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ASSEMBLED CURVES FROM COMPUTER SOLUTION FOR A HYDRODYNAMIC MODEL OF HYPERVELOCITY IMPACT

INTRODUCTION

This is the Eighteenth Quarterly Progress Report on Project NASr-7. The title of the project is "Shock, Flow and Radiation from the Hypervelocity Impact of Microparticles." The analytical and experimental phases of this project are concerned with the phenomena that occur with the hypervelocity impact of microparticles on a massive target, which may be solid, or layered. The overall objective is to obtain a sufficiently fundamental understanding of the physical mechanisms in the hypervelocity impact of a microparticle so the momentum and the energy transferred from the particle to the target may be ascertained and, possibly, the density of the incident microparticles may be estimated.

This Progress Report presents additional curves from the digital computer for the problem that was presented in Progress Report No. 17. The curves of the computer calculations are presented with only minor smoothing of the numerical results. The "raw" data are presented so the amount and manner of smoothing these results at some later time will be readily apparent. The discussion in the preface to the preceding Progress Report shows the need for some modifications such as inserting a steeper shock front. The enclosed curves are in addition to the results of a few representative impacts and of the several summary curves that were presented in the Seventeenth Quarterly Progress Report. The equations and discussion in that Progress Report and in the preface to that report apply to these curves.

STATEMENT OF THE PROBLEM

The problem for solution is the hypervelocity impact of a sphere of aluminum. The aluminum sphere has a radius of about 0.00065 inches and it is incident normal to the surface of the slab. Similitude does not apply to the equations for hydrodynamic flow so the results from one hypervelocity impact cannot be scaled to give the results for another hypervelocity impact. The solution for several diameters of the incident spheres cannot be scaled from the results for the impact of a sphere of one diameter. The results for spheres with more than one diameter require a considerable modification of the computer program so only one diameter is considered in the data that is reported in this Progress Report.

On the assumption of hydrodynamic flow, the enclosed curves follow the penetration of an incident sphere into a semi-infinite slab for six velocities of impact. All of the velocities are assumed to be hypervelocities. A hypervelocity impact is one in which the incident particle is traveling faster than the velocity of sound in the target material. The velocities that were investigated are: 5.68, 15.16, 23.69, 36.0, 47.38 and 60.64 kilometers per second. In our more common system of units, these velocities are approximately 18,700, 49,700, 77,700, 118,100, 155,400 and 198,950 feet per second, respectively.

The enclosed curves are grouped under six headings, which are the magnitudes of the velocities of the incident particle. Under these six general headings, the curves are grouped for different instants of time during the penetration of the aluminum sphere into the slab. For the most general case, there are four curves for each instant of time and these four curves are the velocity distribution, the isobars of the pressure at that time, the curves of constant

density and the curves of constant energy. All four curves are not necessarily included when it is obvious that nothing important is illustrated by their inclusion.

COMMENTS ON LOWEST VELOCITY OF IMPACT

The curves for the lowest velocity have very little significance, since the velocity of sound in solid aluminum is reported in the literature to be about 16,740 feet per second. Most of the velocities for the impact at an initial velocity of 5.68 kilometers per second are well below this value and the presented solution has no relation to the solution to the real impact with plastic effects and the propagation of the shock through solid aluminum. The set of curves for the velocity of 5.68 kilometers per second are included so the results may be compared with the same impact when the major corrections for the fluid, plastic and elastic states of the material are included. This would be a comparison of the hydrodynamic model with the plastic elastic model. A program for the latter problem is now in the process of being formulated.

The organization of the curve sheets follows the arrangement that is outlined above except for one sheet. The first curve, Figure 66, is a summary curve which shows the pressure vs the depth of penetration for an initial impact velocity of 5.68 kilometers per second. This curve is placed with this collection instead of in the thesis because the results for this low velocity are so much in error. There are a group of similar curves in the thesis.

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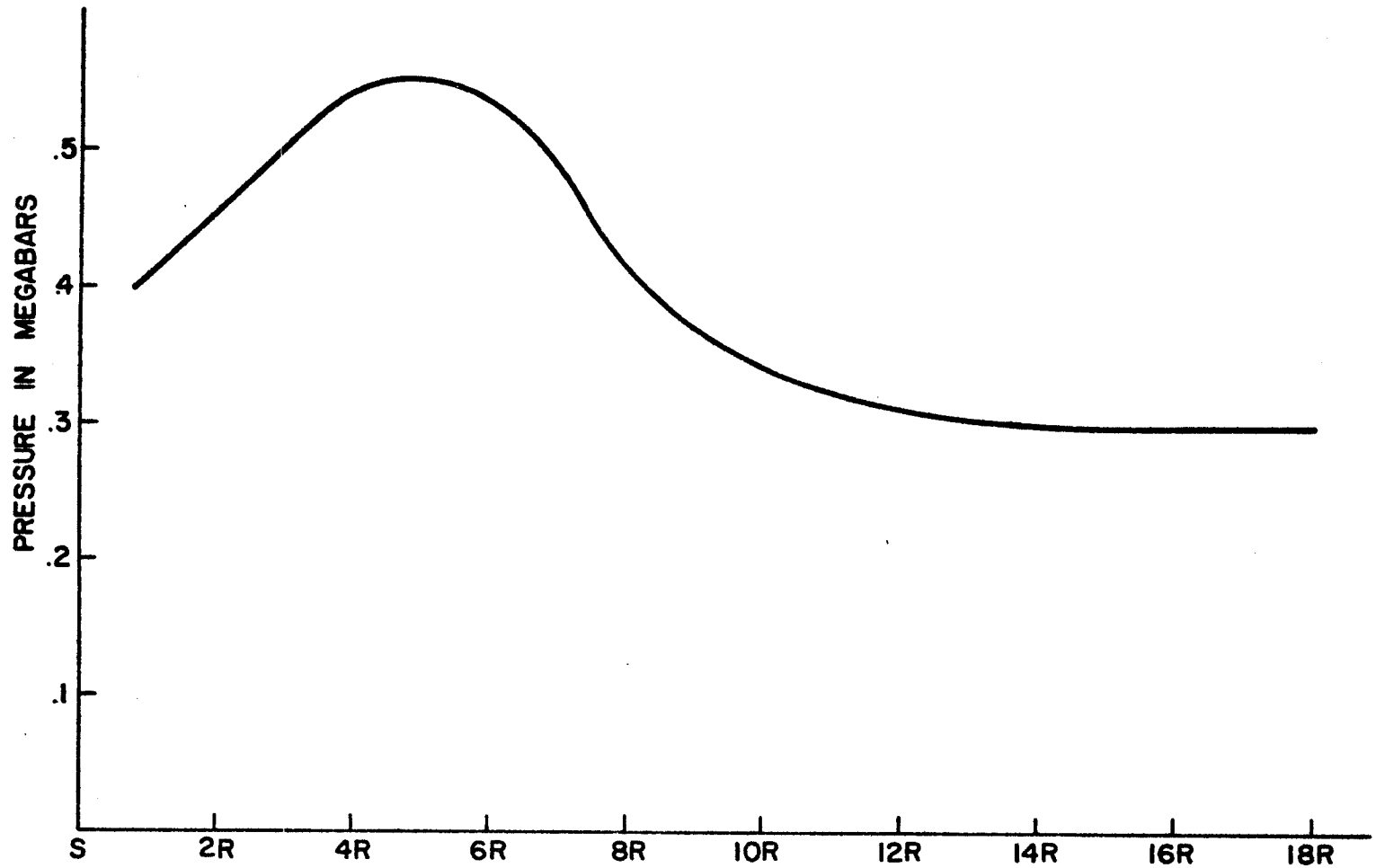

