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Strain Measurement in Australia with Particular Reference to the Cooney Observatory

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Strain measurement in Australia with particular reference to the Cooney Observatory

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A number of groups in Australia are concerned with Earth crustal movement measurement and interpretation. A brief description is given of their activities.

Monitoring crustal movements requires methods of strain determination which have the best attainable precision and long-term stability. Paramount to improvement of the established techniques is need for a facility where the various methods can be compared in a reliable manner. The remainder of the paper describes the research programme of the Cooney Observatory (operated by the University of New England) which has a dominant theme of instrument development and verification.

Rod, wire and laser strain-meters and the necessary peripheral equipment are described. Of interest is the continuing improvement of stable intermediate-length measuring bases in which a controlled temperature and pressure environment is created to eliminate the main systematic sources of instrument error during testing and calibration.

1. Measurement of strain throughout Australia

A number of Australian institutions are concerned with the measurement and interpretation of surface and subsurface Earth strains either by direct measurement of longitudinal and shear strain or by inference from related effects. These are now outlined. Their location is shown in figure 1.

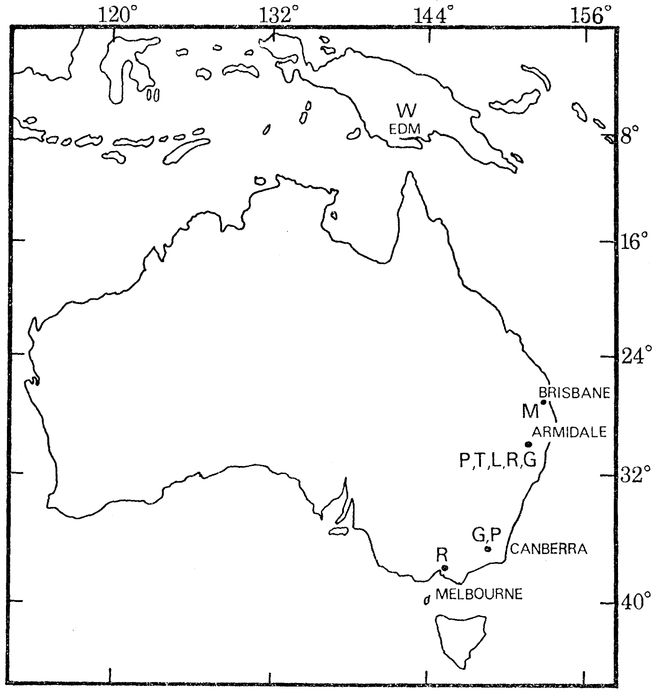

Figure 1. Geographical location of Australian groups concerned with crustal movements. W, water tiltmeter; M, mercury tiltmeter; P, pendulum tiltmeter; T, tensioned-wire strainmeter; L, laser strainmeter; R, rod strainmeter; G, tidal gravity meters; EDM, electromagnetic distance meter.

1.1. *The University of Queensland*

The Physics Department of the University of Queensland has the oldest established programme having its origin in the late 1950s. The activity has been toward earthquake prediction and concentrates mainly upon the relationships between magnetic effects, seismic activity, rock mechanics and research applications of tiltmeters. The main instrumentation is a sophisticated mercury-cistern tiltmeter using capacitance sensing. Apart from a 12-month duration experiment which measured shear strain using photographically recorded fringes formed in an equal-arm Michelson interferometer, this group has not been involved with longitudinal, *in situ*, Earth strain measurement. A review paper describing the research has been published recently (Stacey 1972); there is, therefore, no need for further expansion.

1.2. *University of New England*

The Geophysics Department of the University of New England operates an underground experimental facility known as the Cooney Tidal Observatory. It is ultimately concerned with reliable assessment of the strain within the crust using longitudinal strain instruments. The current emphasis is upon development of instruments and testing facilities for ascertaining short- and long-term behaviour, especially that of the length standard used. This programme is discussed below in detail.

1.3. *University of Melbourne*

The School of Geology of the University of Melbourne is establishing a strain measurement facility, having started in 1971.

At present the site, a disused gold mine 30 km from Melbourne, is being fitted out. The first instrument to be commissioned is a 30 m, temperature compensated, quartz rod strainmeter which is sensed by a commercial capacitance transducer (J. Langdon 1972, personal communication). Records of strain are expected from May 1972, onward.

