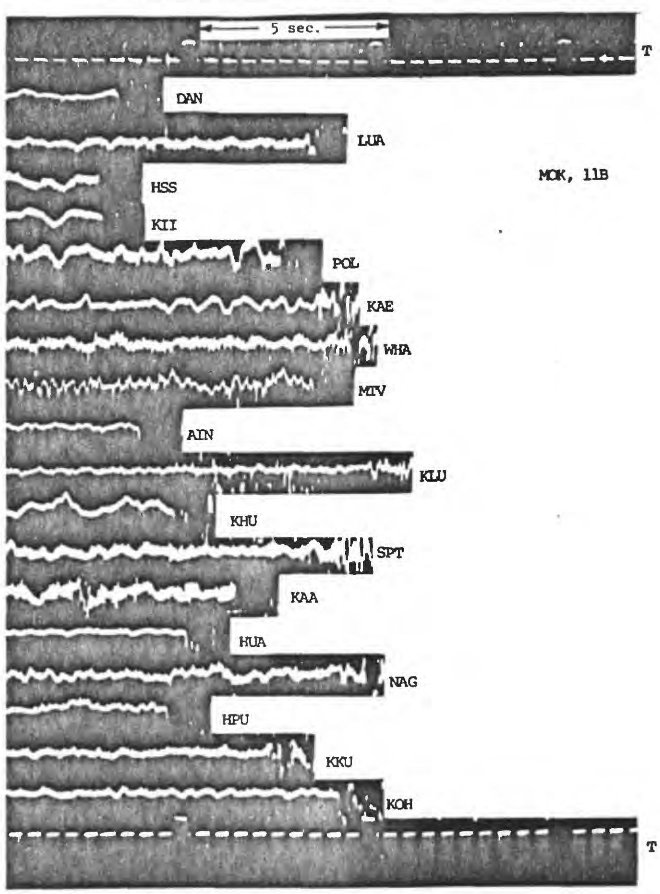
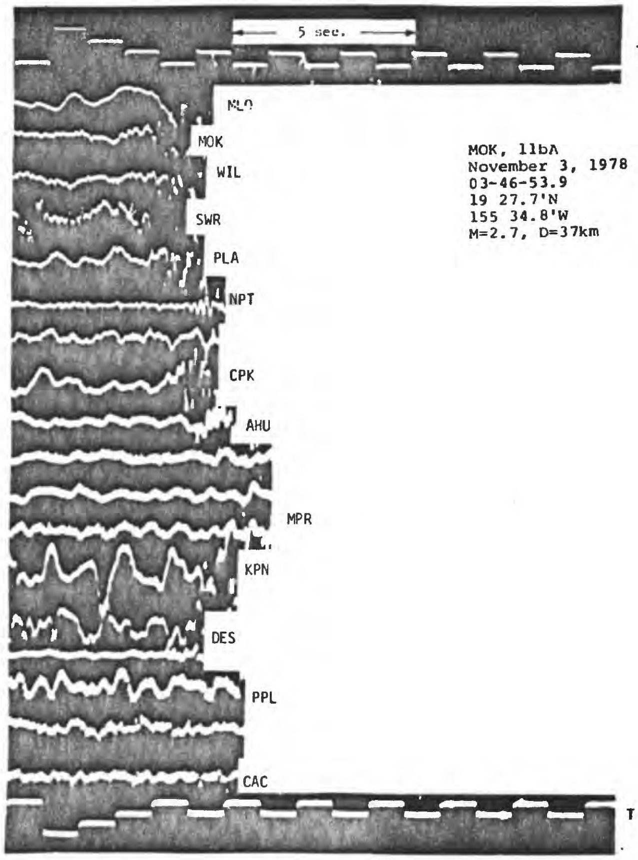
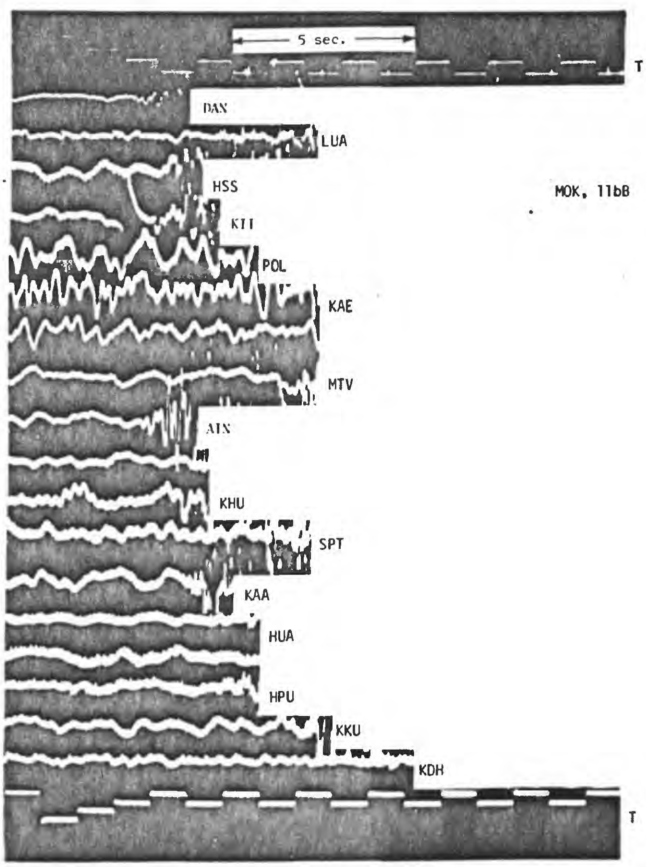