Figure 66. Approximate Peak Pressure vs. Maximum Penetration, Case I

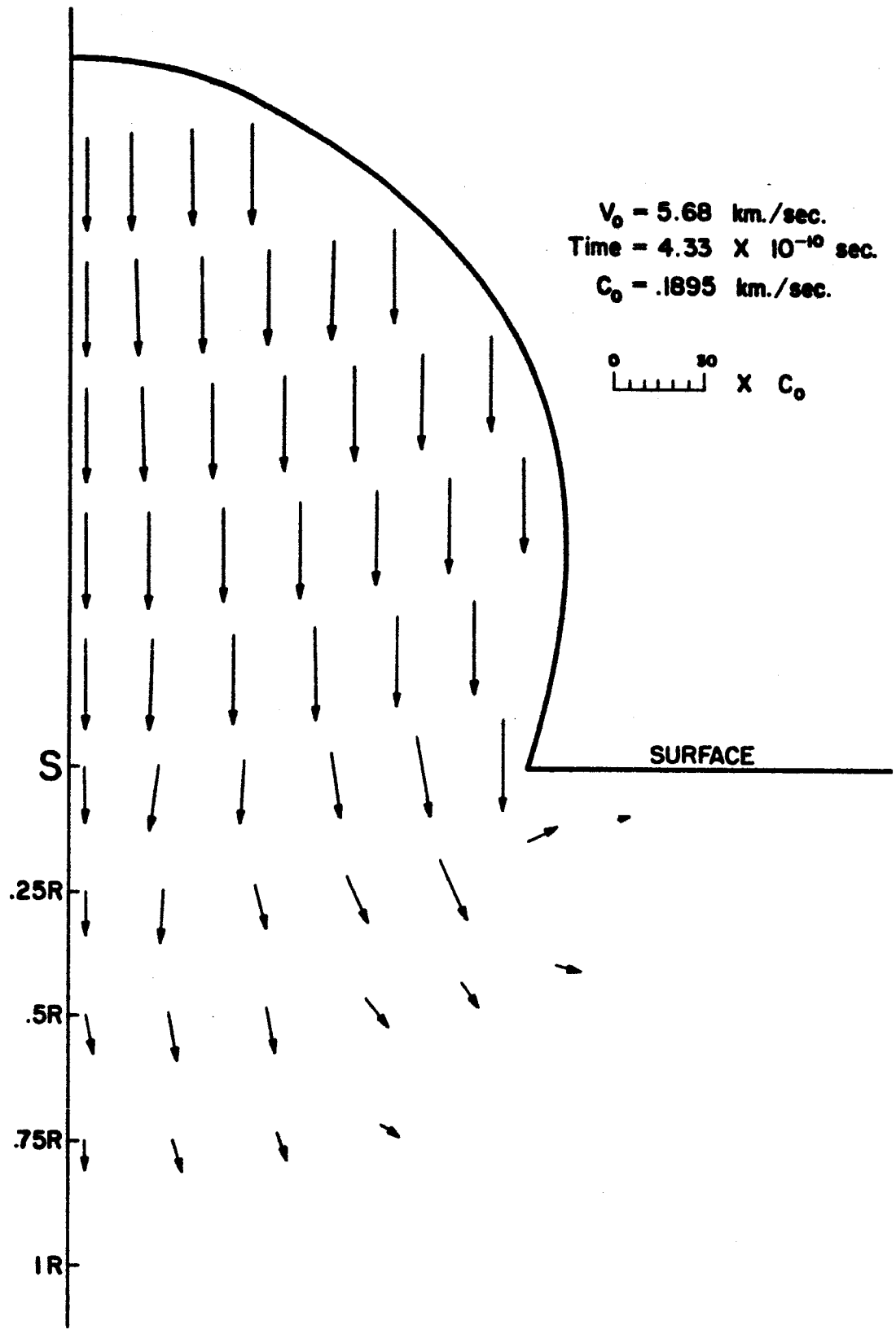

Figure 67. Velocity Map (t = .433 x 10^{-9} sec) I

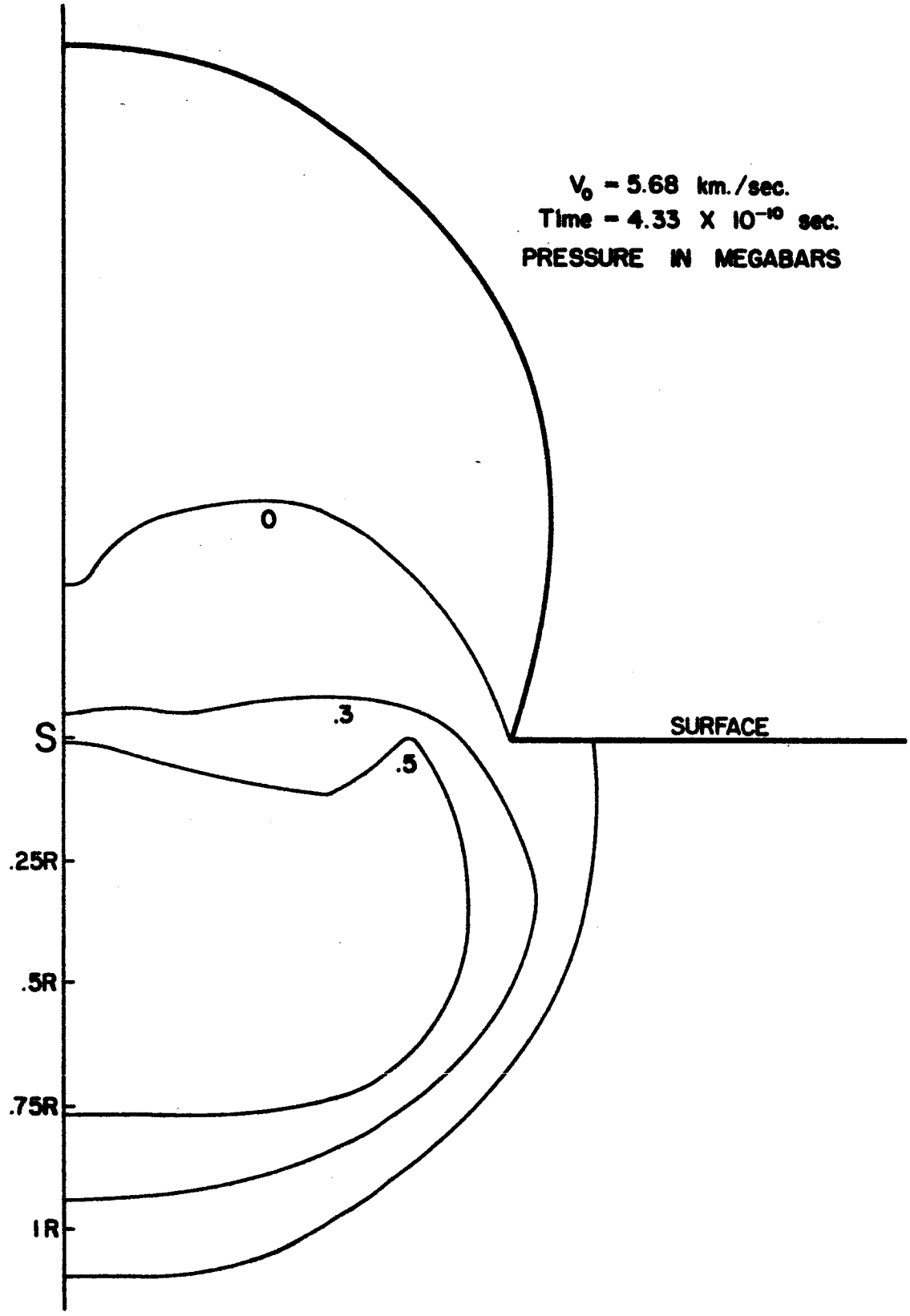

Figure 68. Pressure Map (t = .433 x 10^{-9} sec) I

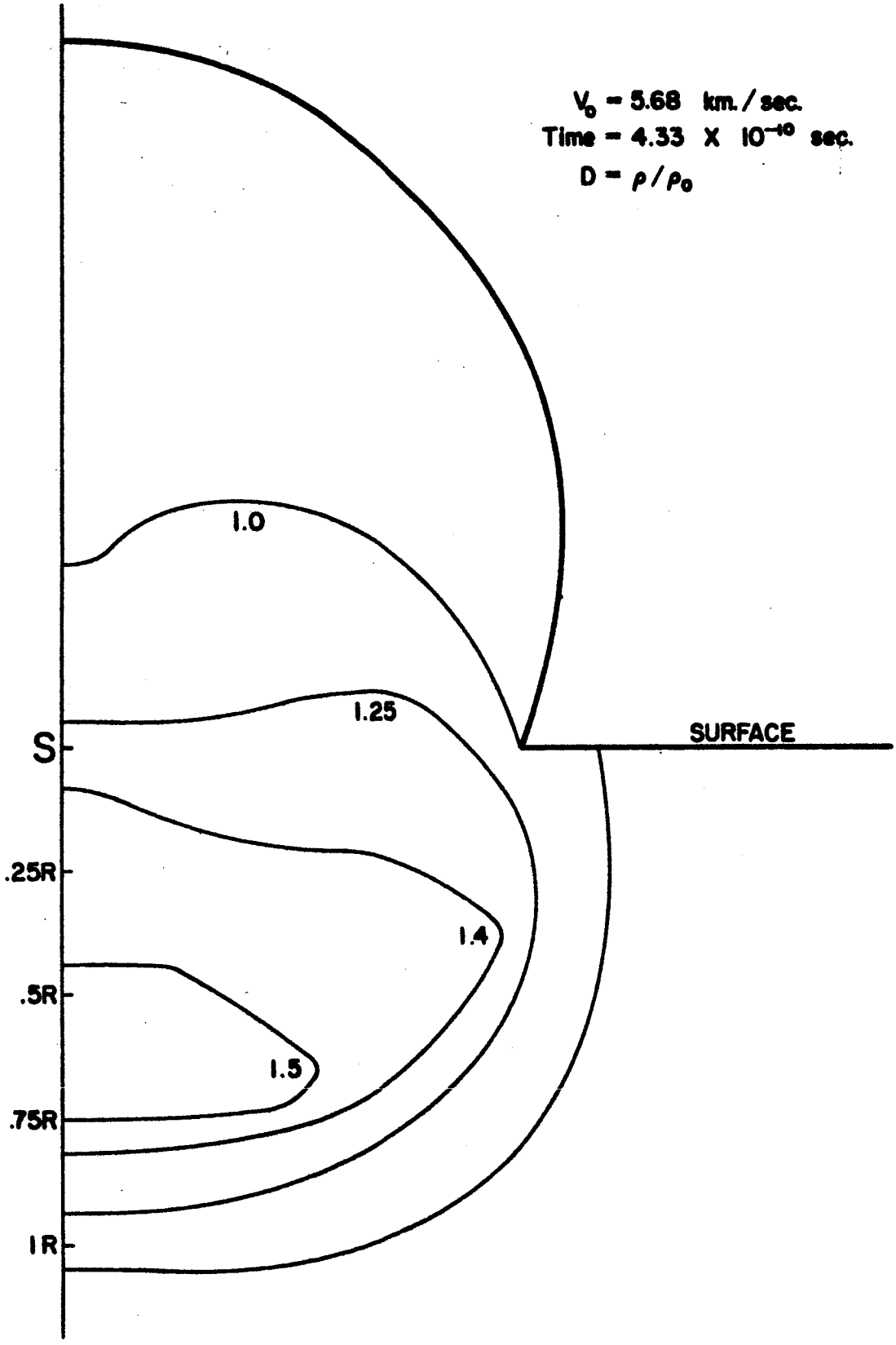

Figure 69. Density Map (t = .433 x 10^{-9} sec) I

