

MEXICAN NATIONAL REPORT ON THE UPPER MANTLE PROGRAM FOR THE YEARS 1966-1967

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INTRODUCTION

The National Upper Mantle Program in Mexico during 1966-1967 has essentially been in charge of the Institute of Geophysics of the N.A.U.M., in various areas of the country. However, cooperation was received from a number of institutions, like the Federal Commission of Electricity (in Physical Volvanological studies), Petróleos Mexicanos (that provided a good amount of gravity information), and others that will be mentioned in this report. In the international aspects, relationships were maintained with the International Upper Mantle Committee, and National Committees in diverse countries for exchange of publications, as well as by attending important meetings in different parts of the world, and receiving visits of foreign specialists.

A - NATIONAL PROGRAMS

GRAVITY

Details on these studies were presented by J. Monges Caldera (*in* Medina Peralta, M. and J. Monges Caldera, 1967) to the XIVth General Assembly of the I.U.G.G. (International Association of Geodesy) in Switzerland, in 1967. The pertinent portions of that report are now transcribed, and the corresponding map included, to give an idea of this program, comprising:

1. Mapping of gravity anomalies and related studies in the Mexican territory.
2. Gravimetric study of its northern part, particularly of the north-eastern portion, where the Peninsula of Coahuila, an ancient geologic structure located in the subsurface, presents a peculiar lack of conformity of gravity anomalies with surface elevation instead of with geology, and,
3. Study of the Neo-Volcanic Axis, which is the transverse igneous range crossing the Mexican territory from east to west, more or less at the latitude of parallel 19° N.

Although the three programs were planned prior to the initiation of the Upper Mantle Program in Mexico, when the Mexican National Com-

mittee of the UMP was established, all were incorporated in its activities.

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Lastly, the Institute of Geophysics has cooperated with the pendulum expeditions that have come to Mexico to participate in measurements along the International Gravimetric Calibration Line, in accordance with a recommendation of the International Gravity Commission, approved in Paris, in September 1962:

1. Gulf Quartz Pendulum, in charge of Richard L. Longfield (1964);
2. Cambridge Invar Pendulum, in charge of C. Browne (1965), and
3. Italian Pendulum in charge of Valentino Tomelleri (1965):

The three expeditions made measurements at Ciudad Universitaria, Mexico, D. F., and at Instituto Tecnológico, Monterrey, N. L., where a change in the observation site was made because of high vibration in the original one and intense changes of day and night temperature in its vicinity.

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1. MAPPING OF GRAVITY ANOMALIES IN MEXICO

This program is aimed at densifying and extending the network of gravity stations in the Mexican Republic. Since the inception of the program thousands of stations have been occupied, and their values calculated and related to base stations using bench marks along level lines as points of reference. Special gravity work has also been executed in marine ports and airports with known elevations while data processing and drawing of maps of gravity anomalies is carried out at the Department of Gravimetry, in Mexico City, thus constituting another very convenient reference network.

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2. GRAVIMETRIC STUDIES IN NORTHERN MEXICO

As a continuation of gravity work reported upon three years ago, essentially consisting of a network of base stations for more extended measurements in the territory of the Mexican Republic, during 1964, 1965 and 1966, in collaboration with the University of Hawaii, a denser gravity network was developed in the northeastern part of the country through measurements taken along roads, and in villages and ranches that could be located in existing maps. Bench marks were taken as reference along level line roads with 6 to 12 km intervals. Where no level lines were available, two Wallace and Tierman altimeters were used for elevation of stations always related to values of bench marks or railroad elevations or some other measured points.

Measurements were also taken by Dr. Lawrence F. Machesky, of the University of Hawaii, in the States of Sonora, Sinaloa, Durango, Chihuahua, Coahuila, Nuevo León and Tamaulipas, along roads marked on 1:250,000 maps of Mexico during 1965 and 1966, with intermediate distances of 6 to 10 km between observing points. These measurements were more or less easily made in level areas, but in the western part of Chihuahua the intricate configuration of the Sierra Madre Occidental (with many inaccessible portions and scanty communication facilities), gravity work is being executed in local airports or airstrips existing in the areas using light aircraft during the winter months of 1966-1967. In this way, Dr. Machesky and the writer occupied more than 400 (four hundred) airports and airstrips (Fig. 1).

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3. STUDY OF THE NEO-VOLCANIC AXIS

A tripartite program of gravimetric measurements is being carried out by the Institute of Geophysics of the N.A.U.M., the Federal Commission of Electricity of Mexico and the Institute of Geophysics of the University of Hawaii along the Neo-Volcanic Axis of Mexico, as part of the of the Upper Mantle Program. It consists of a series of 5 (five) gravimetric profiles crossing that igneous range with intermediate stations whose elevations were already known or determined with altimeters by the field party, as follows.