5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
MOK, 11B

Figure 7s



MOK, 11bA
November 3, 1978
03-46-53.9
19 27.7'N
155 34.8'W
M=2.7, D=37km



MOK, 11bB

Figure 7t

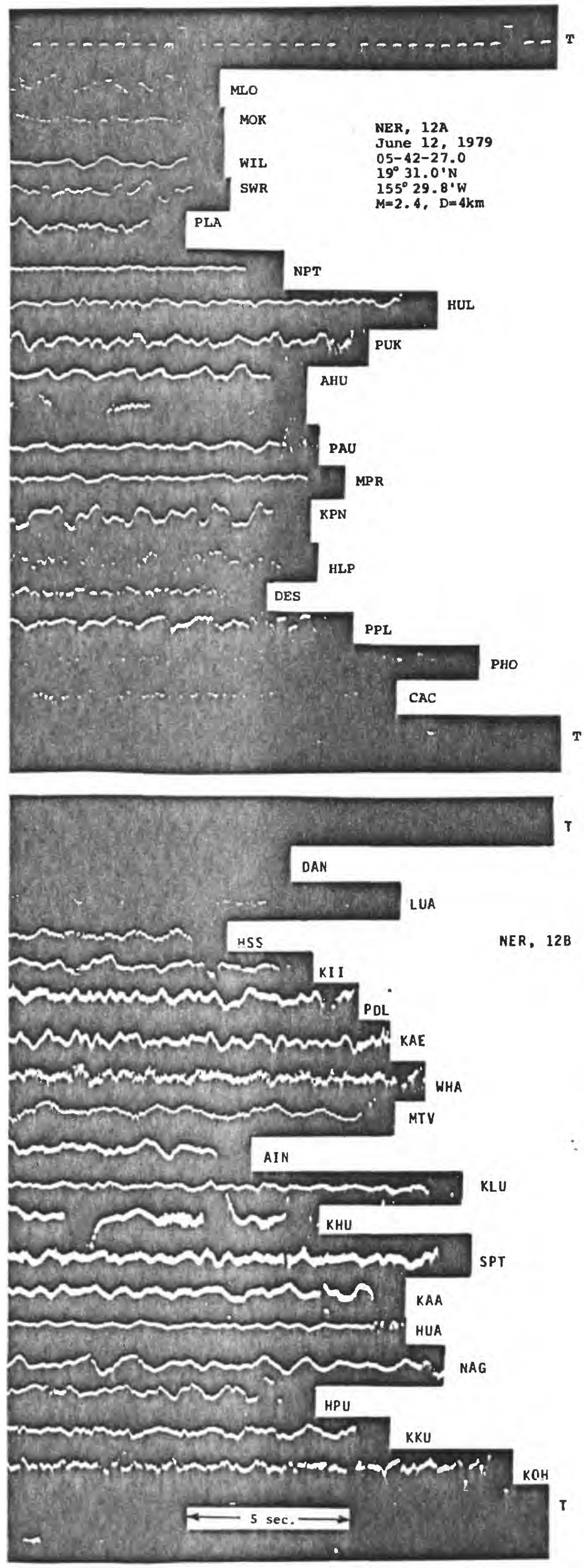

T
MLO
MOK
NER, 12A
June 12, 1979
05-42-27.0
19° 31.0'N
155° 29.8'W