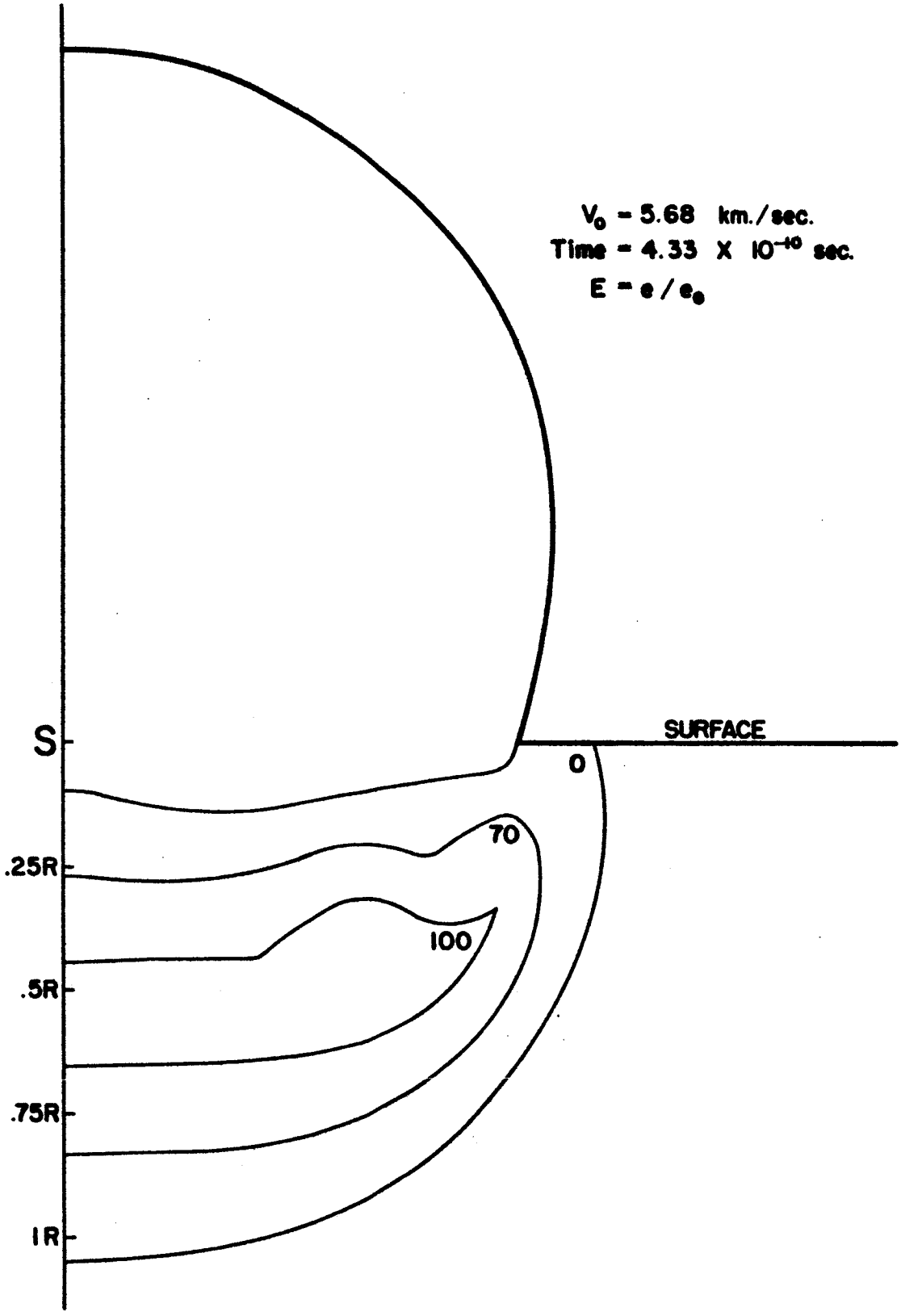

Figure 70. Energy Map (t = .433 x 10^{-9} sec) I

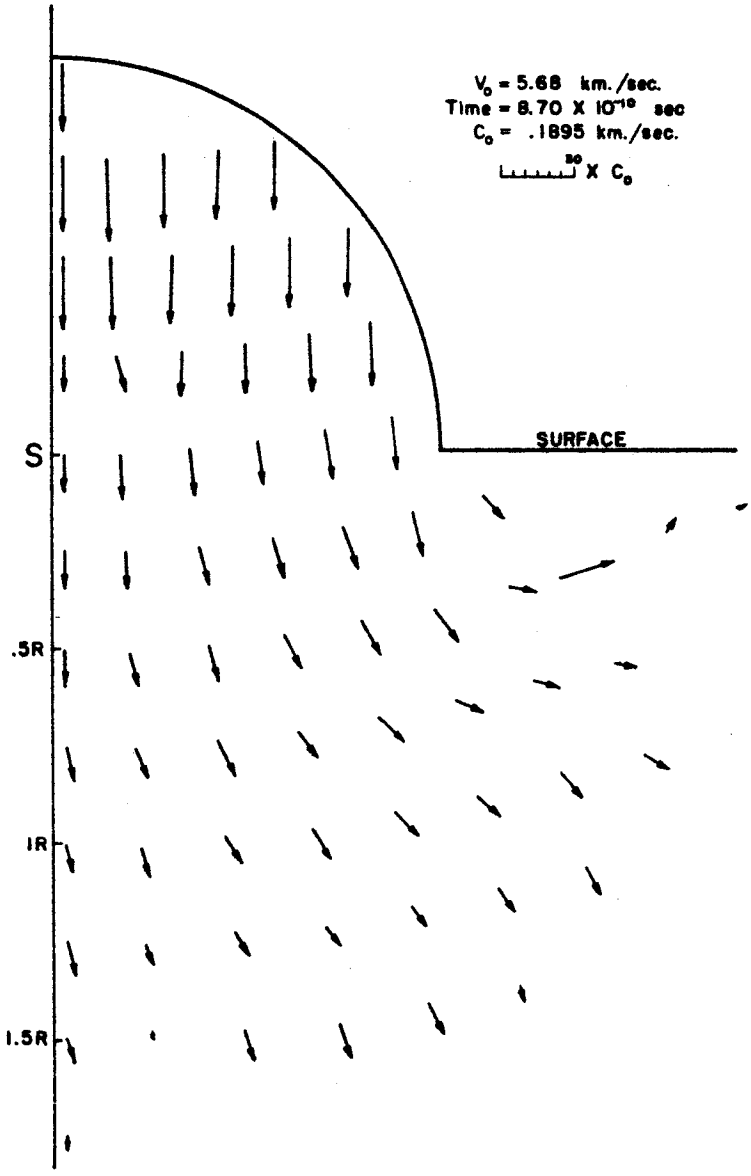

Figure 71. Velocity Map (t = .870 x 10^{-9} sec) I

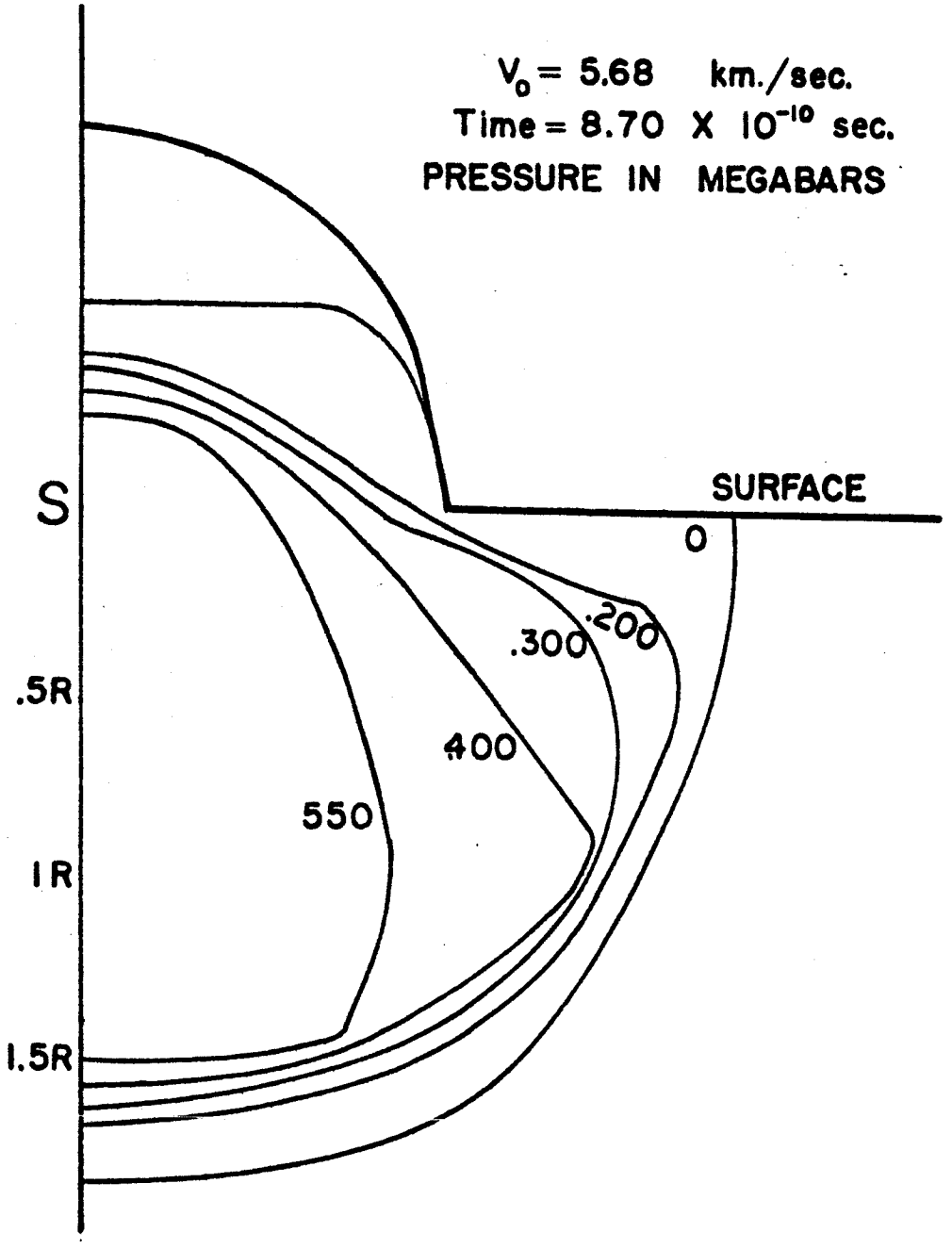

Figure 72. Pressure Map (t = .870 x 10^{-9} sec) I

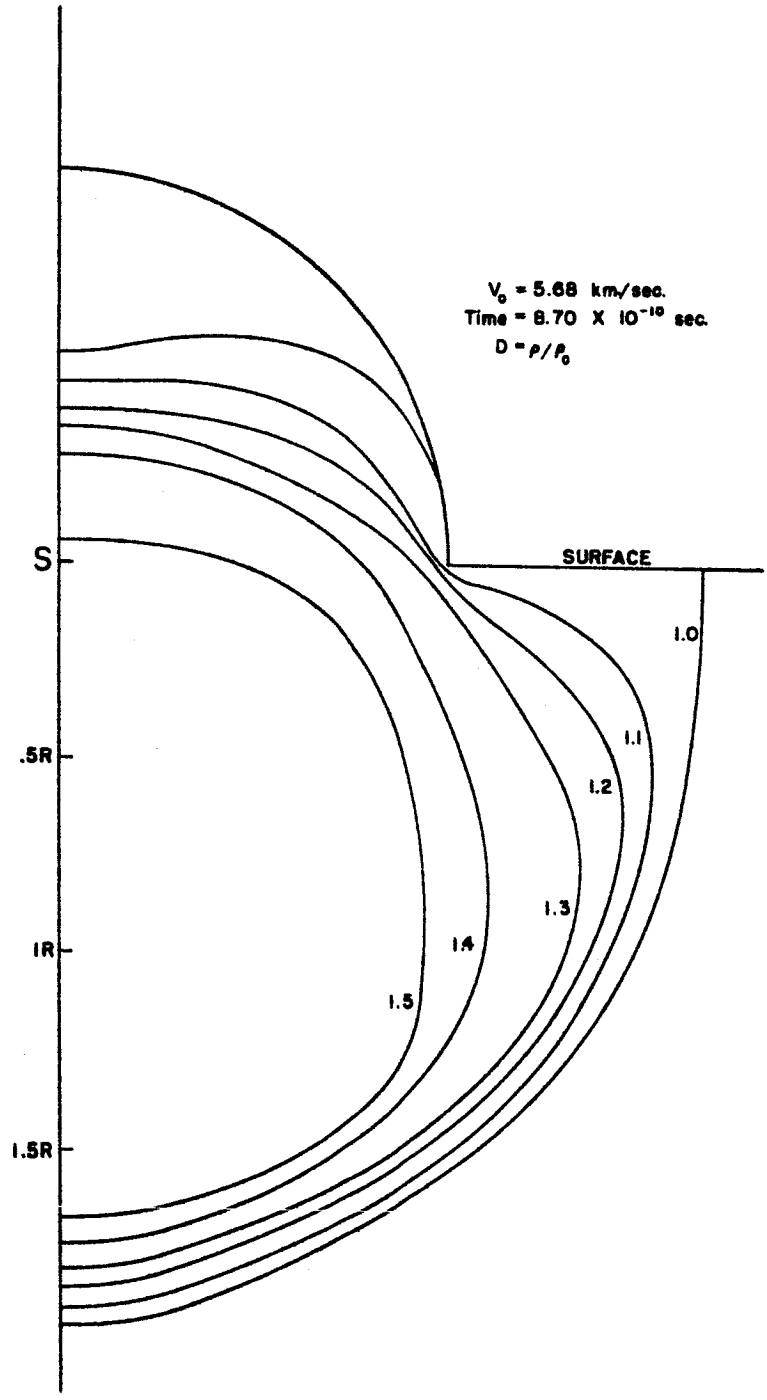