(See Fig. 1)

1. Mexico line.

From Zumpango del Río, Gro., to Zacualtipán, Hgo., through Pa-chuca, Hgo., Mexico, D. F., Cuernavaca, Mor., and Iguala, Gro.;

2. Veracruz line:

From Tecolutla, Ver., to a point 20 km to the north of Ixtlán de Juárez, Oax., through Nautla, Vega de Alatorre, Ciudad Cardel, Veracruz and Tierra Blanca, all in the State of Veracruz, and Tuxtepec, Oax.;

3. Morelia line:

From Silao, Gto., to La Huacana, Mich., through Irapuato, Salamanca, and Moroleón, all in the State of Guanajuato and Morelia, Quiroga, and Ario de Rosales, all in the State of Michoacán.

4. Guadalajara line:

From Juchipila, Zac., to Colima, Col., through Guadalajara, Ciudad Guzmán and Tecalitlán, all in the State of Jalisco.

5. Tepic line:

From Acaponeta, Nay., to Puerto Vallarta, Jal., through Tepic and Compostela, both in the State of Nayarit.

The total number of stations in the five lines was 379, and measurements were taken with the Worden gravimeter number 33, using only the small dial, by Ings. Luis Canales, of the Institute of Geophysics and

Armando de la Peña, a geologist of the Federal Commission of Electricity, under this supervision of the writer.

With respect to gravimetric work of applied nature done in Mexico, the following paragraphs are of interest:

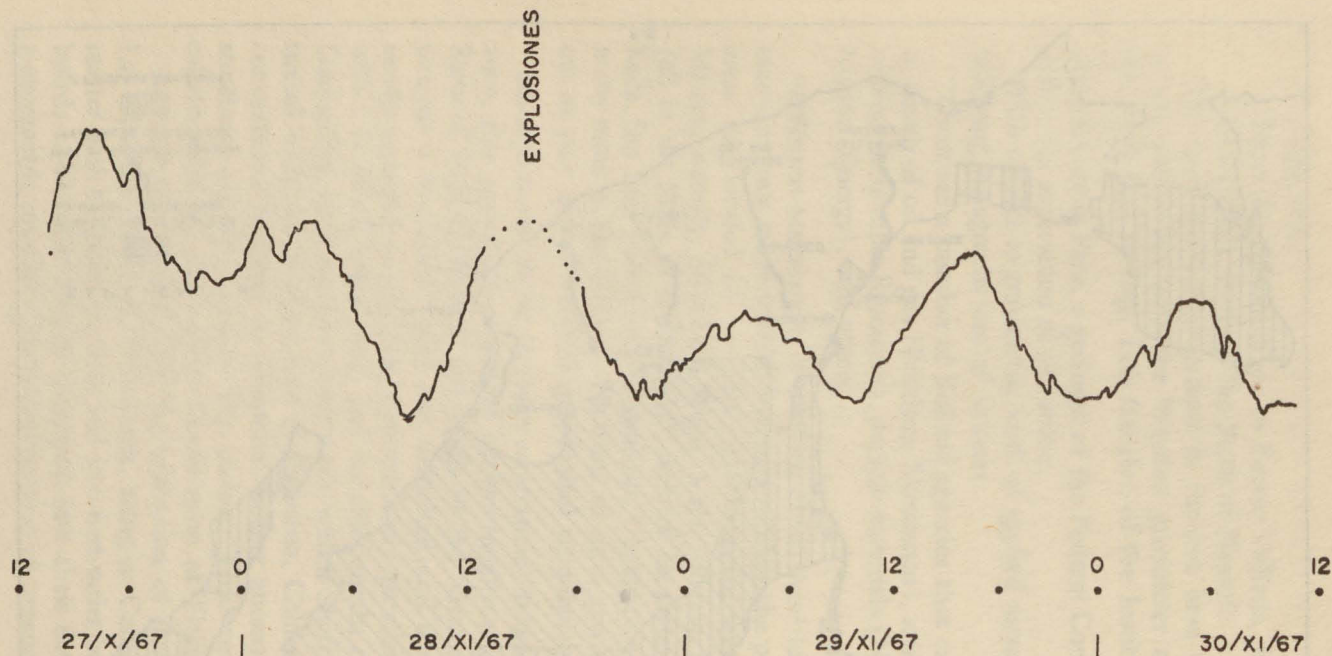
"There are a number of Federal agencies that carry out gravity studies in search of oil and gas (Petróleos Mexicanos), minerals (Higher Council of Non-Renewable Resources), nuclear materials (National Commission of Nuclear Energy), and others...

PETRÓLEOS MEXICANOS. A total of 83,545 Km² have been surveyed and measurements made in 83,420 stations during the period 1964-1966. Study areas are located in northern, northeastern, eastern and southeastern Mexico, namely, Sierra del Burro, Villa Aldama, Ojinaga and Camargo (all in the State of Chihuahua), isolated localities in the States of Coahuila, San Luis Potosí and Tamaulipas, Uzpanapa (State of Tabasco) and many more in the State of Yucatán, where a gravity program was carried out as part of a diversified geophysical reconnaissance.