1.4. *The Bureau of Mineral Resources*

The Department of National Development incorporates many specific task divisions, two of these, the Bureau of Mineral Resources, Geology and Geophysics (B.M.R.) and the Division of National Mapping have activities related to crustal research.

Staff of the B.M.R. are currently in their third year of testing a number of tidal-sensitive recording gravimeters (B. C. Barlow 1972, personal communication) which will soon be placed at selected locations in Australia. The Bureau have provided the two Melchior horizontal pendulums now installed in the Cooney Observatory. An extensive network of inertial seismic stations (Denham & Small 1971) and a volcanological observatory equipped with water-tube tiltmeters are operated by the B.M.R.

The Division of National Mapping recently purchased two laser-power geodimeters for geodetic survey, and which may be used to measure any relative movements between land masses in New Guinea.

1.5. *Australian National University*

The Department of Engineering Physics at the Institute of Advanced Studies, Australian National University, had, until recently, an active interest in inertial seismic and tilt instruments. The instrument most recently developed was a two-axis pendulum tiltmeter employing reluctance transducers in a force-balance arrangement (K. Muirhead 1972, personal communication) for use in 200 mm diameter boreholes.

1.6. *The National Standards Laboratory*

Although long-length standards are of interest to both crustal and standards measurement scientists, the Australian National Standards Laboratory staff have not participated directly in crustal measurement to date. A commercial two-frequency laser interferometer system is to be purchased for improved tape calibration in the new Laboratory location. It is anticipated that this facility will assist the strain-meter standards stability programme of the University of New England.

A series of determinations of the gravitational constant using the free-fall technique has recently been completed.

Finally, there is a proposal to develop an atomic-absorption stabilized laser.

2. Research in geophysics at the University of New England

The important relationships and groups concerned with the tidal research work are shown in figure 2.

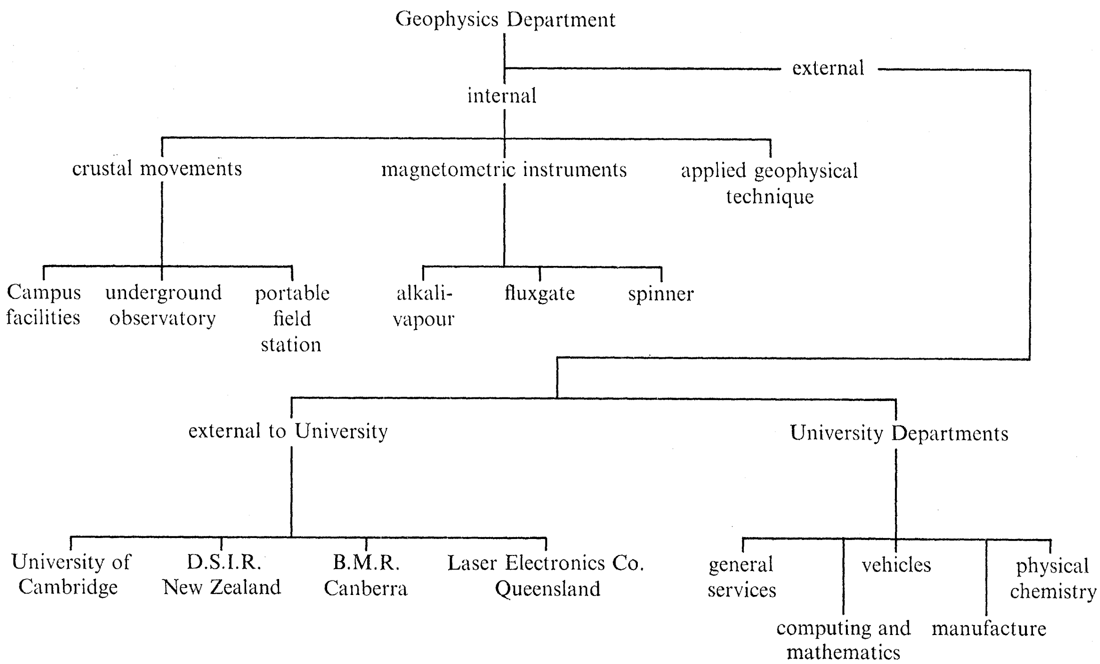

Figure 2. Facilities and coordination relevant to crustal measurements.

Research is in three major areas, crustal movement measurement and interpretation, magnetometer development and application, and applied geophysical technique.