Figure 73. Density Map (t = .870 x 10^{-9} sec) I

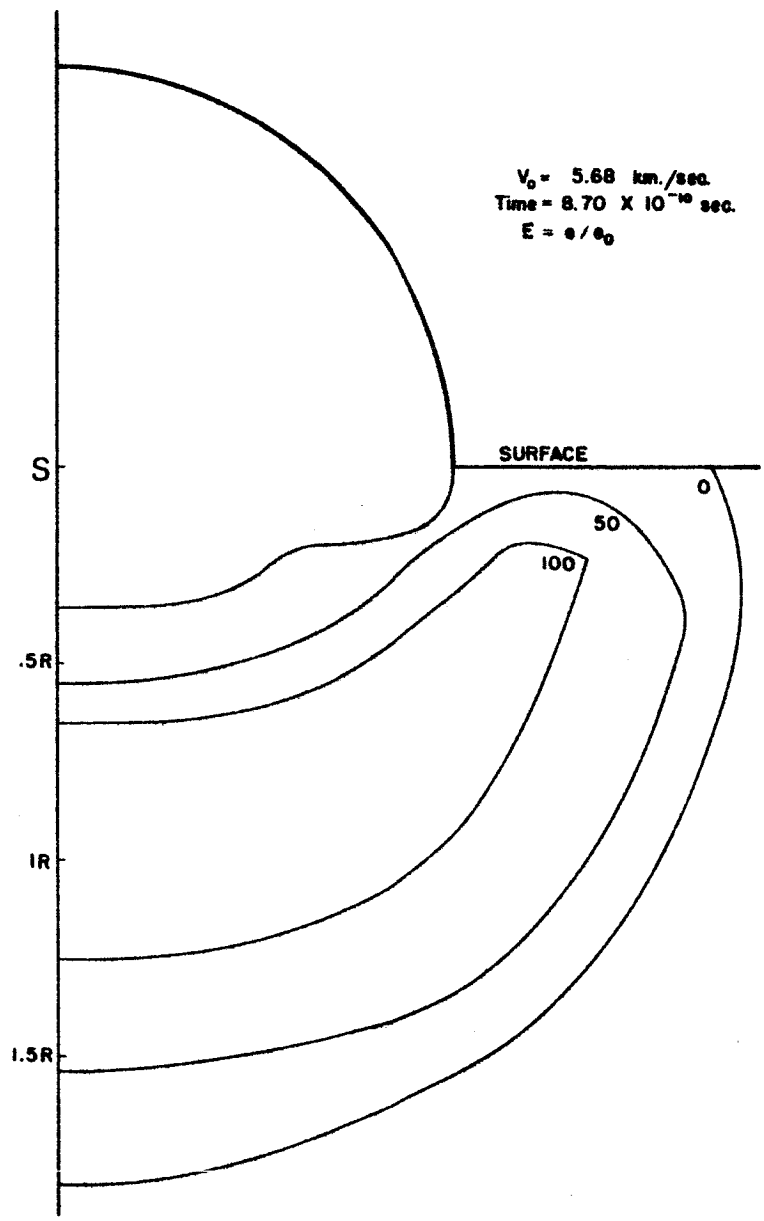

Figure 74. Energy Map (t = .870 x 10^{-9} sec) I

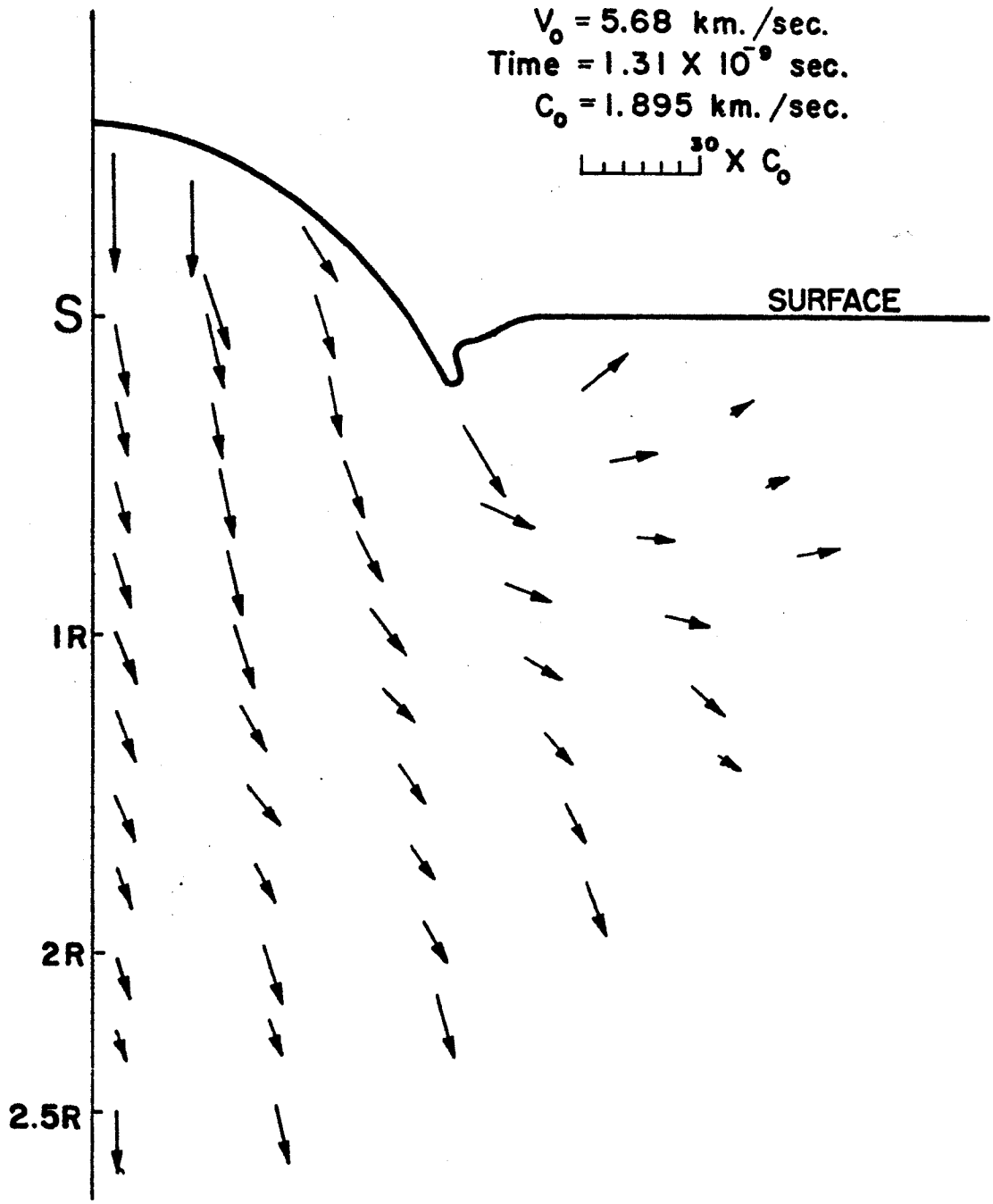

Figure 75. Velocity Map (t = 1.31 x 10^{-9} sec) I

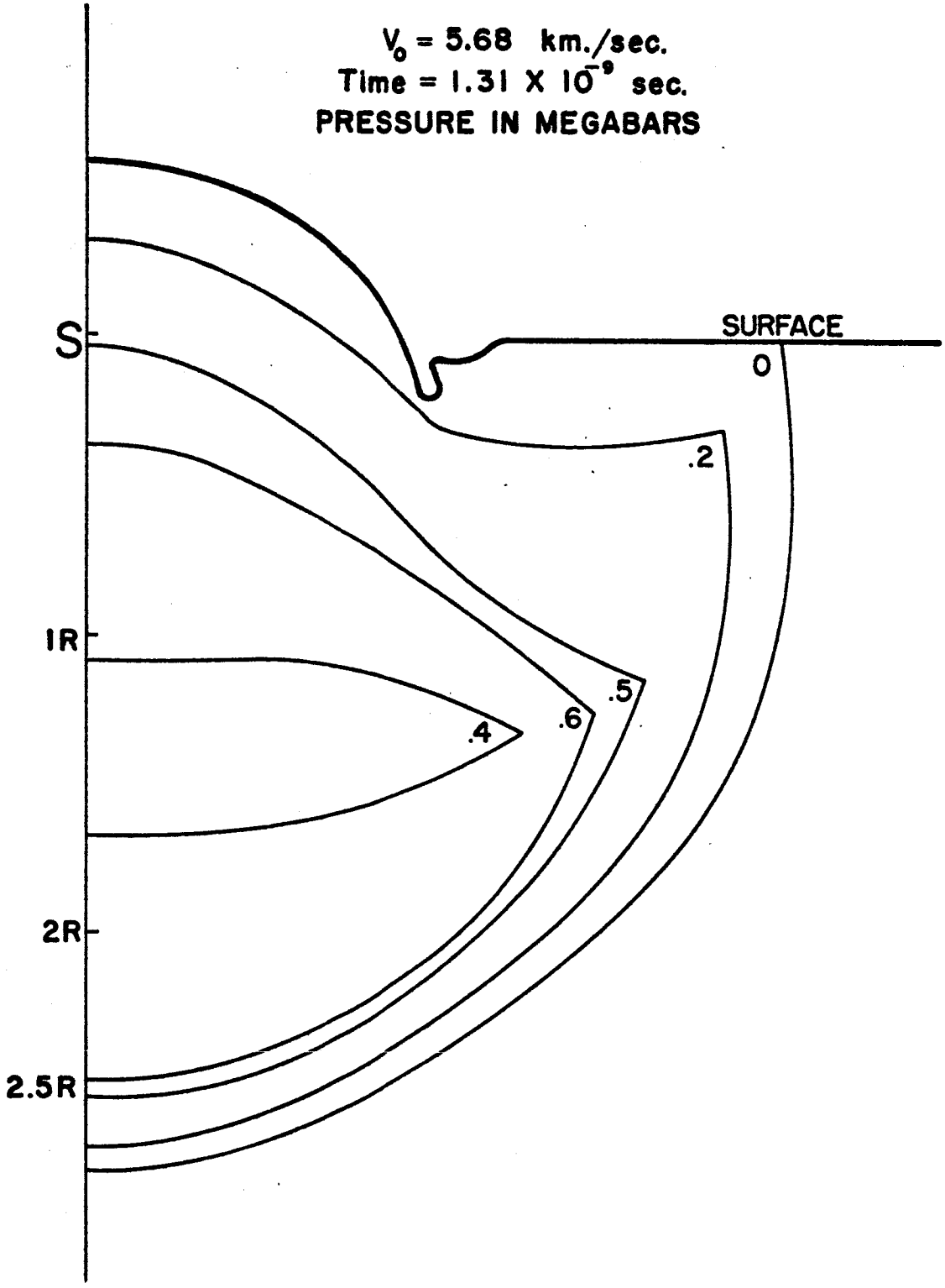

Figure 76. Pressure Map (t = 1.31 x 10^{-9} sec) I

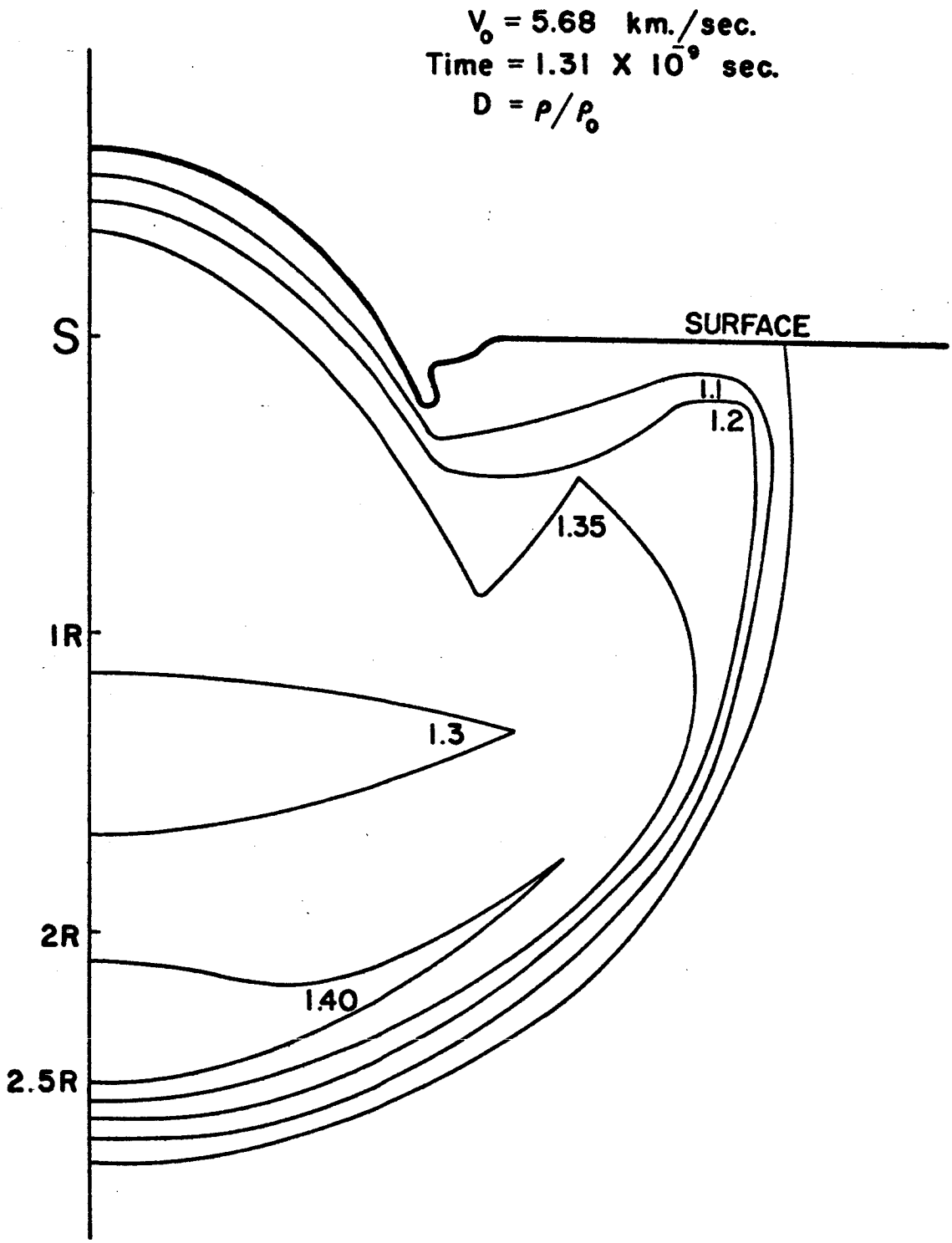