CONSEJO SUPERIOR DE RECURSOS NATURALES NO-RENOVABLES. Among other areas, this agency has surveyed gravimetrically a large tract in Mexicali, State of Baja California, just south of the Mexico-USA border; for this purpose a four-sided figure was delimited and covered by 340 measurements arranged in 18 lines, approximately parallel at 2 km of interval, with a N 50° E orientation, and variable lengths of the order of 19 km. Gravimetric measurements were made with a Sharpe instrument and connected with the geodetic base at Pasadena, California, and processed by conventional methods to determine Bouger anomalies, indicating certain structural conditions below the surface. This work was executed as a collaboration for the Federal Commission of Electricity."

Another area explored for the evaluation of iron deposits was that of Las Truchas, State of Michoacán, using a Canadian gravity meter, a master base of arbitrary value and two first order bases strategically distributed; 1,180 stations were measured, and their data used to configurate a gravimetric map indicating various types of anomalies".





U.N.A.M.- Registro Marea Terrestre - Askania # 104

FIG 2

EARTH TIDE

Some experimental measurements have been made by J. Mateo, member of the staff of the Astronomical Observatory of the National University of La Plata, Argentine, and Visiting Professor of Theoretical Gravimetry at the Institute of Geophysics and the School of Sciences of the N.A.U.M., in the latter part of 1967. The instrumental set used for these measurements consisted of: 1) an Askania gravity meter, of the G-11 model, with 0.01 mgal of sensitivity achieved through an "inner" galvanometer with a sensitivity of 0.08 mgal, 2) an "outer" galvanometer with a sensitivity of 1.5×10^{-4} amp./div., receiving gravity changes converted into electric potential impulses, 3) a recording instrument with a photo-electric element guiding the inscription device to obtain a continuous curve, and 4) the necessary electric feeding system. This equipment, after proper readjustments made by Mateo and the staff of the Electronic Laboratory of the Institute of Geophysics, was provisionally installed in a basement of the "Annex" building of the institution, within the campus of the N.A.U.M.

Temperature variations were somewhat strong during the days of the experimental measurements, as well as microseismic effects due to explosions originated in construction areas in the vicinity of the lava field around the campus. Then, there was the effect of the instrumental "drift", so difficult to control in all kinds of equipments, for which purpose some additional electric experiments were made to select and maintain the proper amount of current volts in the handling of the instruments. All conditions taken in consideration, measurements were conducted from November 30 to December 2, 1967 (as shown in the lower curve of Fig. 2) in contrast to the theoretical curve calculated for the latitude of Mexico City for the same days (upper curve), proving their good correlation; additional readings will be taken at another site in the near future.

MAGNETISM (Terrestrial and aerial)

Measurements of magnetic elements at the Central Magnetic Observatory of Teoloyucan, some 60 Km N of Mexico City, were continued by C. Cañón Amaro, who is also in charge of field work in the Mexican territory at the Institute of Geophysics of the N.A.U.M. Data obtained at Teoloyucan and the network of base stations have been used for the preparation of the "Chart of Magnetic Declination in Mexico for the Epoch 1965.0" (in Cañón Amaro, C., 1967) as well as for yearly reports on magnetic values in the Mexican Republic published in the *Anales del Instituto de*

Geofísica, U.N.A.M. as described in the Mexican National Report on Geomagnetism and Aeronomy presented to the XIVth General Assembly of the I.U.G.G. (International Association of Geomagnetism Aeronomy) in Switzerland, in 1967.

Theoretical work on magnetic and gravity data is also done at the Institute of Geophysics as mentioned in the same report:

“Professors Anselmo Chargoy and Manuela G. de Álvarez, both of the Institute of Geophysics of the National Autonomous University of Mexico, and mathematicians interested in the analysis of geophysical models, have been working on various problems of theoretical nature but leading to a better understanding of the significance of observational and experimental magnetic data. Previous work done by Prof. Chargoy on the definition of the theory of dipoles, quadripoles and octipoles as well as on their implications for the gravimetric and terrestrial magnetic potential have appeared in the *Anales del Instituto de Geofísica, U.N.A.M. Revista de la Sociedad Mexicana de Física*, and other scientific journals in Mexico.

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Mrs. Álvarez has concentrated in the study of models describing the Earth's magnetic field by introducing terms indicating field anomalies at a planetary scale, viz. multipoles of at least 3rd. order in such a way as to make the model very simple, with a good approximation to the real phenomenon. . .”

Magnetic work of applied nature was pursued in the Mexican territory as indicated in the above mentioned report:

“MAGNETIC SURVEYING FOR OIL. *Petróleos Mexicanos*, the Mexican Government oil and gas producing company, has conducted a detailed magnetic survey of the Península of Yucatán, in the southeastern part of the country, in search of deposits of commercial value. The same area had previously been surveyed by a gravity party until 1962 to determine basement rock relief and structural conditions of the subsurface. Magnetic work began in the latter part of the same year, and is still continuing under the supervision of the Exploration Department of *Petróleos Mexicanos* at Coatzacoalcos, Ver.

A relatively large amount of geologic work had preceded the magnetic survey of the Península of Yucatán, including reconnaissance studies along

the axis of Sierra de Ticúl and the southern and central parts of the Península as well as a general stratigraphic study of other isolated areas. Drilling was performed in the Mérida-Progreso zone by the former petroleum companies that operated in Mexico prior to 1938, and whose reports are in the files of Petróleos Mexicanos. At the time of initiation of the magnetic survey, Petróleos Mexicanos had bored three wells on basis of gravimetric results in the northern part of the State of Yucatán, where regional "highs" had been identified two wells ending in igneous rocks and one in evaporities.