The Department of Physical Chemistry has extensive expertise and equipment in precision pressure and temperature measurement, both skills being closely related to the tidal programme.

There is close liaison with the Department of Geodesy and Geophysics, Cambridge University, and the Earth-strain Group of the Department of Scientific and Industrial Research (D.S.I.R.) in New Zealand. The main cooperation has been on the subject of tensioned-wire strain-meter development.

Within Australia a cooperative project shared with the B.M.R. is the siting and maintenance of two Melchior horizontal pendulums systems. These (ORB 53 and 54) were purchased and installed by the Bureau staff in accordance with specifications laid down by Professor Melchior. The Department of Geophysics is responsible for continuing service. The Bureau also supplies tidal gravity predictions for use in the Cooney Observatory.

Another recent association is that with Laser Electronics Co. Limited, an Australian firm with considerable expertise in the use and development of lasers in geophysical applications. An arrangement has been made with the firm to develop an atomic-absorption stabilized laser using the facilities and expertise of both parties.

The magnetometer research is relevant to this account. Considerable expertise is available in the design and manufacture of the alkali vapour magnetometer (Stanley & Clack 1971) which because it operates on the principle of optical-pumping and absorption, is relevant to that needed to produce an atomic-absorption stabilized laser.

Many field instruments used in applied geophysics are available for study of effects correlated with Earth-strain.

3. The crustal movement research

The intention of the programme has been to create a general-purpose facility with specialization developing naturally. Figure 3 is another chart illustrating the organization of the available resources along with this theme.

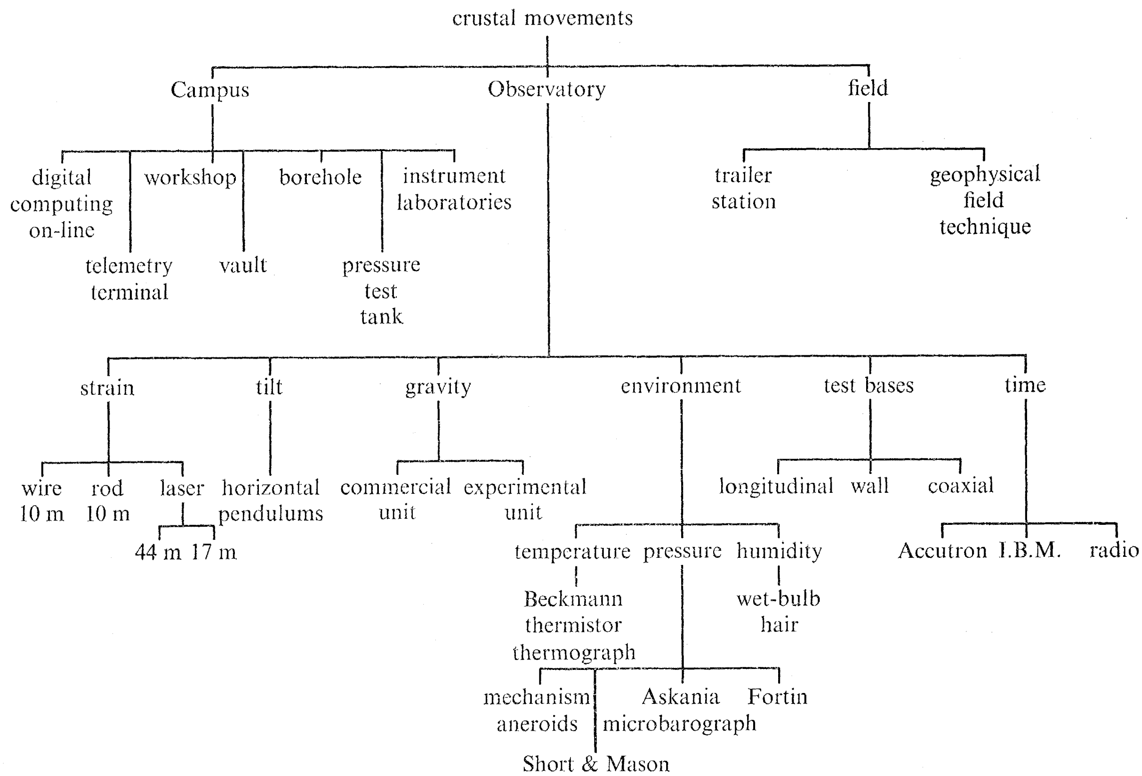

Figure 3. Organization of crustal measurement programme.