Figure 77. Density Map (t = 1.31 x 10^{-9} sec) I

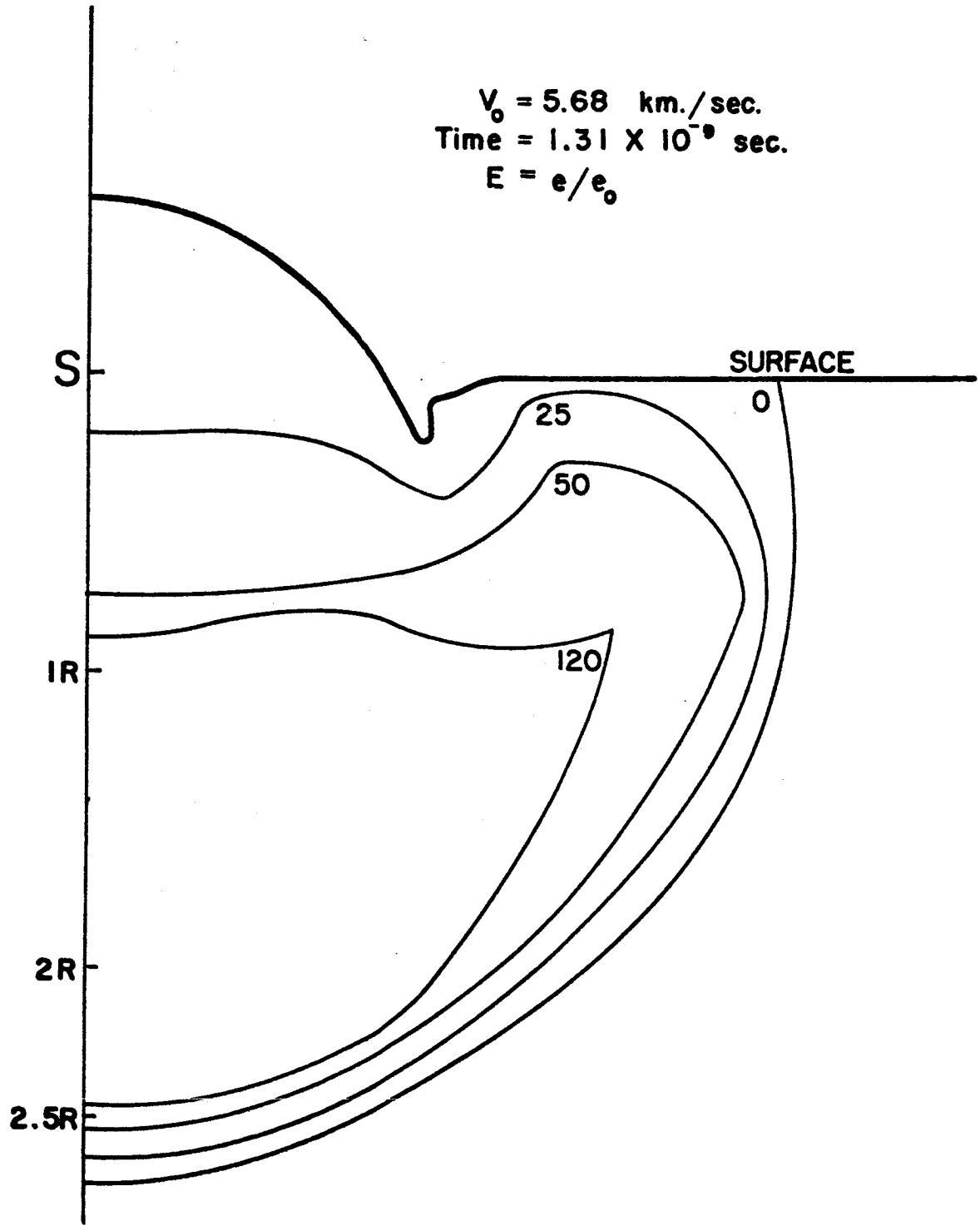

Figure 78. Energy Map (t = 1.31 x 10^{-9} sec) I

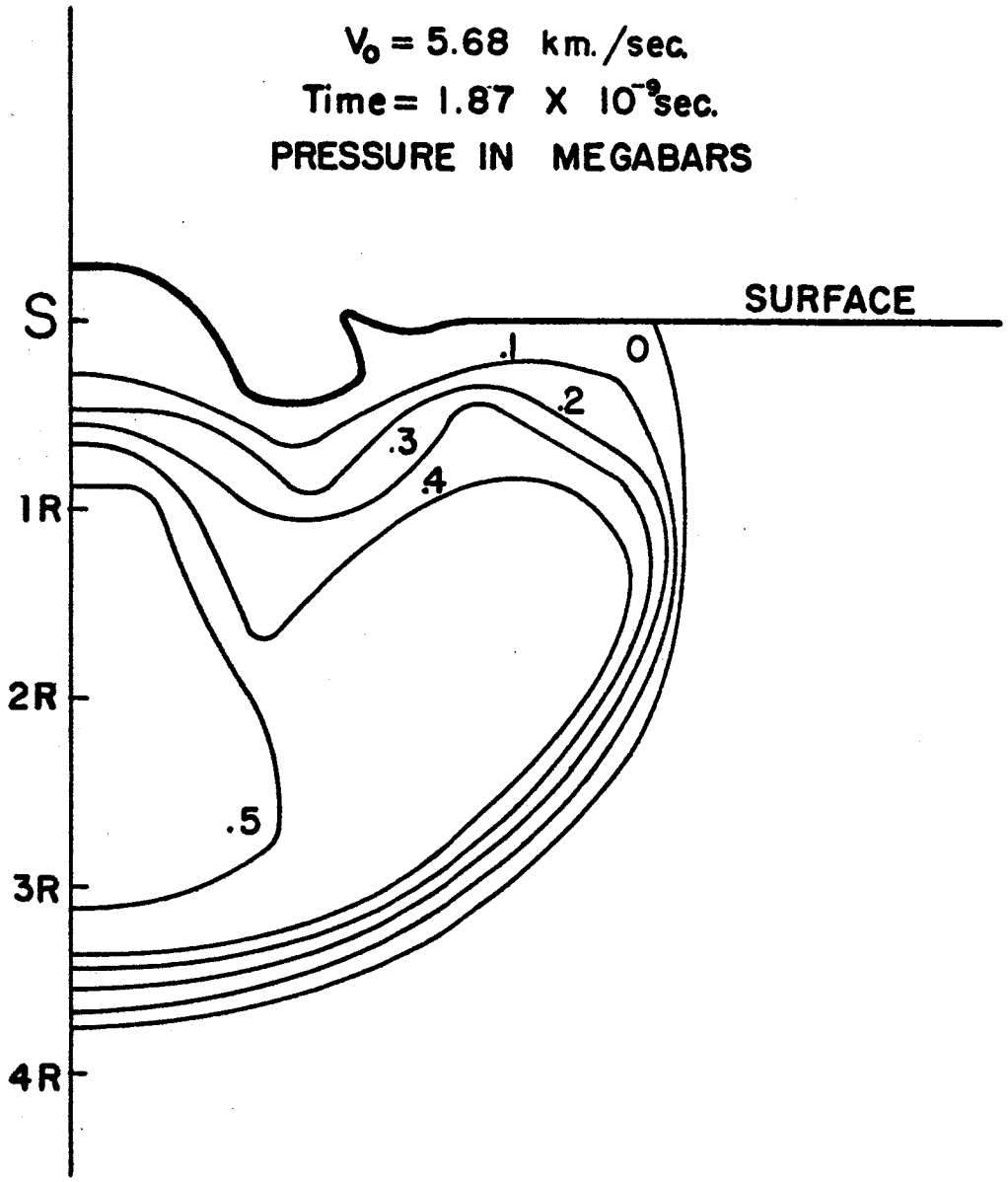

Figure 79. Pressure Map (t = 1.87 x 10^{-9} sec) I

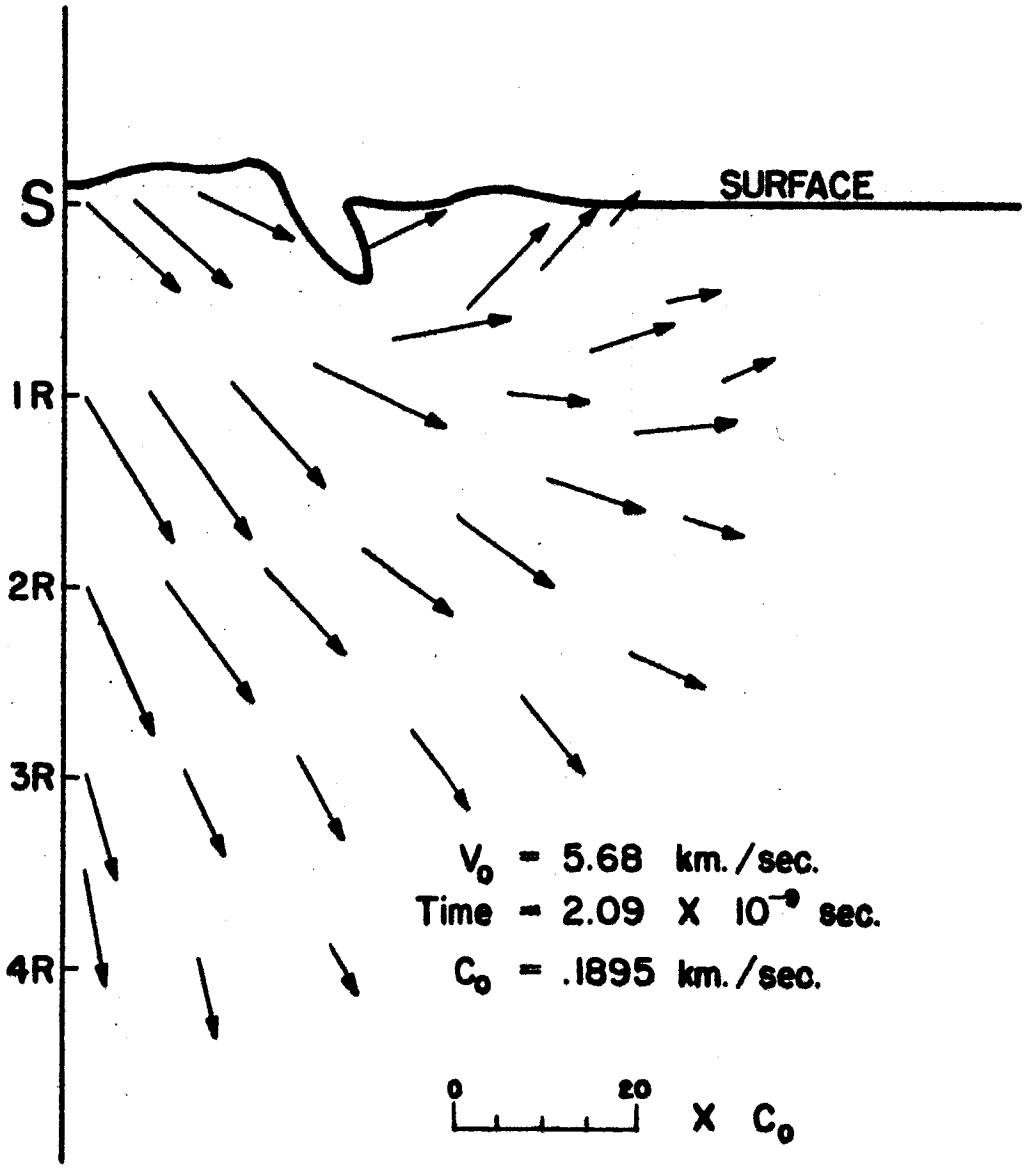

Figure 80. Velocity Map (t = 2.09 x 10^{-9} sec) I