Magnetic work was carried out in new areas to have a good coverage of the Península of Yucatán in a period of almost three years of work to locate areas of magnetic anomalies for more geophysical work. A total of 16,385 stations were observed in 666 days, with an average of 26 stations per day along 16,263 kilometers of routes. Topographic work was simultaneously done and other information gathered during the execution of the program.

Petróleos Mexicanos has also carried out magnetic work in a wide area comprised between the southeastern part of the Mexican Plateau and the Gulf of Mexico coast, from the central part of the State of Veracruz, to the Soto la Marina river, in the State of Tamaulipas. The period of work extended from June 5 to November 21, 1966, utilizing national highways and doing more detailed work in special areas: Actopan-Ixmiquilpan, in the State of Hidalgo, and Río Verde-Cárdenas, in the State of San Luis Potosí as well as to the northwest and west of Tampico, in the State of Tamaulipas. Magnetic anomalies and profiles were prepared from field data, calculated and revised for final drawing of maps at the central offices of Petróleos Mexicanos, in Mexico City.

It is interesting to notice that the national highways utilized for magnetic work east of the Mexican Plateau cross the north-south elongated Sierra Madre Oriental, and that of the three special areas of study, that of Actopan-Ixmiquilpan is located to the west of Sierra de Pachuca, a highly mineralized range in central Mexico while that of Río Verde-Cárdenas lies in the heart of the Jurassic-Cretaceous limestone folds of the Sierra Madre Oriental, and that of Tampico borders the Gulf of Mexico, forming a triangle of great significance for the study of structural and dynamic traits of the coastal plain and its mountainous backbone. Thousands of stations were observed along national highways and in special study areas, including topographic surveying for the preparation of reliable maps.

MAGNETIC SURVEYING FOR MINERALS. Aeromagnetic surveying work for the evaluation of mineral resources was begun in Mexico since 1962 by the Higher Council of Non-Renewable Natural Resources. Instruments included a continuous recording Flux-gate "Gulf-Airborne Magnetometer Mark III", a RT/APN-1 radioaltimeter with sensitivity scale from 0 to 2,000 feet, an "Interprises Mark IX" model camera, and occasionally other electronic magnetometers of various types. The instruments were installed on a "Twin Pioneer" aircraft with flight speed of 100 Knots (185.6 Km/Hr), a great support capacity for taking off and landing in short strips, a maximum height of operation (ceiling) of 7,000 feet, and 4 flying hours of autonomy.

All recorded magnetic anomalies of the 800 rank were compared with geologic data, specially intrusive rock outcrops to detect contacts with other adjacent rocks for the evaluation of economic possibilities of each area from the viewpoint of mining. Other terrestrial geophysical studies, came afterwards, particularly magnetometric lines with adequate separation, sampling of rocks and minerals, and in some areas gravimetric and seismologic surveys. Electrical resistivity, induced polarization and natural potential methods for certain minerals as well as tests of applicability of aerial radiometric methods were also used simultaneously with the aeromagnetic methods.

In general, the aeromagnetometer aircraft operated from a nearby base to fly parallel lines oriented along the geologic structure in study, whose separation depended on requested specifications. Compilation and drawing of isomagnetic patterns were made in a preliminary way in the central offices (Mexico City) for analysis and study by geologists, and later on the final drawing was done in the Department of Cartography and Drafting of the Council. In total, it is estimated that more than 150,000 Km² have been explored by aeromagnetic and supplementary methods in the Mexican territory, with results of great significance for the location and evaluation of mineral deposits, and for the knowledge of the structure and dynamic of the Earth's crust.

The following aeromagnetometric studies were made between 1962 and 1966:

State of Baja California. a) Area to the east of the Álamo region, covering 4,386 Km² with 90 flight lines and 5 control lines with a total of 4,435 Km of aeromagnetic lines, including 5 additional lines of 8 Km of average length; b) Area to the south of San Quintín, with parallel flight lines oriented NE 35° SW and separated 1 Km each

at a constant height of 300 m over the surface, supplemented by a terrestrial magnetometric survey and other geological observations.

State of Sonora. A large disturbed zone in the northern part of Cabullona, with an extension of 1,556 Km², covered by 6 flight lines of 2,240 m each, indicating magnetic anomalies of the 800 rank which coincide with dioritic outcrops, although a very small "high" was located away from that rock with an anomaly of the 350 rank, supplemented with an induced polarization and natural potential survey to define the possibilities of existence of sulphides.

State of Durango. A number of areas in its central and eastern parts (Municipalities of Durango, Mapimí, Rodeo and San Juan de Guadalupe) and covering almost 6,000 Km² were flown by 200 flight lines separated by variable distances (500 to 1,000 m) at an average height of 300 m over the surface with a total of 13,687 Km of aeromagnetic lines.