The Campus

The Department is currently moving into a new, permanent, building, especially designed to allow quality instrument work as well as normal teaching requirements. One ground floor room has no windows or ventilation and is for use as a reasonably quiet test room. Provision is made for a seismically isolated block. In the quadrangle outside is a 7 m deep, 0.8 m diameter borehole that will be used for teaching and instrument testing purposes.

A test base, 8 m long, has been set up on the brick wall of the basement in the adjoining Geology building. In this area temperature remains within a degree Celsius over several days enabling extensometers to be tested at low sensitivity. The wall is strained diurnally with an amplitude of 3 parts in 10^6 so full gain can only be used for limited periods of time.

In order to compensate mechanical strainmeter records for effects of changing barometric pressure, it is desirable to have recording barometers. An Askania microbarograph with electro-optical readout has been loaned by the B.M.R. to assist development of the Department's own units. At present a force balance system is being investigated by an honours student. A pressure vessel has been constructed in which adjustable pressure variations of $\pm 10\%$ ambient can be provided for equipments of up to 300 mm × 600 mm cross-section.

The Observatory

A disused gold mine has been fitted out with essential services. The tunnels have been divided into chambers with brick walls to isolate the various experiments. A description of the general details of the Cooney Observatory has been published (Green & Sydenham 1971, see also Green & Sydenham 1972).

The main concentration of effort is on strain instrumentation and preliminary work included the compilation of a survey of technique (Sydenham 1971) to assist formulation of the programme which started seriously in 1970.

A tensioned-wire strainmeter of improved design (see Sydenham 1969*a* for a description of original units) is in operation, the results of a study made of progress with this new technique (Sydenham 1972*a*). Three other units, complete with calibrated electronic amplifiers and recorders, are in use on other projects. One is used to determine if the force exerted by the inductive, half-bridge, microdisplacement transducer is significant. This is being examined using a laser-powered, electrical read-out, autocollimator technique to detect small rotations of the balance as the transducer is energized at various core positions. Two others are being used to ascertain the relative stability of the longitudinal stabilized base (see below) with invar wires and fine quartz canes. A fifth, less precise, unit is used in a teaching equipment intended to give experience in fine mechanical design and the dynamics of mechanical systems.

A 10 m quartz tube extensometer was built in mid-1971. Tidal records were obtained (Sydenham *et al.* 1972). This installation was intended as a research tool for investigating a method of temperature compensation using a second tube of a material having a significantly higher coefficient of thermal expansion. This idea is modelled on Colby's 1890s equipment (used for land survey) with the exception that electronic signal mixing is used instead of mechanical linkages. Preliminary calculations show the method capable of reducing the effective thermal coefficient of the measuring tube by two orders of magnitude.

Two laser interferometer extensometers have been constructed. One, 40 m long, is in the same direction as the wire, quartz tube and measuring base. This will assist intercomparison when all are operating satisfactorily. The second is approximately 20 m in length and is also mounted horizontally but at 90° to the longer. Mounts, decoupled from the vacuum housing, support a two corner-tube version of the Michelson arrangement. The reference arm is temperature compensated using re-entrant mounts and all critical optical paths are in vacuum. Industrial Victualic water pipe has been employed to enclose the path. The standard rubber sealing rings have been found to be adequate (the flanges are filed smooth) and a vacuum of better than 0.1 Pa (10^{-3} Torr) is maintained by a 115 l/min two-stage rotary pump.

Fringe chasing, operating directly on the fringes which are reflected out through a perspex window, is employed using a modulated tracking system driven by an electromagnetic loudspeaker unit. To increase the frequency response, a superior design will be used in which a parallel plate micrometer (driven by a piezoelectric device) deflects one beam of the interferometer transversely. This has the same displacement sensitivity as moving a cornercube but has the distinctive advantage that considerably less mass needs to be moved thus gaining in response.

At present unstabilized lasers have to be used (5 mW He-Ne with Vicor tube mirror supports) but plans are in progress to produce a stabilized laser which will act as a control for all others. This depends upon the availability of funds and upon the results of the stabilized base research for it may be proven that etalon frequency control such as that used by Berger & Lovberg (1970) may be superior for a given cost.