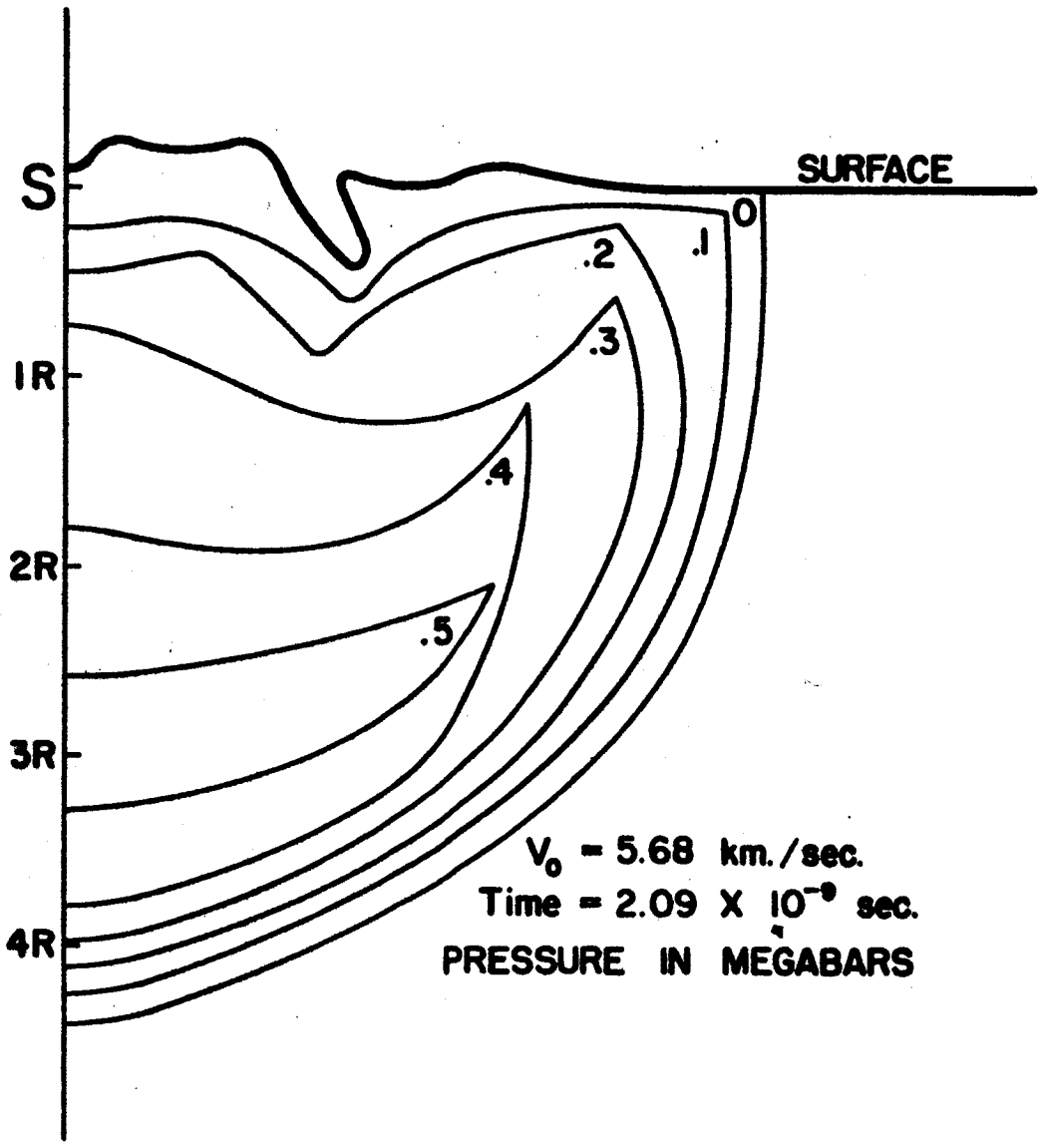

Figure 81. Pressure Map (t = 2.09 x 10^{-9} sec) I

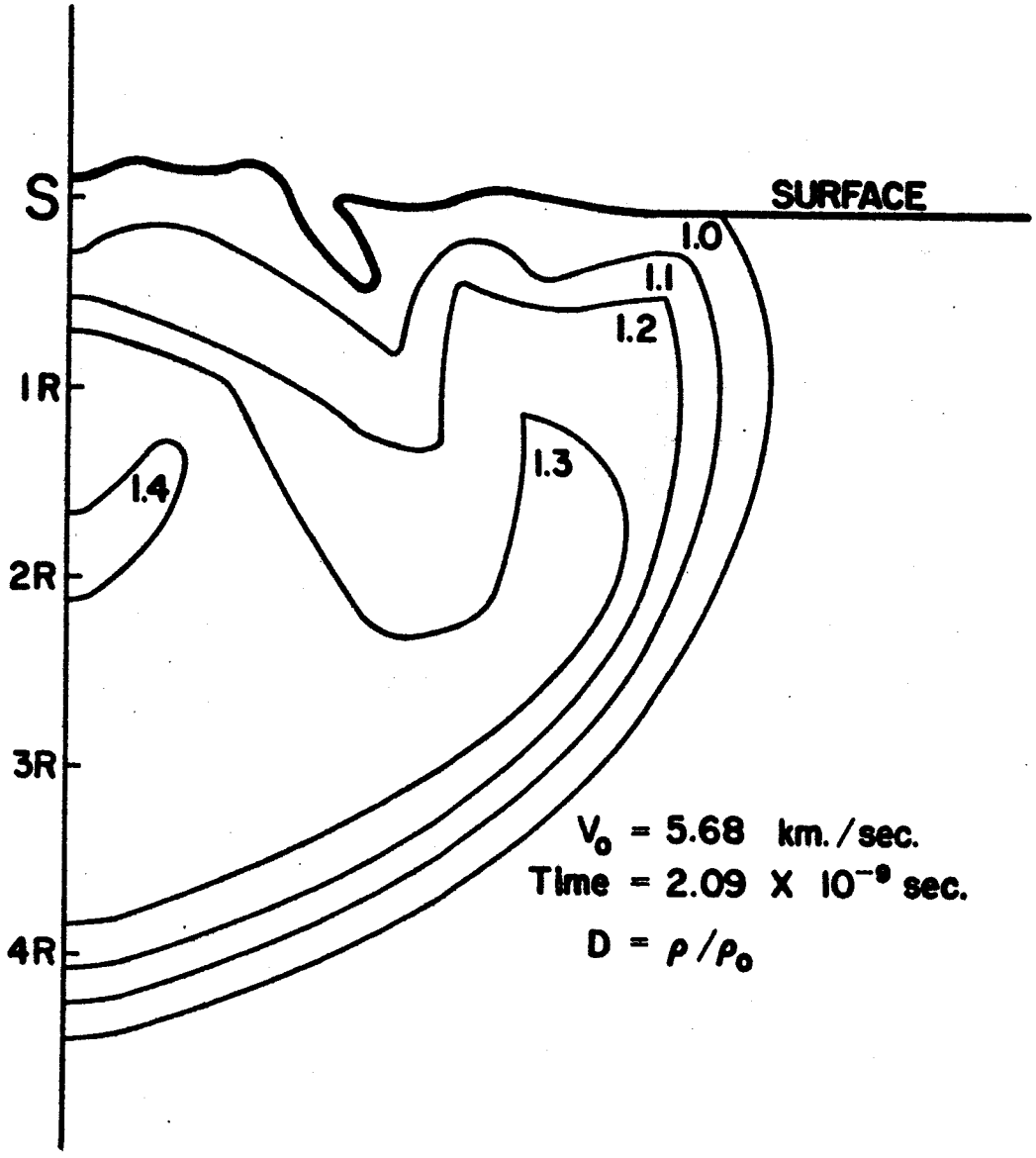

Figure 82. Density Map (t = 2.09 x 10^{-9} sec) I

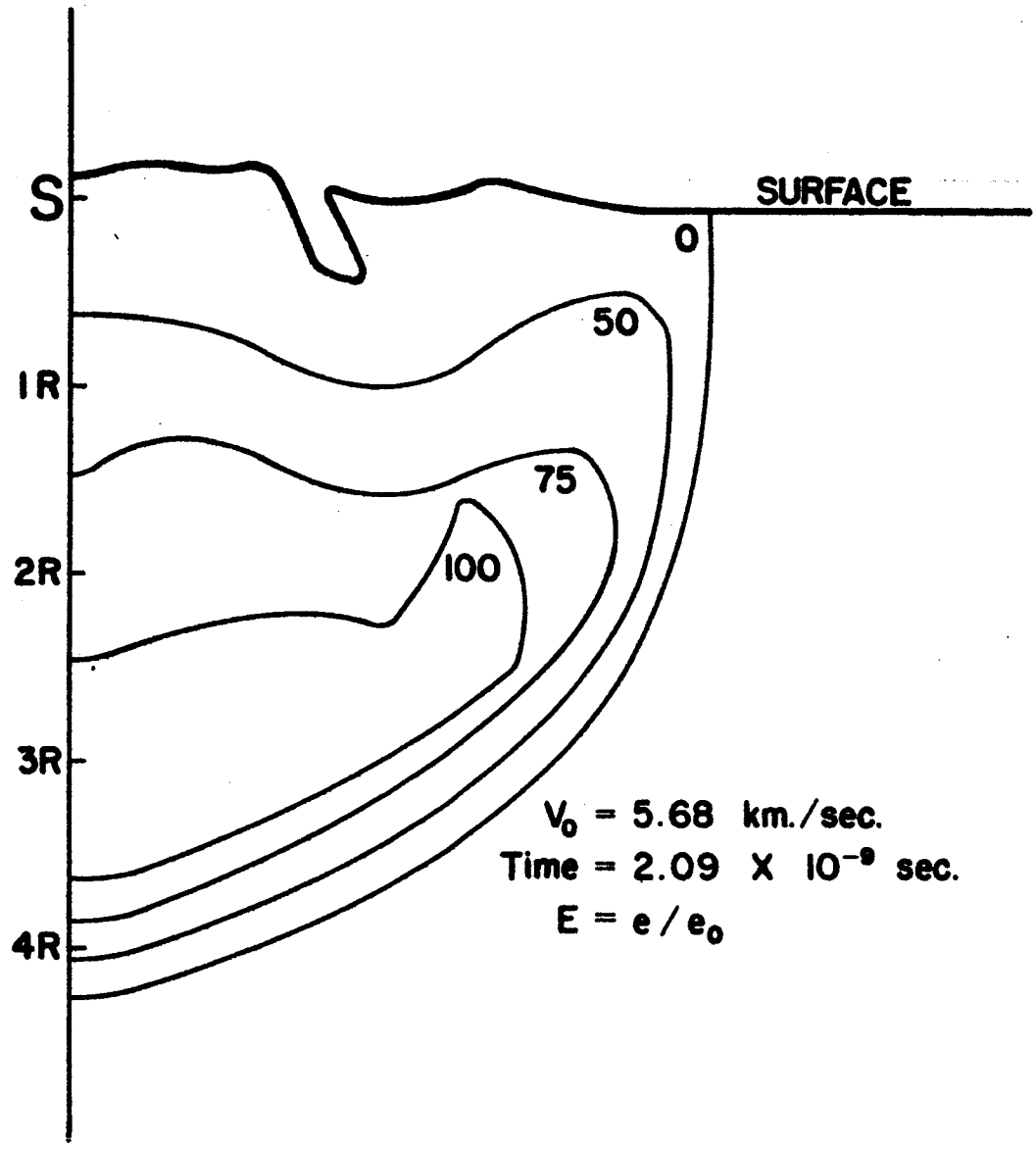

Figure 83. Energy Map (t = 2.09 x 10^{-9} sec) I

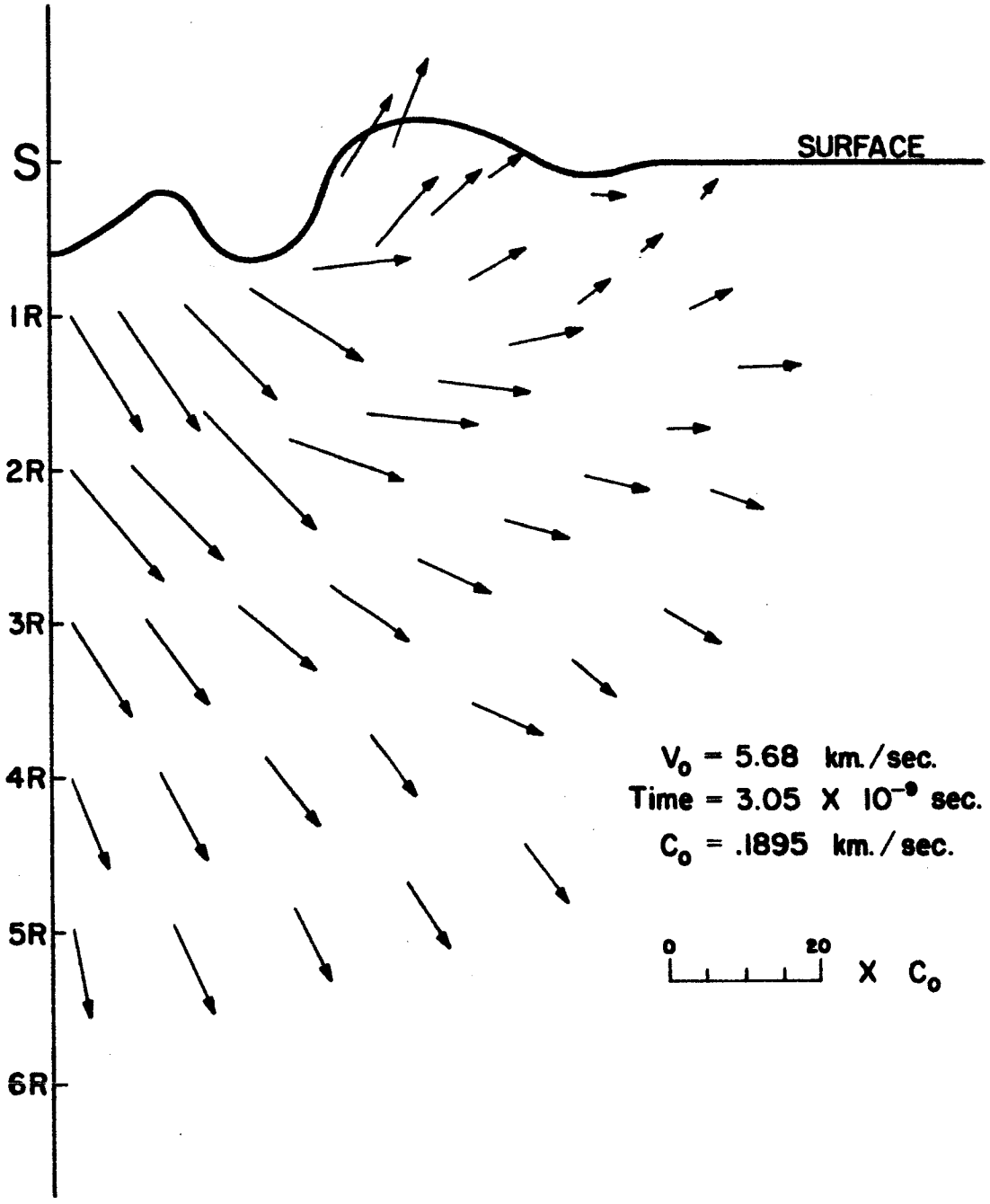

