# OBSERVATION METHODS AND INSTRUMENTS

## TGD-TYPE GEOTHERMAL-GRADIENT METERS

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The TGD-type instruments developed at the Institute of Oceanology for measuring geothermal gradients in clastic deposits are described. Improvements in instrument design and measuring techniques made during use of the TGD resulted in better-quality data and more effective studies. The technique used to measure the heat conductivity in bottom samples is described.

The TGD-type instruments developed at the Institute of Oceanology, USSR Academy of Sciences for measuring the geothermal gradient in bottom deposits are effectively used in field operations to measure the heat flow from the sea bottom. Improvements in instrument design and measuring techniques made during use of the TGD resulted in improved data quality and research effectiveness.

The method most generally used to determine the heat flow is the indirect method in which the heat flow is computed from the vertical geothermal gradient in the bottom deposits and their heat conductivity. The vertical geothermal gradient is usually measured by immersing heat sensors in the deposit; the sensors are installed in geological core samplers or special bottom probes, together with a measuring device, and launched on a cable from aboard ship [1]. The heat conductivity of the bottom can be measured directly in the deposit or in the geological core sampler (after the core sampler has been hoisted aboard ship) using the needle-probe method [5].

The heat flow is defined by the formula

$$Q = \Delta Tk$$

where $\Delta T$ is the temperature gradient and k is the coefficient of heat conductivity of the deposit.

The TGD-65 thermogradiometer and its modifications, developed in 1965 at the Institute of Oceanology as instruments for measuring the geothermal gradient in bottom deposits, are automatic instruments designed to be installed in standard geological core samplers [3]. The instrument consists of a measuring-recording unit in a durable housing and a set of external heat sensors with connecting leads. A block diagram of the TGD-65 is shown in Fig. 1. The temperature sensor TS is connected to a measuring bridge circuit B. The bridge is balanced with potentiometer P, which operates in a scanning mode. The potentiometer and recorder are driven by an electric motor M through reduction gear RG. The output voltage of the measuring bridge is applied to the phase detector PD via amplifier A. The signal from the detector is fed to recorder-amplifier RA and then to recorder R. The bridge circuit and phase detector are supplied by an auxiliary generator G. The device is turned on and off by programmer PR, which connects the circuit to the power supply PS.

The heat sensor and measuring circuit of the device are selected with the specific features of the measurement of the thermal gradient in the sea in mind. Foremost among these special features is the difficulty of submerging the heat sensors in the bottom at great depths and the comparatively low thermal gradient in the bottom deposits. The average thermal gradient is about 0.05° C/m; the minimum is 0.002° C/m and the maximum some tenths of a degree per meter. To improve the measuring accuracy the baseline between heat sensors in the bottom should be increased. But this baseline is governed by the ability of the geological core sampler to penetrate the bottom. The average depth of penetration of direct-flow core samplers is 3-8 meters, depending on the nature of the bottom; with pneumatic core samplers the penetration is 10-15 meters. These quantities also govern the maximum spacing between sensors. However, in view of the circumstance that the measurement of thermal gradient in the surface layer of

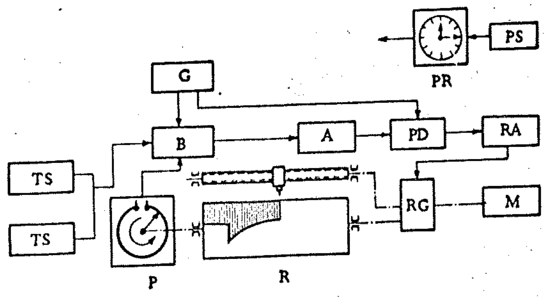

Fig. 1. Block diagram of thermogradiometer TGD-65.

sediment may be considerably in error, owing to the specific conditions of heat transfer between the bottom water layer and the bottom, the distance between heat sensors is selected so that the upper sensor is about 1-2 meters in the deposit. Thus, when operating in heavy bottom deposits the corer penetration is about 3 meters, and the spacing between sensors is usually no more than 2 meters. With this baseline the temperature difference between upper and lower sensor will vary between 0.004°-0.5° C, as a function of the magnitude of the gradient.