M=2.4, D=4km
WIL
SWR
PLA
NPT
HUL
PUK
AHU
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
T
DAN
LUA
HSS
NER, 12B
KII
PDL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
5 sec.

Figure 7u

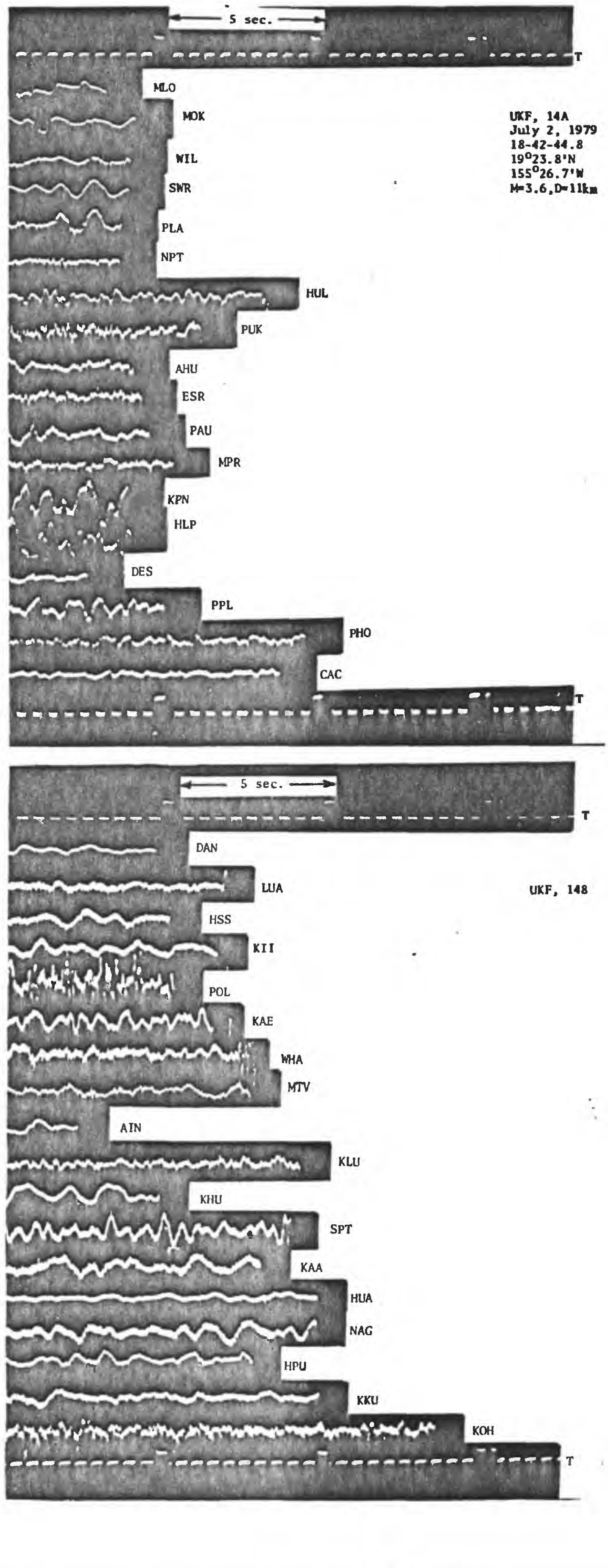
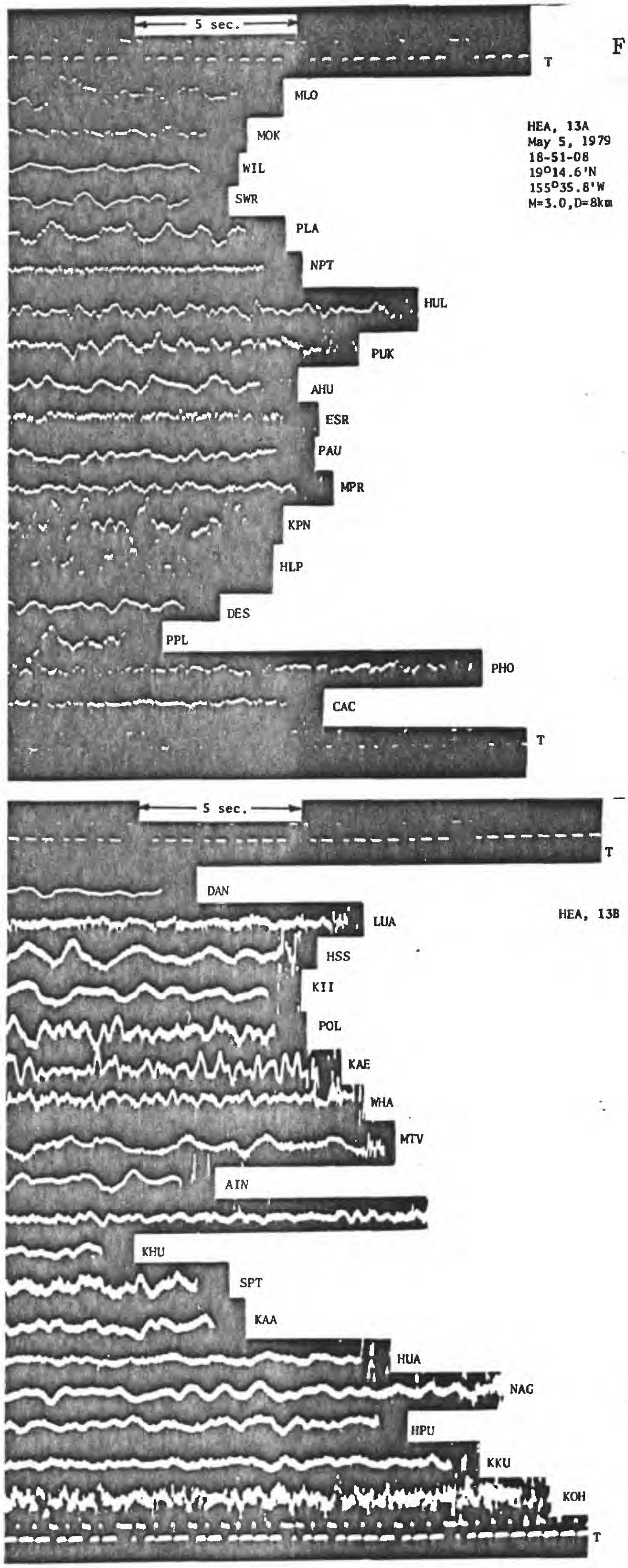