Figure 84. Velocity Map (t = 3.05 x 10^{-9} sec) I

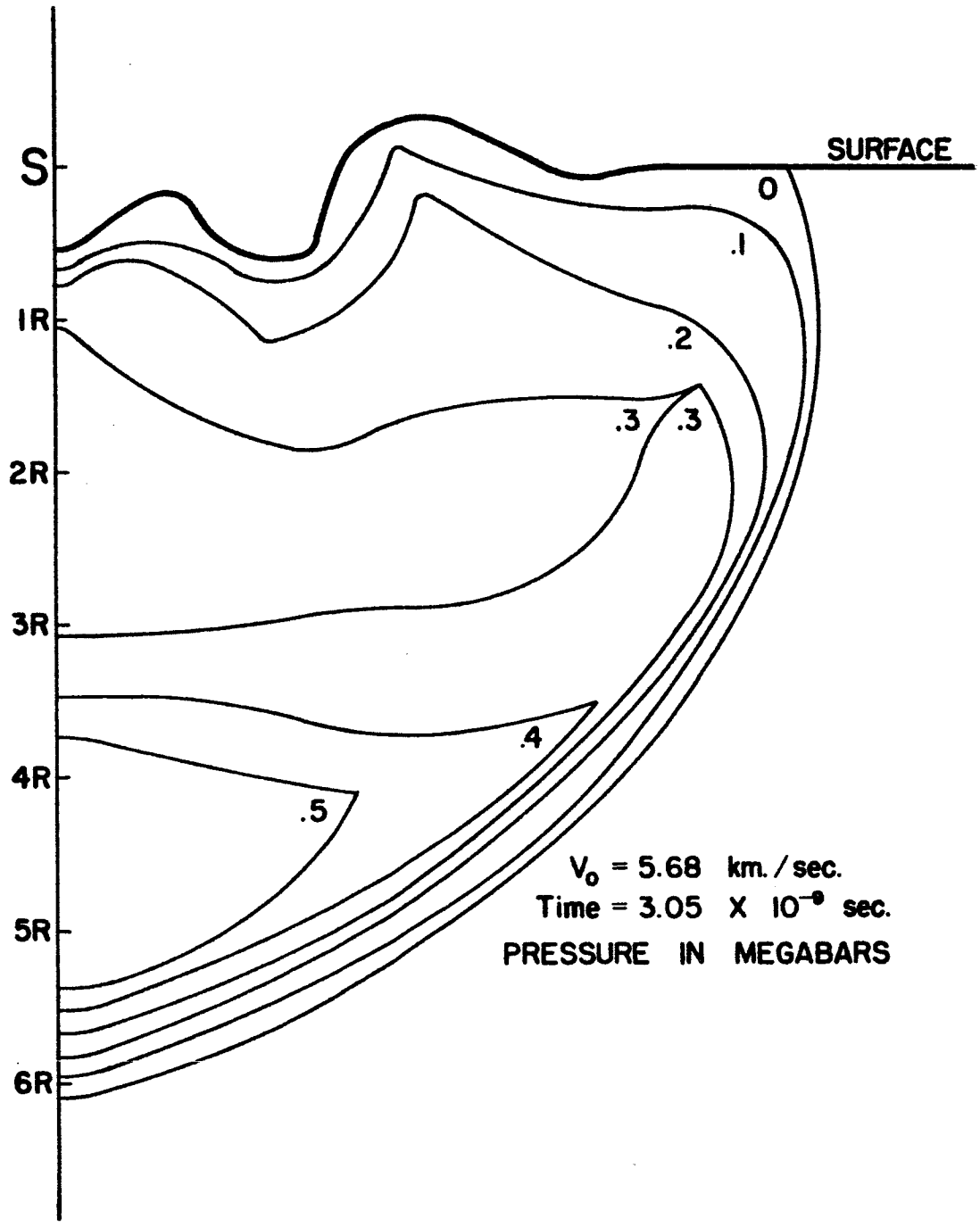

Figure 85. Pressure Map (t = 3.05 x 10^{-9} sec) I

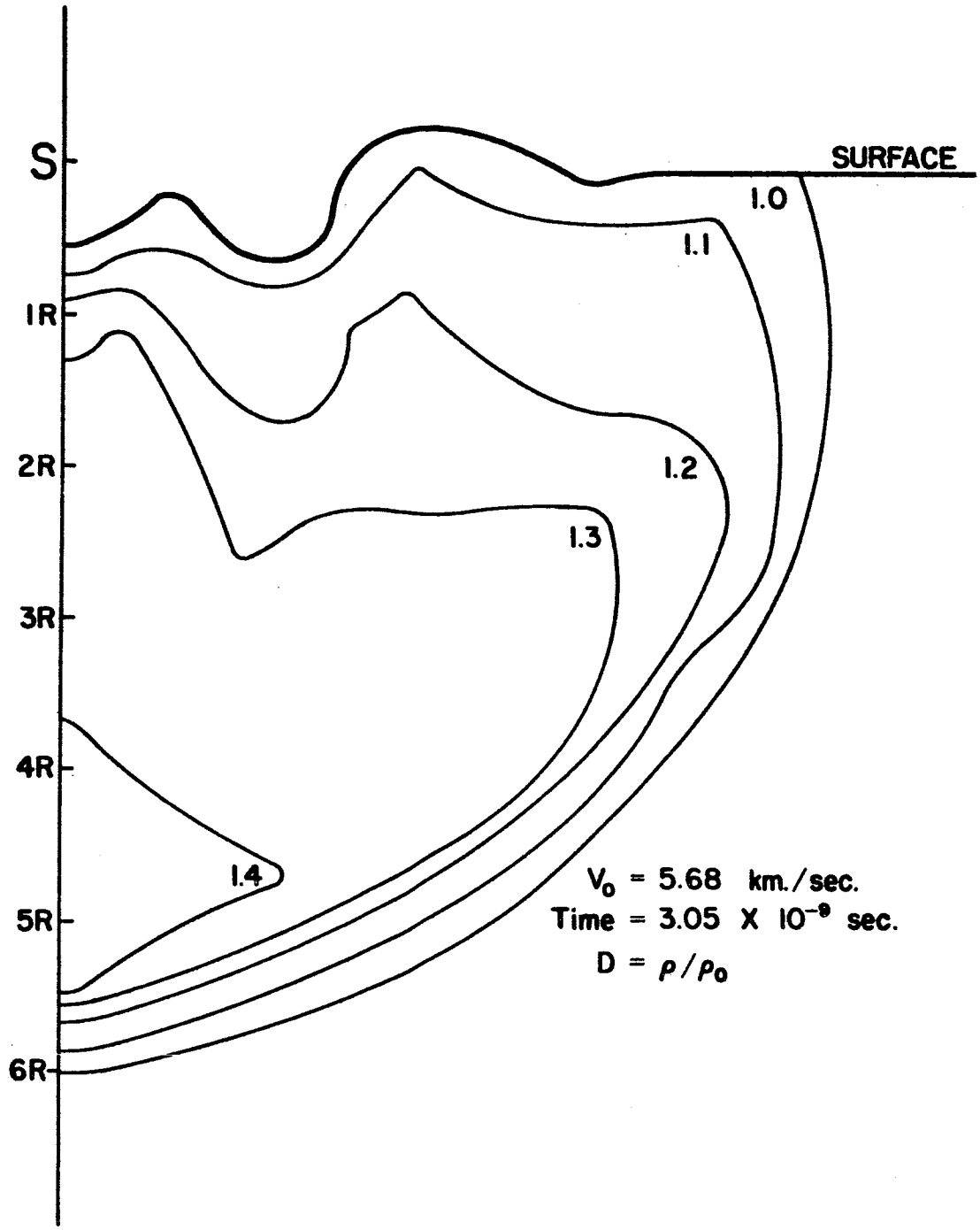

Figure 86. Density Map (t = 3.05 x 10^{-9} sec) I

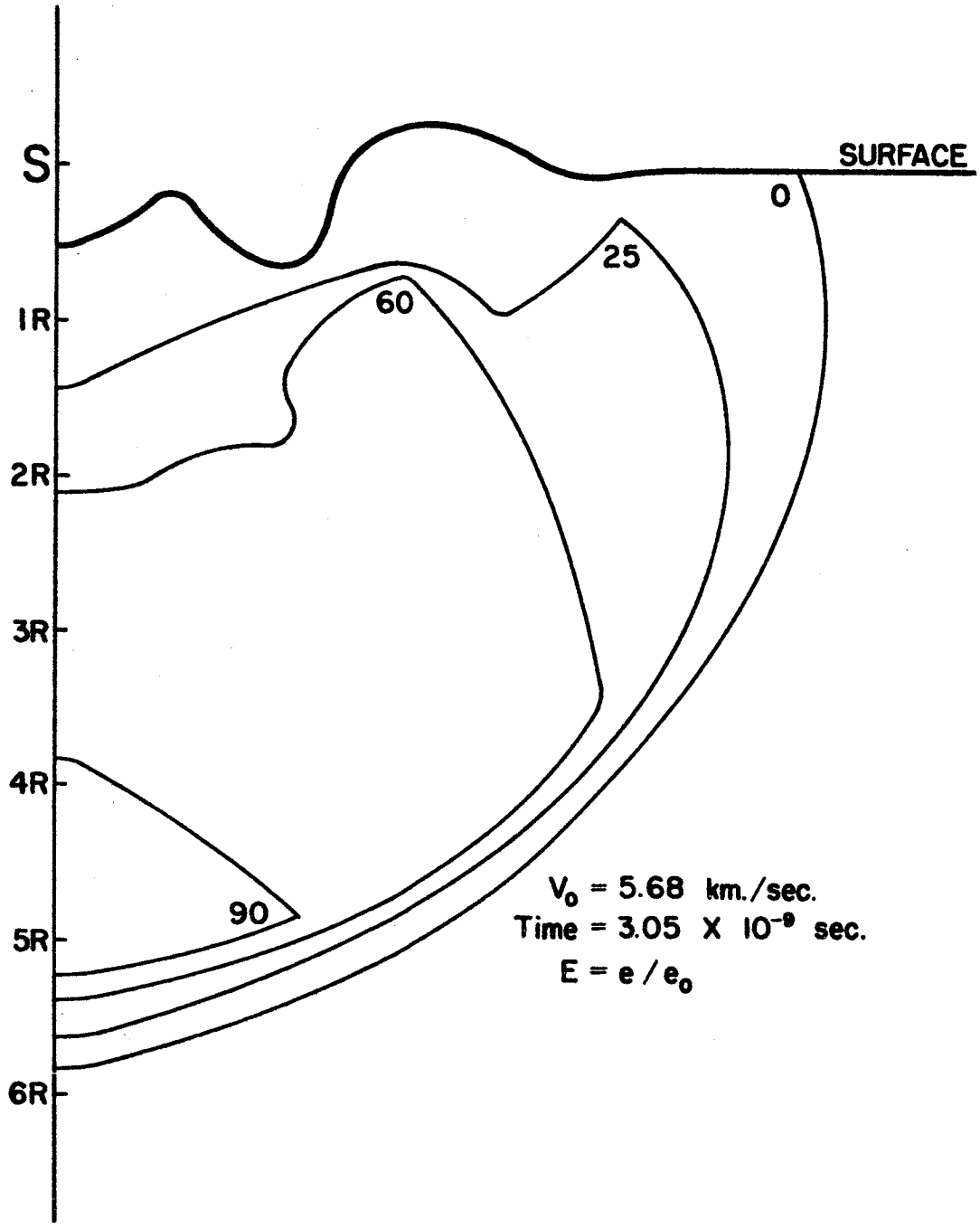

Figure 87. Energy Map (t = 3.05 x 10^{-9} sec) I

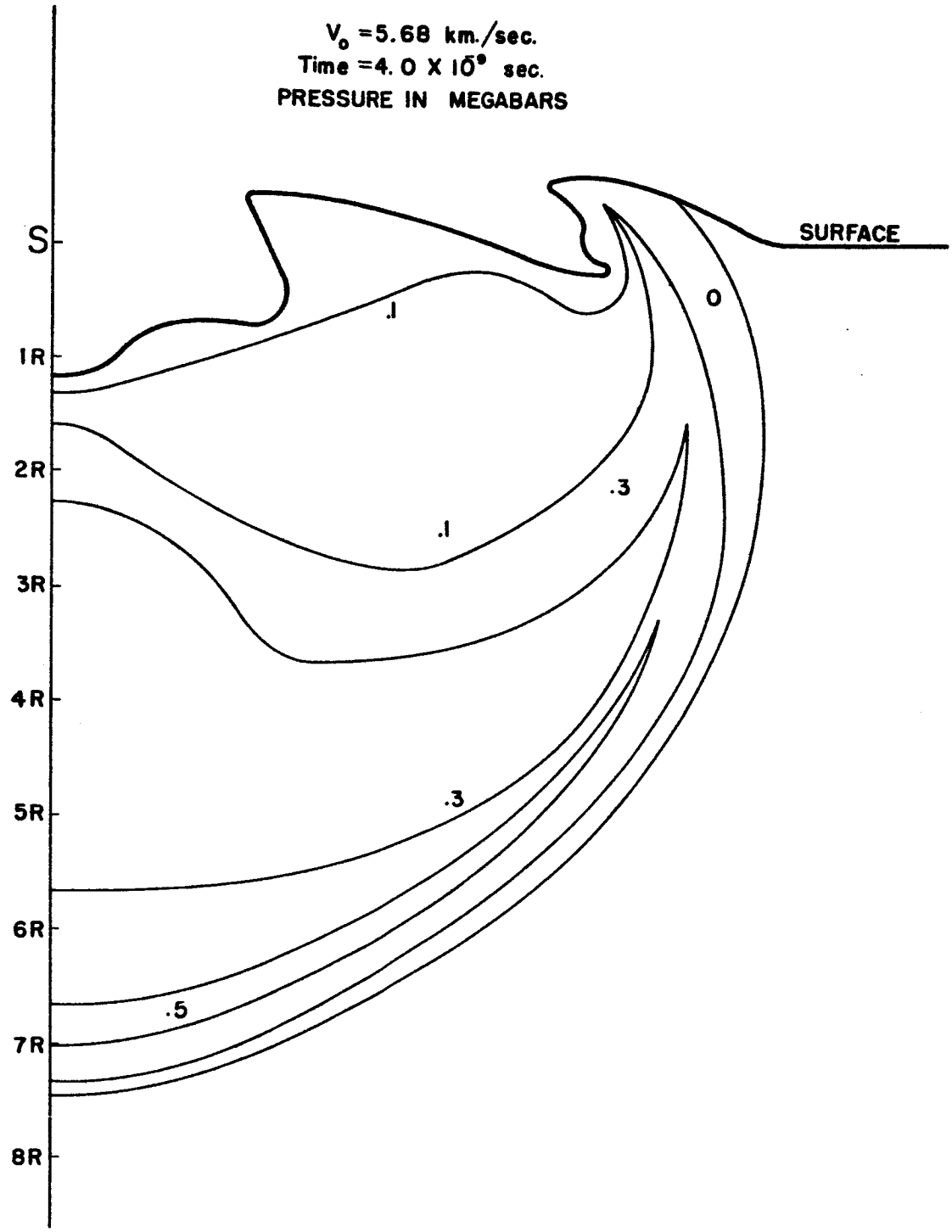