It is quite clear that to determine the gradient by means of measurements of the absolute temperature at each sensor, to the required accuracy of thousandths of a degree, is practically unrealizable and unsuitable. The TGD-65 uses an AC differential-bridge circuit which permits direct measurement of the temperature gradient. Taking into account the lowest measured values, MMT-1 thermistors, with a conversion conductance of 5% per 1° C, were used as heat sensors. High-resistance thermistors should be used to reduce the effect on the measurements of resistance variations in the circuitry. But at the same time this is accompanied by an increase in the effect of reactance on the operation of the measuring circuit. Attempts to use a DC measuring bridge to eliminate the effects of these components were unsuccessful owing to the generation of galvanic currents in the circuitry. This was because one of the heat sensor leads was an insulated conductor and the body of the core sampler was used as the second lead. Two-conductor leads considerably complicate the hermetic sealing of the lead-in connection to the sensor and are ordinarily not used. The optimum heat sensor resistance for the TGD-65 circuit is 2-5 KΩ.

Particular attention was given to the selection of heat sensors having stable and identical characteristics. As a rule the sensor characteristics are taken and then pairs are selected. Characteristic correspondence is maintained in a working temperature range of 0° C to 6°-8° C. In use, the measuring circuit and sensors are calibrated periodically.

In view of the fact that the measuring cycle is of some minutes duration, no special requirements are placed on the time constant of the sensors, and it is largely determined by the construction of their shielding arrangement. To eliminate the thermal influence of the core sampler on the sensor readings, the sensors should have minimum thermal contact with the core sampler and good contact with the medium to be measured. The shielding is designed for the large mechanical loads generated as the corer enters the compact bottom. Based on tests, a construction was devised in which the end face of the heat sensor is protected by a strut, with the thermistor placed in its central section. This system sharply reduced the number of damaged sensors when operating with the thermogradient meter in dense bottoms.

The measuring bridge is balanced by the potentiometer, which rotates on the same axis as the recorder drum. When the bridge is unbalanced, the phase detector signal is applied through an amplifier to the recorder, which inscribes a line on the chart paper as the drum revolves. In the first instruments the recording was accomplished with electrothermal paper; in later models waxed paper is used. This not only permits simplifying the circuitry of the instrument and reduces the power required, but also improves the quality of the recording. As the potentiometer contact passes through the point of phase balance, the bridge output voltage changes by 180° and the record stops. Each revolution of the drum corresponds to a measuring cycle, with a simultaneous shift of the stylus carriage along the drum axis so that the next recording takes place on a parallel line. The scale of the instrument can be chosen within the limits of 0.3° C to 1° C as a function of the gradient expected.

The instrument's pressure housing with the measuring-recording unit has electrical lead-ins for connecting the heat sensors. Outlets are located on the upper cover of the housing to reduce the probability of damage when the instrument is embedded in the bottom. The thermosection 10 < t < 100 sec. is defined by the quantity q/4Πk. The value of k is computed with known q. A standard bridge measuring circuit is used to measure temperature. T = φ(t) is recorded with the EPP-09 or PS-01-21 potentiometers. The power required by the probe-heating element is about 1 watt and is regulated with a pointer-indicating instrument. If the temperature and heater power are regulated to 1% the thermal conductivity can be established to ±3%. The accuracy of establishing the heat flux amounts to ±(10-15)%. Heat flux studies using this equipment have become an indispensable adjunct to geophysical studies at sea on the R/V's Akademik Kurchatov, Dmitri Mendeleyev, Vityaz' and Vavilov. Thermal gradient measurements have been made in the Pacific, Indian and Atlantic Oceans and in the Black Sea and Sea of Okhotsk. These measurements have provided new data on the deep heat flows through individual areas of the ocean and sea bottoms.

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# OCEANOGRAPHIC MODIFICATION OF THE SEISMIC WAVE-REFLECTION TECHNIQUE

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An automated shipboard system for data collection, used to modify the oceanographic reflected-wave method, is considered. It is distinguished by its high efficiency, great depth accessible to investigation and large information capacity.

The development of modern, high-speed oceanographic vessels has brought with it the requirement for reliable geophysical measurements made continuously over extended times at ship speeds up to 18 knots. This imposes the following requirements on the seismic reflection method: (1) an increase in the effectiveness of the sources of excitation of elastic waves; (2) improved reliability and noise immunity of the recording channel; (3) smaller size, better durability and increased sensitivity of the receiving devices at high towing speeds; (4) recording of original data on magnetic tape in a form suitable for processing in an electronic computer; (5) operational checking and analysis (rapid-processing) of the data obtained.