All strainmeters, and that includes laser interferometers, are subject to dimensional instability for mechanical components must be employed. Intercomparison of the various types on a common rock-face does not lead to wholly conclusive answers on drift and calibration for there is difficulty in ensuring which instrument is correct. (King *et al.* (1969) provides one of the few published long-term experimental intercomparisons between different instruments.) The approach being pursued is to investigate the attainable limits on length stability of steel structures which are temperature and pressure controlled to exacting limits. The first measuring base was constructed in a surface laboratory (Sydenham 1969) and this 12 m unit was controlled in length to a few parts in 10^7 with no obvious drift characteristic. A second improved 10 m unit has been built in a chamber of the Cooney Observatory and nearly two orders of magnitude in improvement were obtained. The relative drift rate between the base and an invar wire extensometer reduces to 10^{-8} per day after 3 weeks of operation. The drift rate is predictable, the noise perturbation over a day being considerably less. Since publication of the results (Sydenham *et al.* 1972) changes have been made. A fully distributed heater has been added. A base-load cooling unit counteracts the majority of the heating provided by fluid friction enabling on-off control to be obtained without the need to switch the pump. This has reduced the cyclic length change from 1.6 μm to 0.25 μm and the drift rate is smoother. It is thought that the observed drift is predominantly due to wire creep and work is in progress to erect a tensioned-member extensometer using 1 mm Vitreosil cane hanging in catenary. This will assist the separation of drift rates.

Daily atmospheric pressure variations alter the length of mechanical objects by a few parts in 10^9 which is significant in tidal measurement research. The open-sided base is, therefore, limited as pressure is not controlled. This also prevents a laser interferometer from being compared.

A second base is being made which overcomes this disadvantage. This is a coaxial arrangement of waterjackets and insulating layers. It consists of a central 200 mm diameter steel pipe surrounded by a water jacket 50 mm thick. Impervious thermal insulation, 100 mm thick, surrounds the jacket and the whole is housed inside a 750 mm diameter pipe filled with water. The system mass is close to 2000 kg, half of this being in the fluid forming the separated jackets. Two separate control systems, coarse outer and fine inner, will be used to control the inner tubes temperature to several microkelvins. The central-tube ends are closed to form a vacuum chamber.

This facility will provide an improved test facility in which rod, wire and laser strainmeters can be intercompared. The controlled environment will also enable etalon experiments (such as that proposed by Bostrom (1970) using a natural beryl crystal) to be conducted in the search for an ultrastable length standard.

The use of a stabilized base as a long-term standard of length is a distinct possibility for the reliability is in terms of years and the cost minimal.

An important source of instability in a strainmeter could be the terminal mounting arrangements. Expanding bolts, surface glued and potted studs, and dead weight are all used in extensometers and tiltmeters. In order to determine the secular drift of a site, and to be sure it is not partially an instrument defect, data is needed on the time behaviour of mounts. An honours student is currently engaged on this problem. A study of microdisplacement transducers (Sydenham 1972*b*) revealed that the inductive transducers already used were capable of the 10 nm resolution needed. Sets of two similar mounts will be used, measurements of their relative movement giving an indication of the merits of various types. As caliper gauging will not repeat with the precision needed, fixed gauge heads will be used switching each to a common electronic unit.

The Observatory programme has strain and tilt instruments but not gravity. A gravimeter used for tidal recording in fixed location deep underground is less complex than that needed in surface work as the dynamic range is small and the temperature reasonably constant. An honours student is constructing a vertical spring-mass unit. A Ni-span C spring (a material having low mechanical hysteresis and thermoelastic coefficient) supports a 300 g mass. The spring extends 1 m so gravity tides will cause length changes of 100 nm amplitude. A transducer resolution of 1 nm will enable tides to be resolved to 1 %.

Finally, a two-wheel trailer station has been made which will operate and record from up to eight instruments in the field for at least a week unattended on its own battery supplies. This will be used to study regional differences in strain.

The continuing cooperation of the Earth-strain groups of Cambridge University and the D.S.I.R. is greatly appreciated.

Financial and technical support needed to create the facility and provide the instruments has come from many sources – the Australian Research Grants Committee, Carpentaria Exploration Limited, University of New England Grants, University of Cambridge, New England Antimony Mines NL, Sydney Water and Sewage Board and Henry Wigan (Australia) Limited have each assisted and their aid is much appreciated.

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