5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
UKF, 14A
July 2, 1979
18-42-44.8
19°23.8'N
155°26.7'W
M=3.6,D=11km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
UKF, 14B

Figure 7v


5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
HEA, 13A
May 5, 1979
18-51-08
19°14.6'N
155°35.8'W
M=3.0,D=8km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
HEA, 13B

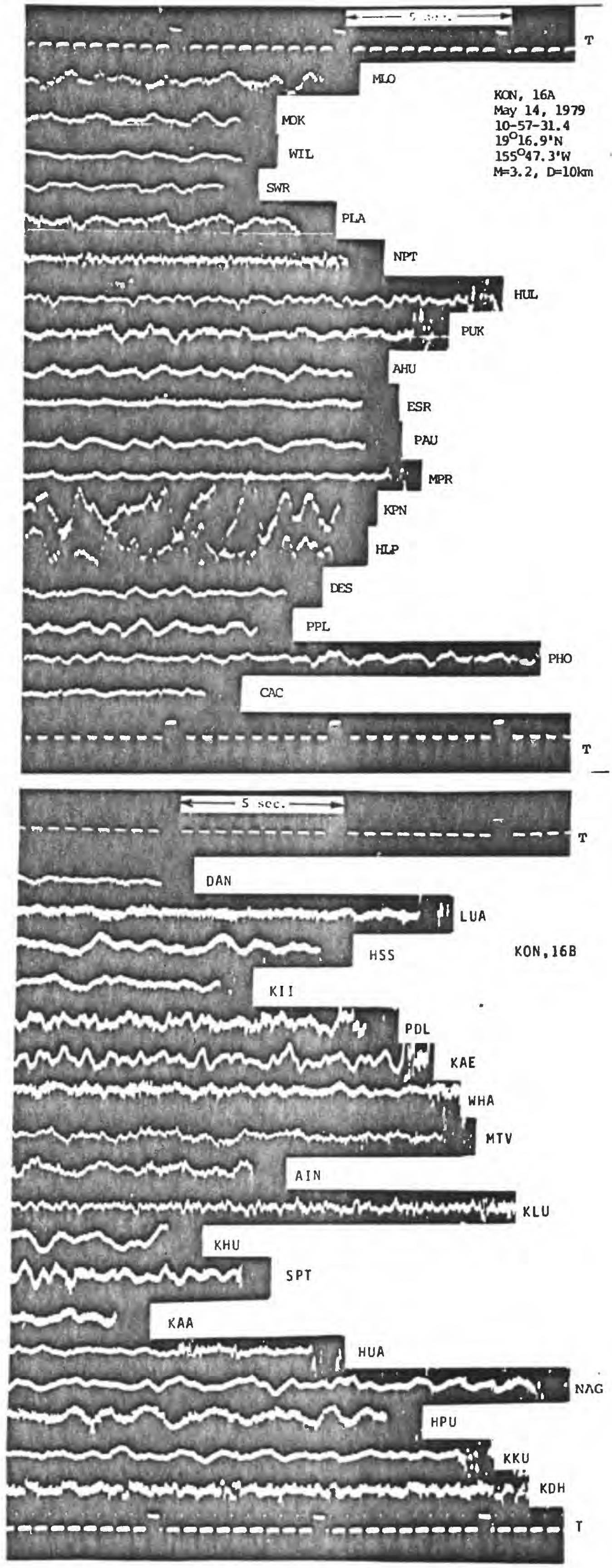

T
MLO
KON, 16A
May 14, 1979
10-57-31.4
19°16.9'N
155°47.3'W
M=3.2, D=10km
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5 sec.
T
DAN
LUA
HSS
KON,16B
KII
PDL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KDH
T