Excitation of elastic waves. In seismic operations at sea with the wave-reflection method, the elastic waves are usually generated from the ship while underway by a high-explosive charge or non-explosive sources [1, 5 and others]. To realize a high signal-to-noise ratio and great depth capabilities, either a large high-explosive charge or a towed group of pneumatic sources involving as many as tens of units is required [6]. The non-explosive sources of sufficient power presently known are not suitable for group towing at high speed and their use demands a substantial refitting of oceanographic vessels and the installation of high-power compressors. In the present stage of development of the oceanographic reflected-wave technique the explosive source is chosen, but with a small charge weight so as to limit the zone of destruction of living organisms and high-enough energy capacity to yield a good depth for investigation at high ship speeds and without requiring special refitting.

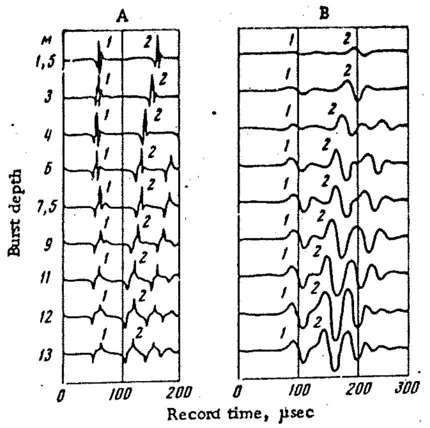

Fig. 1. Influence of explosion depth of a 50 gram charge of TNT on the shape of the radiating pulse:

1) first shock; 2) second shock; A) filter: 200-300 Hz; B) Filter: 20-30 Hz.

Studies of deep underwater TNT charges [8] have shown that in the seismic frequency range (10-100 Hz) the shock wave in the medium transfers only 1.5-4.5% of the chemical energy of the explosion. At depths great enough for a gas bubble to exist and without convection, 20-22% of the burst energy of small charges is concentrated in gas bubble oscillations; the period and energy of the pulsations depend on the depth of the explosion and on the charge weight.

Figure 1a shows graphically the overall effect of the interaction between shock wave and pulsations with various TNT charge depths (charge weight 50 grams) in the 200-300 Hz frequency band. An examination of the shape of the observed pulses reveals that the shock wave energy predominates at the high frequencies, while at low frequencies it is commensurate with the energy of each pulsation, or even less. The main portion of the useful energy of a deep-water explosion is concentrated in the impulses of the gas bubble and their reflection from the bottom. Therefore, if the burst occurs at optimal depth—equal to one-fourth the prevailing wavelength—a seismic sounding pulse of maximum possible energy and simple form [2, 4] can be obtained in a sufficiently narrow frequency band as a result of the in-phase combination of the direct pulse and the pulse reflected from the water surface. The graphs of Fig. 1b show that a resultant signal of maximum energy, simplest form and longest duration, is observed in a frequency band of 20-30 Hz with the burst of a 50 g charge at a depth of 12-13 m.

These considerations are corroborated by a large quantity of experimental data [7, 8] illustrating the increase in amplitude of the reflected signals (averaging up to 18 dB for various regions) resulting from the use of optimal depths and small charges and equivalent to charges 20-30 times heavier near the surface. As an example we cite below our experimental data on the relative increase in amplitude of the reflected waves from surface and deep bursts of TNT and ammonite charges.

These data are in good agreement with the observations of Lavergne [8] and show that a 200 g charge at a depth of 15 meters can yield the same seismic effect as a 5 kg charge at 1.0 depth.

Receiving Apparatus. Modern oceanography has imposed more stringent requirements on towed receiving gear, stemming primarily from the speed of oceanographic vessels. To carry out seismic operations while underway at high speeds (12-15 knots) required a substantial change in the design of the receiving arrangement, including improvement in noise immunity and mechanical strength, and a reduction in the cross-sectional area of the tow as a whole. The technique discussed above, of exploding small charges at the optimal depth, does not provide a time interval between bursts of 30-45 sec, i.e., with a ship speed of 12 knots the burst interval is about 300 m. Hence the receiver must be about 600 meters long to ensure continuity of seismic profiling. At towing speeds above 10 knots the strength characteristics of polyvinylchloride hose