In zone 6 ground pressure becomes so intense that shelling of rocks, crushing of the side walls, and uprising of the floor necessitates a heavy lining throughout the periphery of the bore.

From the foregoing, it becomes evident that the shape or cross-section of a tunnel and of its lining depends largely on the material penetrated, its cohesion, stratification, and the depth overlying the bore. The yardage of masonry lining, per lineal foot of tunnel, may, in certain sections of a tunnel, vary by 100 per cent. from that of adjacent sections. For instance, the cost of the lining of the Simplon tunnel varied from $28 per lineal foot for the light sections to $229 per lineal foot for the heaviest sections.

Lining Tunnels.—The necessity of lining a tunnel, partly or throughout its length, depends chiefly on the nature of the material penetrated, its stratification, cohesion, etc. A bore with little overlying depth, driven through a simple formation from portal to portal, can be left unlined, if the material has not been, and is not liable to become, affected by weathering, and if, during construction, it has been demonstrated that the rock is solid, and that slips or falls are not to be anticipated. In complex formation, where alternate strata of igneous, metamorphic and sedimentary rock are expected, an exact knowledge of the location of contact zones and of the length of the sections of different formation becomes necessary, in order to decide whether and where a lining is to be provided.

The following classification can be established with reference to the necessity of lining tunnel: (1) Tunnels necessitating a lining at the very outset, *i.e.*, immediately following the excavation, as, for instance, bores driven through materials possessing little cohesion, such as sand, gravel, weathered rocks, and rocks subjected to intense pressure, causing it to crush upon being tunnelled. (2) Tunnels capable of being driven without making the lining follow closely the excavation, when the walls and roof are capable to resist ground pressure without heavy timbering or lining, for several months, as, for instance, bores driven through materials sound and solid upon being tunnelled, but which, when exposed to air or humidity for any great length of time will swell and disintegrate, lose their compressive strength, and thus become inadequate to resist heavy ground pressure. (3) Tunnels capable of standing alone, for years, without timbering or lining, but which, eventually, will require a permanent lining to check or prevent chemical action to disintegrate slowly, but continuously, the periphery of the bore, or else to check slips of rocks loosened by the slow eroding action of underground water. (4) Tunnels capable of standing permanently without a lining, when driven, for instance, through hard and solid rock, not subjected to weathering, and free from underground water or minerals, capable of being disintegrated by mechanical or chemical action.

It is not abnormal to encounter in one bore, one or several of the classifications referred to above, all depending upon the geologic formation of the range; therefore, the better the knowledge of the formation, the closer will be the actual cost of the bore to that estimated. In short tunnels, where maintenance and reconstruction work can be carried on under favorable conditions, the question of lining the bore at the very outset becomes of secondary importance, whereas in long tunnels, the cost of lining or re-lining, without interruption of traffic, runs from two to three times that of lining at the very outset.

Driving Methods.—The driving method best adaptable to a particular case depends chiefly on the formation of the range to be tunnelled. The so-called American, German, Belgian, English, Italian and Austrian methods of tunnelling were originated and adapted to overcome natural obstacles of varying character. In very treacher-

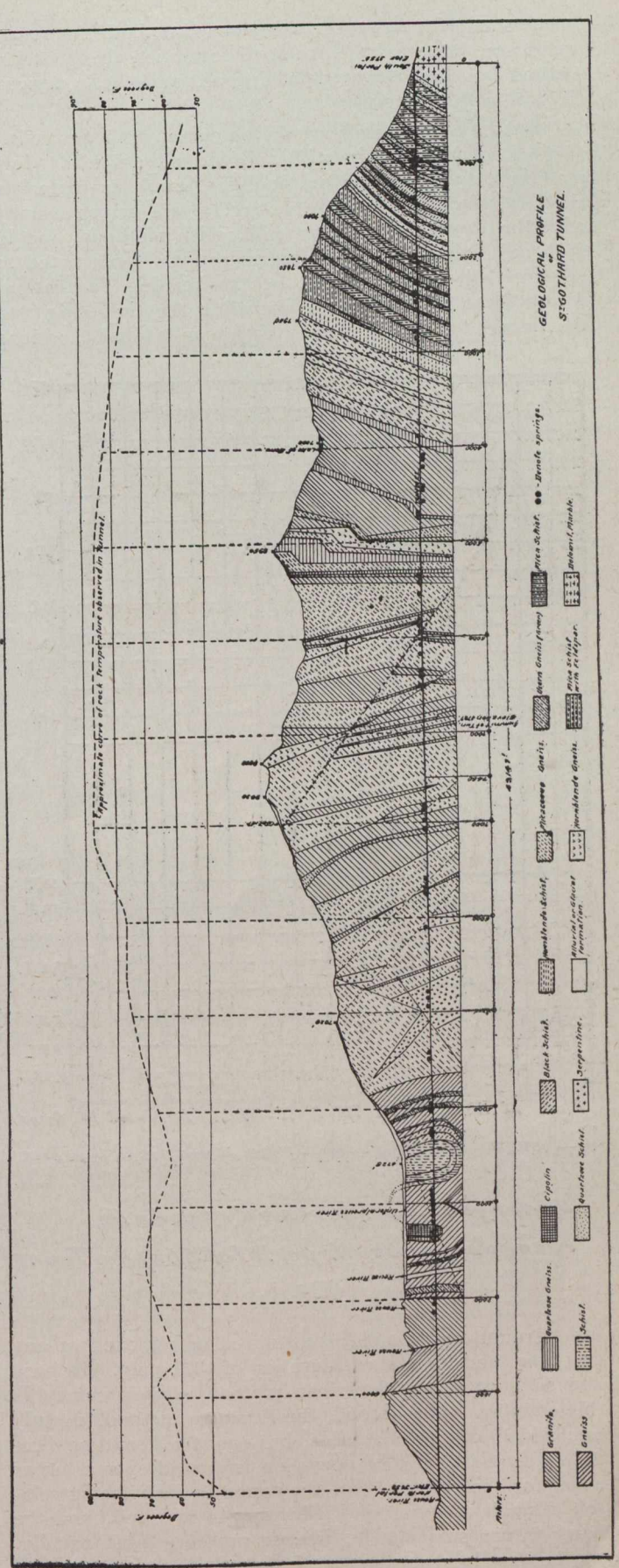

Fig. 4.—Geological Profile of St. Gothard Tunnel.