Figure 7w

Figure 7x

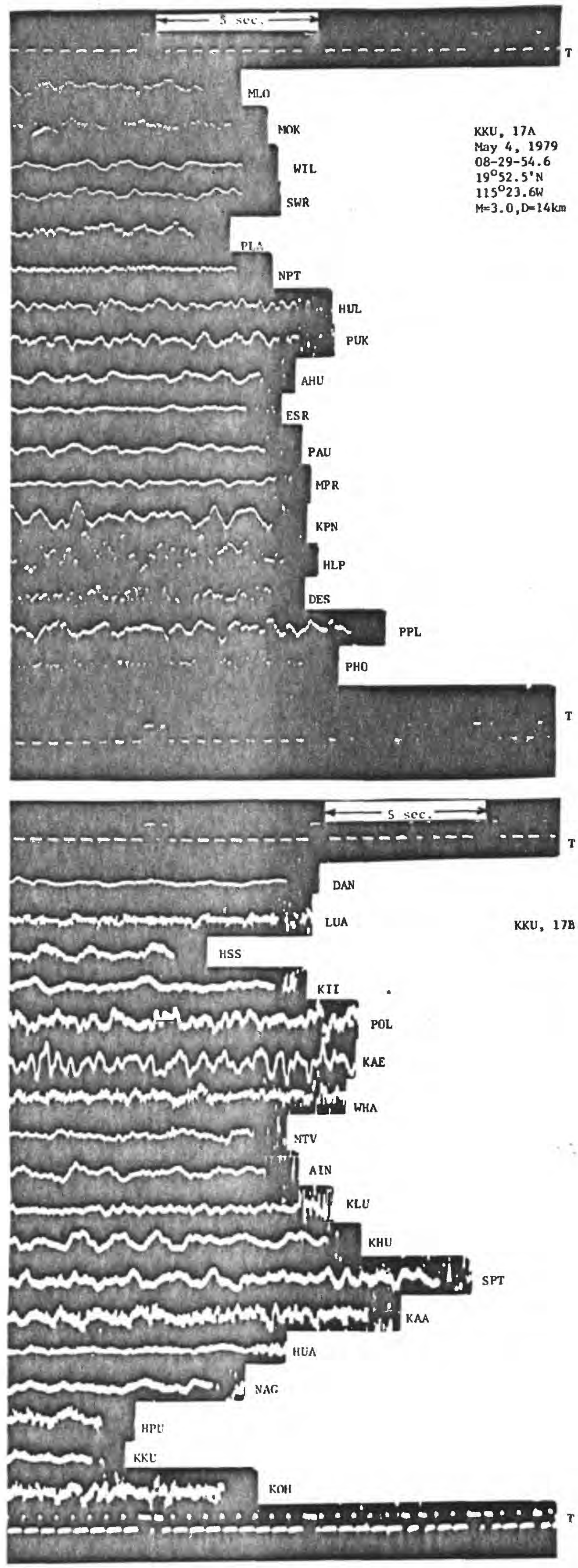