States of Jalisco and Colima. From a base at the port of Manzanillo, a large area was covered by 157 flight lines with a separation of 1 Km and 5 transverse control lines similarly separated, and supplemented by a geologicmagnetometric survey over anomalous areas with terrestrial lines oriented in various directions and separated by distances of 200 to 300 m with reading stations every 50 m as well as a gravimetric study.

States of Michoacán and Guerrero. Area with a total extension of 17,328 Km² flown by 156 aeromagnetic lines and 5 transverse control lines separated 1 Km from each other, with a total of 16,900 Km of aeromagnetometry from a base in the port of Zihuatanejo, supplemented by a detailed geological and geophysical terrestrial survey.

State of Oaxaca. Area with an extension of 8,470 Km² flown by 105 aeromagnetometric lines and 5 transverse control lines separated 1 Km from each other, with a total of 8,623 Km at a height of 300 m over the surface, whose results were compared with geological and geophysical data of various sources."

SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

The Department of Seismology of the Institute of Geophysics operates a network of 14 stations throughout the country; 4 additional stations were

being installed during 1964-1966, while other projects were also in development, as indicated in the Mexican National Report to the XIVth General Assembly of the I.U.G.G. (International Association of Seismology and Physics of the Earth's Interior) in Switzerland (*in* J. Figueroa Abarca, 1967): Other activities involved:

"SPECIAL PROGRAMS. Through arrangements concluded with Prof. Leon Knopoff, of the University of California at Los Angeles and associates, a special seismological study of the main fault system of the Gulf of California, and of its peculiarly localized seismic activity at each end by means of a network of 4 stations located on both sides of that oceanic reentrant (and forming a rhomboidal figure) was begun in 1964. The 4 stations had instruments of extreme sensitivity and high amplification, aimed at recording P waves, with identical sets of short period horizontal seismographs as well as a vertical component long-period seismograph, all provided with galvanometer recording devices into which a filter could be optionally inserted to avoid obtrusive recordings (for instance, microseisms); additionally, there were peripheral instruments and autonomous power sources.

A complete analysis of the problem involving the significance of short-period seismicity, Rayleigh wave observations and teleseismic events, use of surface wave techniques for structures immediately adjacent to the Gulf of California, differential amplitude spectra and other aspects of the problem has been published by Knopoff and Pilant in *Geofísica Internacional*, in January 1966...

THEORETICAL WORK IN SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR. Some problems of theoretical seismology have been approached in recent years by members of the staff of the Institute of Geophysics...

Dr. Ismael Herrera, Director of the Institute of Geophysics, based on the integral representation theorems for elastodynamics, has used a new and remarkable method to obtain the surface wave terms of the Green's function for a two-dimensional multilayered half space, by generalizing the orthogonality properties of surface waves when not only Love waves but Rayleigh waves are included. Elastic wave propagation has also been studied in several papers by Dr. Herrera. Using a perturbation method in the first paper, Dr. Herrera carried out his study by means of the integral representation of elastodynamics, which permits to express solutions to

problems as integrals of known quantities; in the second (written in company with A. K. Mal, of the University of California, Los Angeles), within nonparallel boundaries by treating small inhomogeneities; and in the third, by developing a first order theory to treat the scattering of elastic waves in thin inhomogeneities (of great importance for certain geological formations satisfying these conditions as dykes, lenses, etc.)

Surface wave transmission was also studied by Dr. Herrera in the same series of contributions by introducing the notion of surface wave content at a point, to obtain a one-dimensional transmission model of scattering by small perturbations in the elastic medium. Both authors (Herrera and Mal) have applied the same technique to study the propagation of Love waves in a layer of nonuniform thickness, lying over a half-space assumed to have a plane free surface while the interface protrudes into it in a certain finite region. After suitable interpretation of results, the theory was extended to include the case in which the area of the perturbed region is large, although only the scalar problem was considered.

At the Third World Conference for Earthquake Engineering, held in New Zeland, in February 1965, Drs. I. Herrera and E. Rosenblueth and Ing. O. P. Rascón, discussed the earthquake spectrum prediction for the Valley of Mexico, reporting on field and laboratory tests to determine the dynamic properties of underlying clay; data were used in conjunction with the linear, one-dimensional theory of multiple wave reflection in stratified media and results treated in accordance with an approximate theory which permits computing the probability of spectral responses for various degrees of damping, to be compared with spectra obtained from earthquake records while missing information for deep strata is found by trial and error and velocities measured for the upper layers adjusted on reasonable bases. In the same occasion, Drs. Herrera and Rosenblueth discussed the response spectra on stratified soil representing viscously damped single-degree systems resting on stratified media. Since the soil is assumed to rest on a viscoelastic homogeneous half space of rock, motion arriving at the rock-soil interface is idealized as a stationary Gaussian process, and the transfer function for the soil formation treated independently for each frequency of interest through use of a matrix formulation.