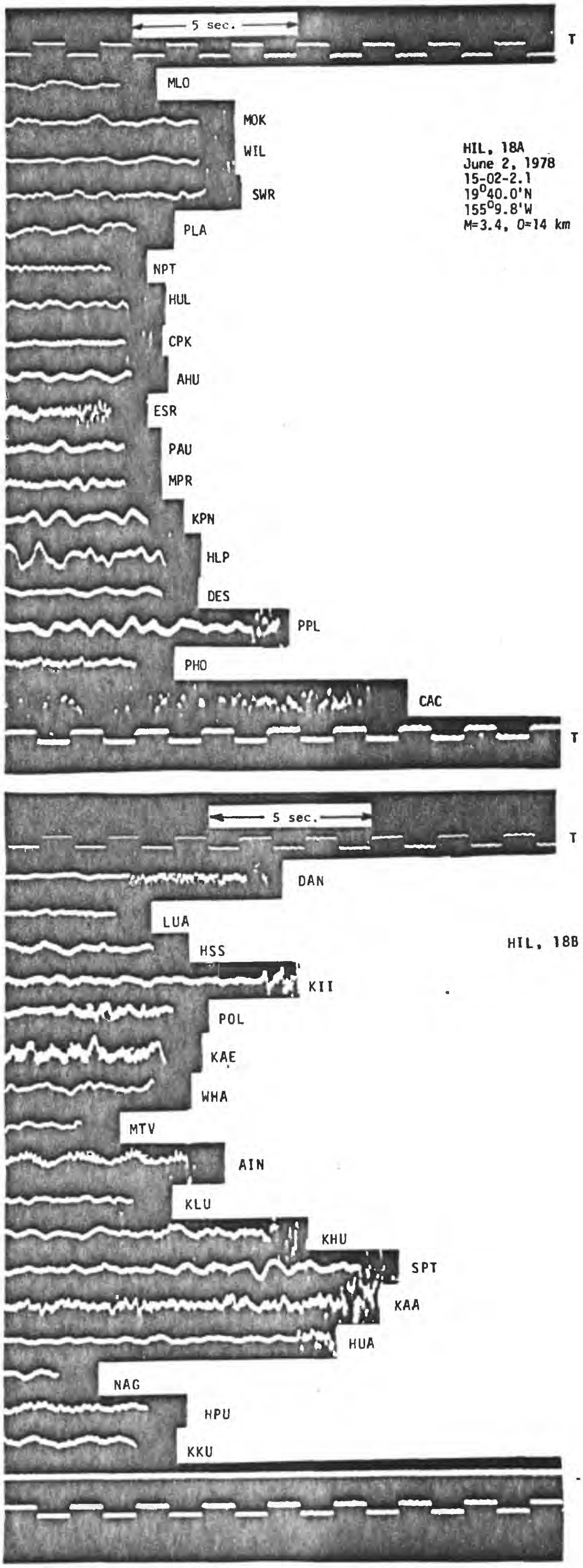