Prof. Sergio Ferráes, of the Institute of Geophysics, has recently been giving attention to the study of earthquake mechanism by S waves by means of determinants through a direct computational technique, representing an analytical modification of Adams technique, to determine

the direction of motion along the fault plane. The mathematical procedure involves the derivation of equations for computing the direction cosine of the "direction of motion" for a type I source, i.e., a couple of two equal and opposite forces with moment at the focus of the earthquake. In another paper on the same problem, Prof. Ferrás has applied the geometric relations indicated by Scheidegger with respect to the convergence of all tangential component vectors on two points defined as the pole and the antipole of the movement. In practice, the projections of circles do not pass through a point, but form a small triangle, whose centre may be considered the pole and the antipole of the movement.

Prof. Ferrás is also attempting to predict earthquake activity in the area of Mexico City on basis of stochastic models to infer properties of natural seismic courses, which in that area have been studied by means of the Poisson and the Yule-Furry methods; this study indicates that: 1) No relation exists between magnitude of any earthquake and that of preceding shocks, 2) earthquakes do not occur at random and independently of each other in time, and 3) Probably the Yule-Furry method fits satisfactorily into the seismic process, although more research is needed. These papers will soon be published in the pages of the *Bulletin of the Seismological Society of America*, the *Journal of Geophysical Research* and *Geofísica Internacional*."

Seismologic studies of applied nature were conducted as follows:

"For a number of years, the Division of Exploration of Petróleos Mexicanos, the Mexican Government oil company, has been actively engaged in a varied geophysical program for oil and gas exploration, of which the largest part is seismologic (refraction and reflection). This is definitely not a new activity in our country, since seismic reconnaissance work by the refraction method was done in the Golden Lane area in 1922, and later on across the Laguna de Tamiahua, on the Gulf of Mexico coast in the State of Veracruz. A good account of these early stages of geophysical prospecting in Mexico has been given by S. Figueroa (at present Chief of Exploration of Pe-Mex), mentioning places, names, methods and results of high historical and technical interest, and giving indications for present and future operations on land and under sea-water.

In this respect it must be said that almost 30 seismic field parties (mainly for refraction work although reflection is also done), are constantly maintained in activity, together with office personnel in the various branches throughout the country. Among recently surveyed areas mention

should be made of the Peninsula of Yucatán, following a geologic prospection (combined with gravimetric work) as well as in the Laguna de Tamiahua that led to the discovery of a rich oil reservoir under sea-water, now producing several thousand barrels a day. In the same article by Figueroa, a description is given of the successive stages of the geophysical exploration of that area, including details on characteristics of the reservoir and its relationships with the Golden Lane structure on land.

Theoretical analysis of seismic problems is also made by Pe-Mex specialists, most of whom publish their contributions in the *Boletín de la Asociación Mexicana de Geofísicos de Exploración*, a professional society gathering geophysicists working in various applied disciplines. Many problems have been dealt with, like elimination of parasitic noise in seismograms, statistical correlation, optimal cover for seismodetectors, application of Fourier formulae to the study of seismic equipment, etc. During the 1964-1966 lapse covered by this report, increasing attention has been given to theoretical and practical problems linked to submarine exploration."

PHYSICAL VOLCANOLOGY

In the Mexican National Report on Volcanology, presented to the XIVth General Assembly of the I.U.G.G. (International Association of Volcanology and Chemistry of the Earth's Interior) in Switzerland, in 1967 (*in Mooser, F. and M. Maldonado-Foerdell, 1967*), reference is made to some special studies as follows:

"...

II. TECTONOPHYSICS

The study of factors involved in the formation of the Trans-Mexican Volcanic Belt has received attention from one of the authors (F. Mooser) during the last three years. At the beginning of 1967 two-thirds of this approximately 1000-Km long and 100-Km broad volcanic zone had been mapped by photo-geology at a scale of 1:50,000 in the offices of the Comisión Lerma-Chapala-Santiago of the Ministry of Hydraulic Resources. This new detailed survey has led to the discovery and precise location of volcanic cones in a far greater number than previously determined. At the same time, outstanding tectonic features, unobserved in detail until the present, have been clearly defined.

From the above-mentioned surveys, a condensed map at a scale of 1:500,000 was prepared, containing all the Quaternary cones and visible faults; it clearly exposes both the general and the detailed structure of the Trans-Mexican Volcanic Belt. Copies of this map were sent to the International Upper Mantle Committee in May, 1966.

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In the light of present knowledge, the Trans-Mexican Volcanic Belt represents an intermittent zone of crustal fracturing, varying in width and extending from the southern Gulf of California straight through the continent to southeastern Mexico, at which point, however, it does not link up with the Guatemalan Volcanic Belt (figure 3). East and west of the Tuxtla volcanoes the belt is interrupted, probably due to the presence of great thicknesses of marine sediments, which owing to their plasticity and weight prevent dikes from rising to the surface. The new map also proves that Colima, Tancitaro and Popocatepetl volcanoes do not belong to a continental prolongation of the marine Clarion Fracture Zone, as previously supposed, but that these structures grew on separate side branches of the main belt.

Analysis of the map of the Mexican Volcanic Belt has also led to the development of a new theory... on differential crustal heating and volcanism (F. Mooser). It would seem that previous to any volcanism at the surface, the normal distribution of isotherms in the crust must be disturbed. A first result of this new heat anomaly would be the thermal expansion of the lower plastic, crust, leading to the creation of perpendicular fractures in the brittle and fragile upper crust along the P-F boundary. These fractures will generally reach a length of 30-40 Km, being formed at a depth of about 7 Km and eventually extending to the surface, where they may permit the ascending magmas to produce major strato volcanoes. As the heat anomaly continues to rise, a process involving millions of years, eventually as well or geotumor is formed at the surface, as a result of thermal expansion of the upper crust. At this stage the fractures parallel to the belt are produced. These are generally 5-30 Km long and, while suffering maximum tension at the surface, eventually tear into depths of about 5 Km, where they have the possibility of intercepting magmatic bubbles that can produce cinder cones and small, relatively short-lived volcanoes. Proceeding farther with this theory, horsts and graben may also be formed due to differential thermal expansion of various portions of the upper crust and its breaking along and faults.

Finally, it seems that even the formation of rift faults which generally vary in length between 40 and 70 Km, may also be explained on the basis of a weakening of the shear strength of the crust by heating along the belt; in the long run, this would cause the crust to collapse under its own weight (faults)."

Information on research on paleovolcanology, paleotectonics and paleogeography in the Mexican territory is also contained in the above mentioned report. The pertinent paragraphs are transcribed in this report:

"...

IV. PALEO-VOLCANOLOGY

A reconstruction of the volcanic cycles that formed the basin of Mexico City was attempted by F. Mooser (1963) in connecting with the tectonic evolution of the Trans-Mexican Volcanic Belt. The process began in the Middle Tertiary, originating the northernmost broad fracture alignment followed principally by andesitic emissions of lava. Later, specially in the Pliocene, large andesitic volcanoes appeared in the central portion along perpendicular fractures, thus giving rise to the Sierra de las Cruces and the Sierra Nevada, which define the western and eastern borders of the basin. During late Tertiary and Quaternary, the third and southernmost alignment developed along east-west fractures, forming the basaltic Sierra del Chichinautzin and Iztaccihuatl as well as Popocatepetl volcanoes.

Another paper, discussing the general evolution of Tertiary and Quaternary volcanism of Mexico, was read by M. Maldonado-Koerdell (1965) at the Summer Meeting of the International Association of Volcanology in Rome. It deals with the geo-historical and paleogeographic data of Mexico during that geological "middle age" of apparent quiescence (in the sense of time-consuming processes on the surface) and phenomenal crustal and sub-crustal effervescence (violently manifested at times through fissure and explosive volcanics), with multiple and complicated fracturing and faulting, and originating a peculiar pattern that has exercised a definite influence on volcanism in Mexico. At least, for the Quaternary, there were zones of weakness curiously enough aligned with the general trend of pre-Tertiary structural units that have been interpreted in the light of seismicity and volcanism as originated since then."

B - NEW PROGRAMS

One of the most significant structures in the Mexican territory is the so-called Neo-Volcanic Axis that crosses the country from E to W, more or less along parallel 19° lat. N. An accumulation of volcanic apparatuses is found in this belt (Pico de Orizaba, Popocatepetl, Iztaccihuatl, Nevado de Toluca, Volcán de Colima, Ceboruco, among the largest and still active in historical times), as well as minor ones (essentially cinder and subsidiary cones). The Neo-Volcanic Axis of Mexico is also an area of geothermal manifestations, although there are other zones to the north, northwest, south and southeast, viz. the Cerro Prieto geothermal field, near Mexicali, Baja California, the most promising discovered until now.

In the early fifties Ing. Luis F. de Anda, of the Federal Commission of Electricity, became interested in the possibilities of geothermal resources in Mexico, after visiting the Larderello area in Italy. Under his influence, a small experimental field was developed at Pathé, in the State of Hidalgo (central Mexico), for study and training of personnel. A report was presented by Ing. de Anda to the XXth Session of the International Geological Congress, held in Mexico City in 1956, and published in Vol. 1 of its Proceedings in 1957.

Since then more attention was given by the Federal Commission of Electricity to other geothermal areas in the country, one of which definitely has the largest potential value at Cerro Prieto, B. C. In the latter part of 1966 some preliminary arrangements for enlarging the scientific and technical study of such areas were concluded with the Institute of Geophysics of the N.A.U.M., and a preliminary program was prepared as a basis for a more complete project between both institutions. In 1967 this project was initiated with the Institute of Geophysics as the scientific agency to carry out research and training of personnel, and the Federal Commission of Electricity as the technical agency providing human and material cooperation in the execution of the program, for whose development an application of funds was also made to the United Nations.

Some of the operations in execution have already been alluded to in this report, for example, the gravimetric, magnetic, and seismic measurements in the Neo-Volcanic Axis, which also are a part of the Upper Mantle Program. In the latter months of 1967 a special study of another field situated in the State of Puebla (eastern Mexico) was initiated for geothermal, electric, and heat-flow objectives and will be continued throughout 1968. Preliminary results indicate that this area known as "Los Humeros" (The Smokes) was formed by an ancient crater of unconsolidated cineretic material through which vapours escape in the form of pseudo-fumaroles in abundance.