5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
PUK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
T
KKU, 17A
May 4, 1979
08-29-54.6
19°52.5'N
115°23.6W
M=3.0,D=14km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T
KKU, 17B

Figure 7y


5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
CPK
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
HIL, 18A
June 2, 1978
15-02-2.1
19°40.0'N
155°9.8'W
M=3.4, D=14 km
5 sec.
T
DAN
LUA
HSS
KII
POL
KAE
WHA
MTV
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
HIL, 18B

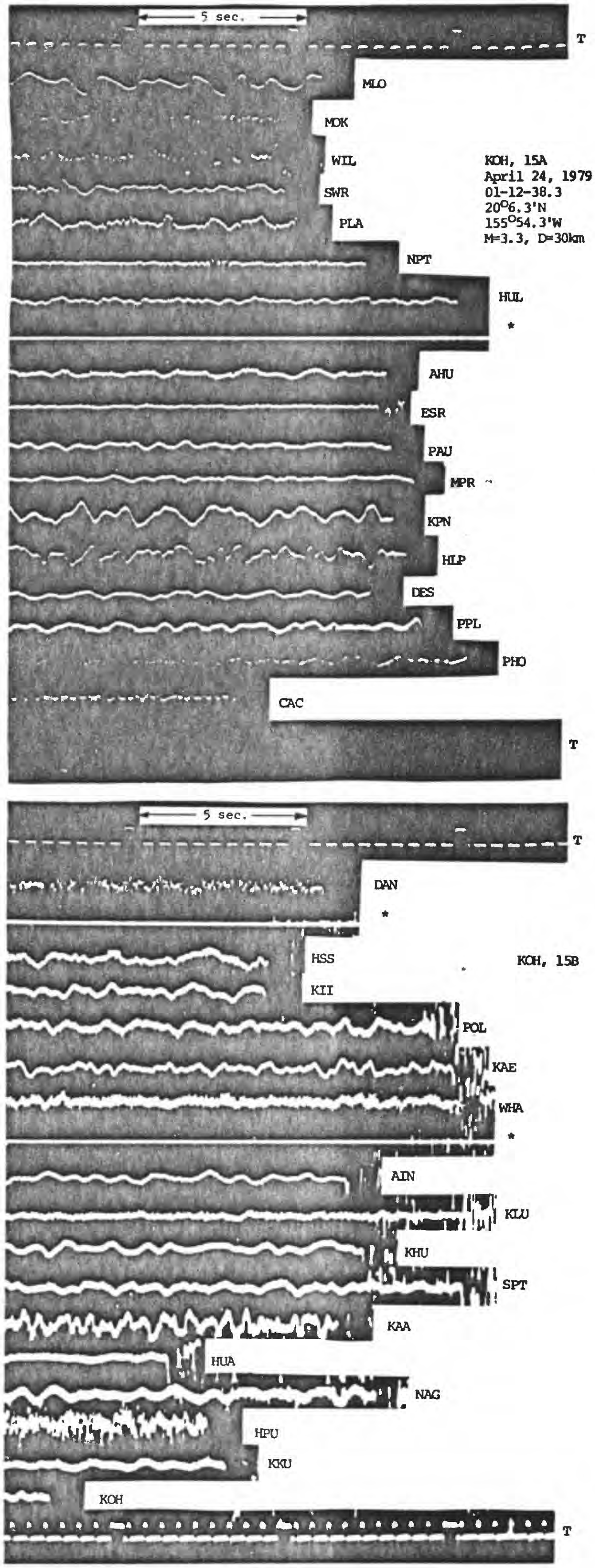
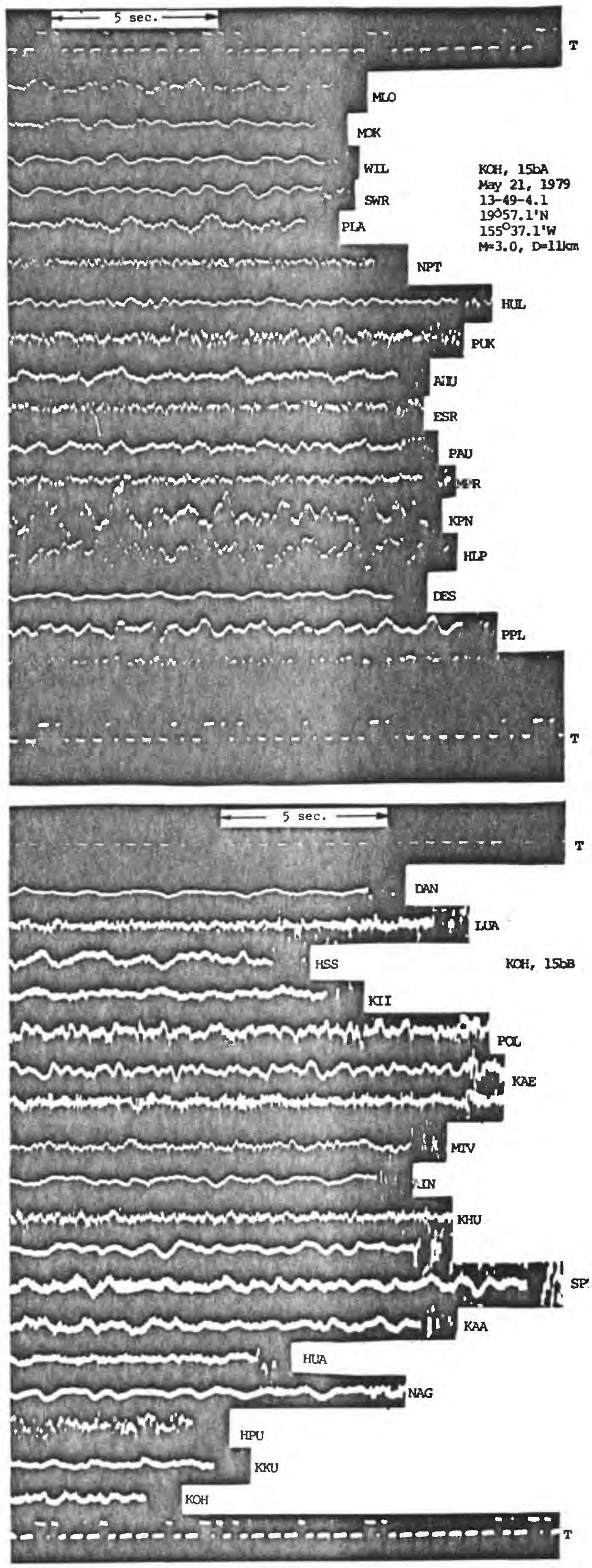

5 sec.
T
MLO
MOK
WIL
SWR
PLA
NPT
HUL
*
KOH, 15A
April 24, 1979
01-12-38.3
20°6.3'N
155°54.3'W
M=3.3, D=30km
AHU
ESR
PAU
MPR
KPN
HLP
DES
PPL
PHO
CAC
T
5 sec.
T
DAN
*
HSS
KII
KOH, 15B
POL
KAE
WHA
*
AIN
KLU
KHU
SPT
KAA
HUA
NAG
HPU
KKU
KOH
T

Figure 7z

Figure 7z+


5 sec.
T
MLO
MOK
WIL
SWR
PLA
KOH, 15bA
May 21, 1979
13-49-4.1
19°57.1'N
155°37.1'W
M=3.0, D=11km
NPT
HUL
PUK
AIU
ESR
PAU
MPR
KPN
HLP
DES
PPL
T
5 sec.
T
DAN
LUA
HSS
KOH, 15bB
KII
POL
KAE
MTV
AIN
KHU
SP
KAA
HUA
NAG
HPU
KKU
KOH
T