Other promising geothermal areas in the Neo-Volcanic Axis are located

to the W of Mexico City, and have been known for some time in their manifestations, although they have received very little attention. There are still other areas in Mexico that will also be taken in consideration at different stages of development of the joint program of the Federal Commission of Electricity and the Institute of Geophysics, that will produce important results with respect to the Upper Mantle program in this country, very specially for a better knowledge of the relationships between the Earth's crust and the Upper Mantle (including some heating processes, rock deformation, etc.) The program is also very important for volcanological studies, as indicated in a previous section of this report.

C - INTERNATIONAL WORK

The collaboration of the Pan-American Committee of Geophysical Sciences of the Pan-American Institute of Geography and History, with headquarters in Mexico City, has continued with the Institute of Geophysics of the N.A.U.M., in Central American countries in various aspects. A regional geophysical program has been in operation for a number of years, including gravimetric, terrestrial and aeromagnetic, and geohydrological studies, with special attention to the areas of the Gulf of Fonseca and the Nicaraguan Depression. This work has also received the cooperation of the National Cartographic Agencies of the six isthmian countries, and of the Inter American Geodetic Survey.

During 1967, in the Guatemalan territory, field work was initiated for the preparation of the "Chart of Magnetic Declination for the Epoch 1970.0" in the Central-American countries by Ing. Jorge Andrade G., of the National Geographic Institute of that country. These operations will be continued in 1968 in El Salvador, Honduras, and western Nicaragua in a second stage, and in eastern Nicaragua, Costa Rica and Panamá in a third and final stage. About 80 stations in the whole isthmus will be occupied and/or re-occupied, for annotation of magnetic values, anomalies, disturbance, etc.

A survey of the situation of geophysical studies in the Central American countries was published elsewhere (*in* Maldonado-Koerdell, M., 1966), with emphasize on programs in development and their coordination and systematization. It is now well known that for a number of years, the efforts of the Pan-American Committee of Geophysical Sessions of the PAIGH have concentrated in the area of the Gulf of Fonseca, as well as in the Nicaraguan Depression. A report on progress made in the study of both areas was presented at the Symposium on the Upper Mantle of the I.U.G.G., at Zurich, Switzerland, in September-October, 1967.

Relations and cooperation are also maintained in various ways with the Andean Geophysical Program, a Sub-Committee of the International Upper Mantle Committee of the I.U.G.G., at the University of California, Los Angeles. For the coming Pan-American Symposium on the Upper Mantle, to be held in Mexico City, on March 18-21, 1968, a number of papers on work done in the Central-andean area in South America will be presented by members of that group, headed by Rev. Ramón Cabré, S. J. of the Observatorio "San Calixto" at La Paz, Bolivia. There are now five countries where National Committees for the Upper Mantle have been established: Argentina, Brazil, Chile, Colombia and Ecuador, although studies are conducted for such purposes in other countries.

BIBLIOGRAPHY

- CAÑÓN AMARO, C. *et al.* 1967. Mexican National Report on Geomagnetism and Aeronomy presented to the XIVth General Assembly of the International Union of Geodesy and Geophysics, St. Gall, Sept. 26-Oct. 7, 1967. *Anales del Instituto de Geofísica, UNAM*. Vol. 12, pp. 59-66, 1 fig.
- FIGUEROA ABARCA, J. 1967. Mexican National Report on Seismology and Physics of the Earth's Interior presented to the XIVth General Assembly of the International Union of Geodesy and Geophysics, Zurich, Sept. 26-Oct. 7, 1967. *Anales del Instituto de Geofísica, U.N.A.M.*, Vol. 12, pp. 67-98, 10 figs.
- MALDONADO-KOERDELL, M. 1965. Geohistoric and Paleogeographic Data and Evolution of Volcanism in Mexico. *Bulletin Volcanologique*. Vol. XXVIII, pp. 65-67.
- MALDONADO-KOERDELL, M. 1966. Informe sobre la Situación de los Trabajos Geofísicos en los Países Centro-Americanos. *Publicación del Instituto Panamericano de Geografía e Historia*, núm. 290, 75 pp. (mimeógraph).
- MEDINA PERALTA, M. and J. MONGES CALDERA. 1967. Mexican National Report on Geodesy presented to the XIVth General Assembly of the International Union of Geodesy and Geophysics. Berne, Sept. 26-Oct. 7, 1967. *Anales del Instituto de Geofísica, UNAM*. Vol. 12, pp. 1-18, 4 figs.
- MOOSER, F. 1963. Historia Tectónica de la Cuenca de México. *Boletín de la Asociación Mexicana de Geólogos Petroleros*. Bol. 15, 11-12, pp. 239-245.
- MOOSER, F. and M. MALDONADO-KOERDELL. 1967. Mexican National Report on Volcanology presented to the XIVth General Assembly of the International Union of Geodesy and Geophysics. Zurich, Sept. 26-Oct. 7, 1967. *Anales del Instituto de Geofísica, U.N.A.M.*, Vol. 12, pp. 99-106, 5 figs., 1 pl.