Figure 88. Pressure Map (t = 4.00 x 10^{-9} sec) I

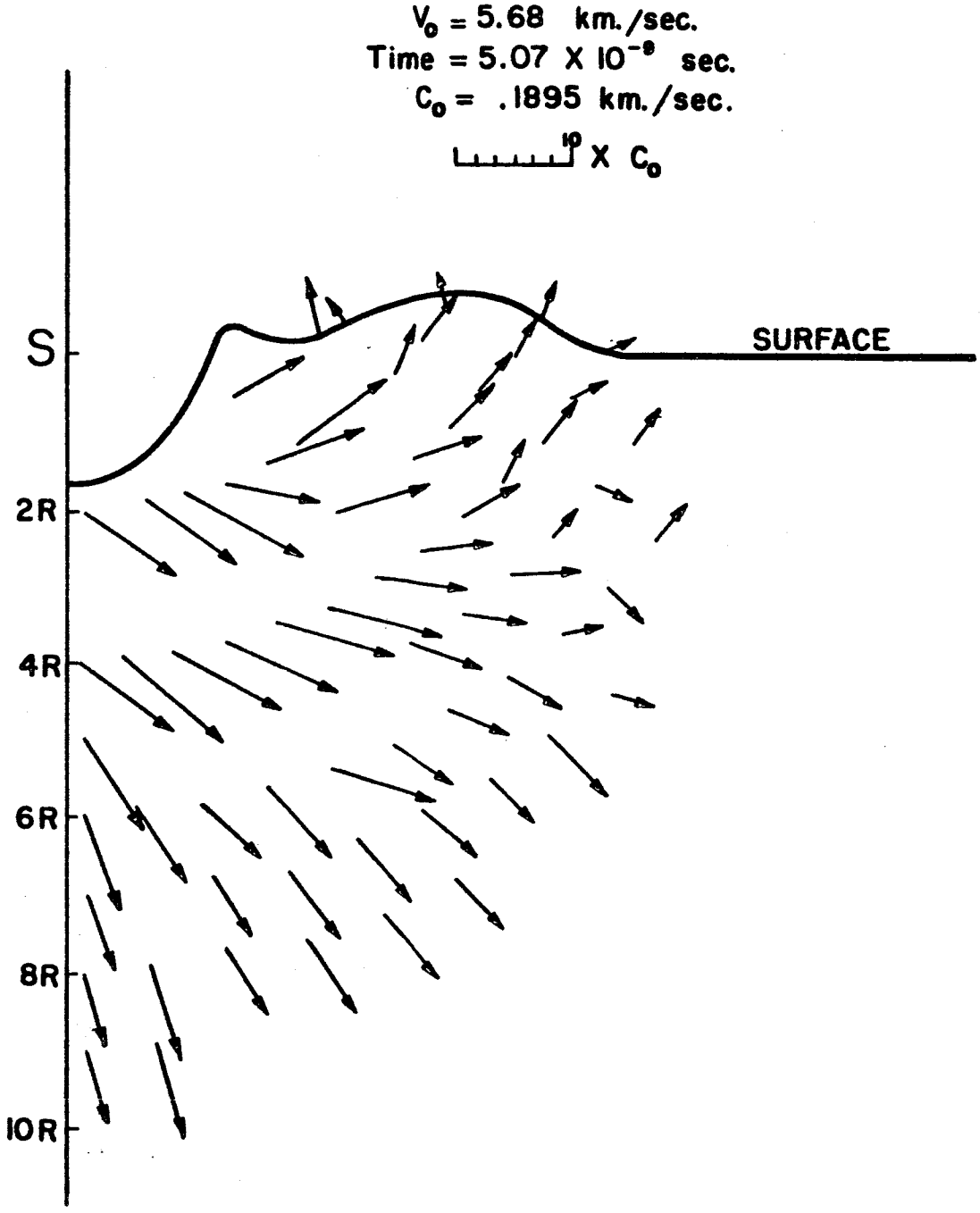

Figure 89. Velocity Map (t = 5.07 x 10^{-9} sec) I

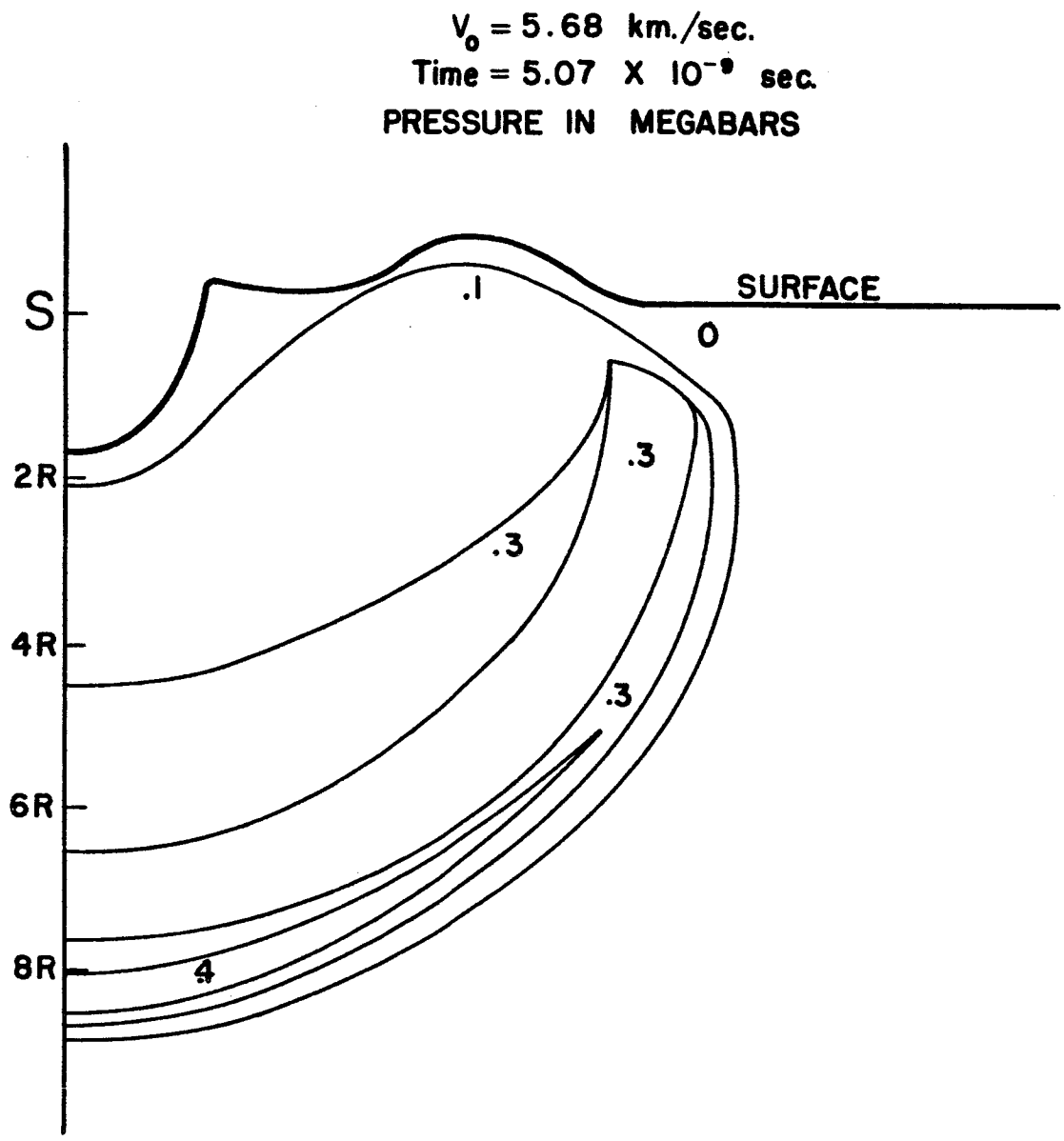

Figure 90. Pressure Map (t = 5.07 x 10^{-9} sec) I

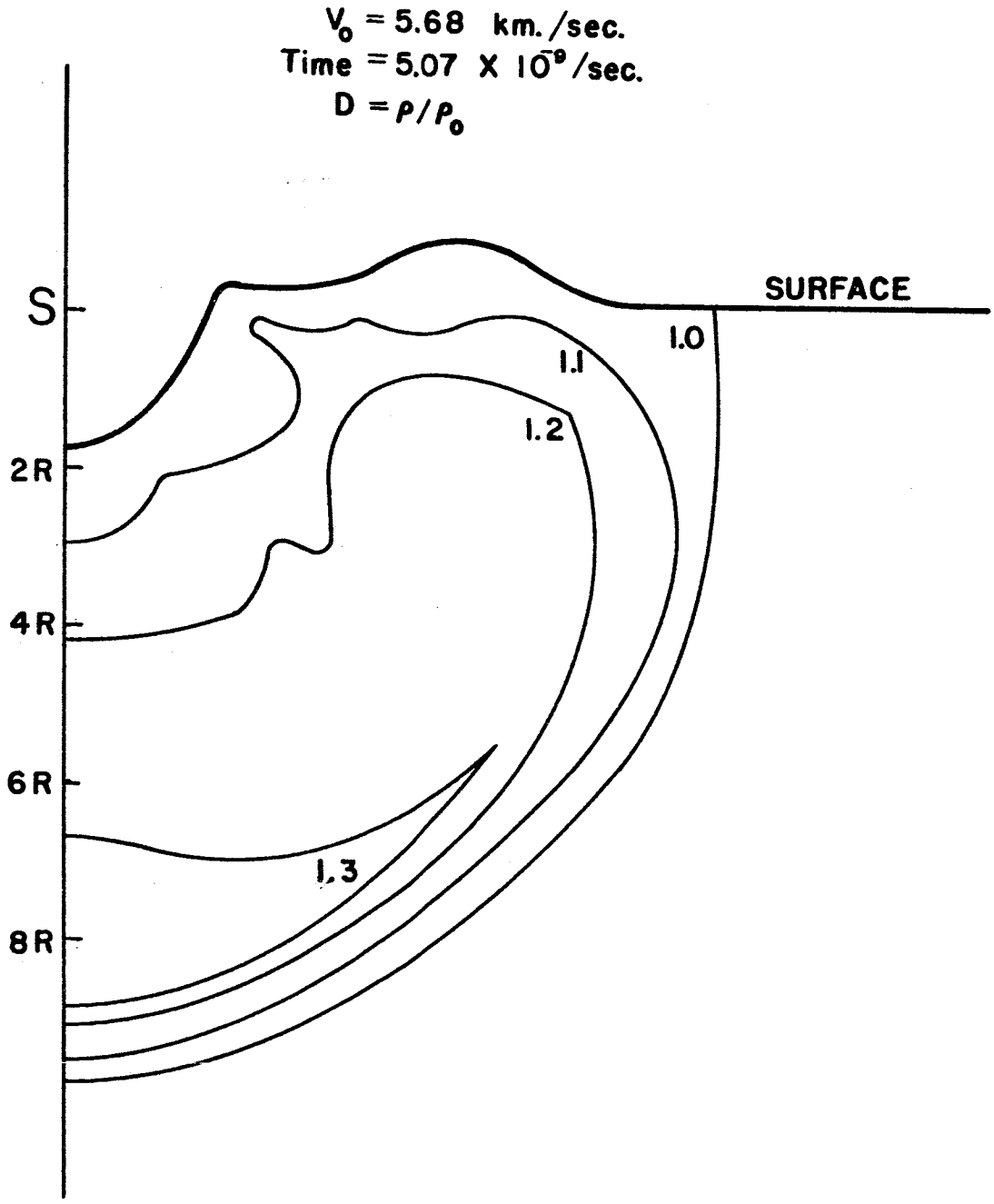

Figure 91. Density Map (t = 5.07 x 10^{-9} sec) I

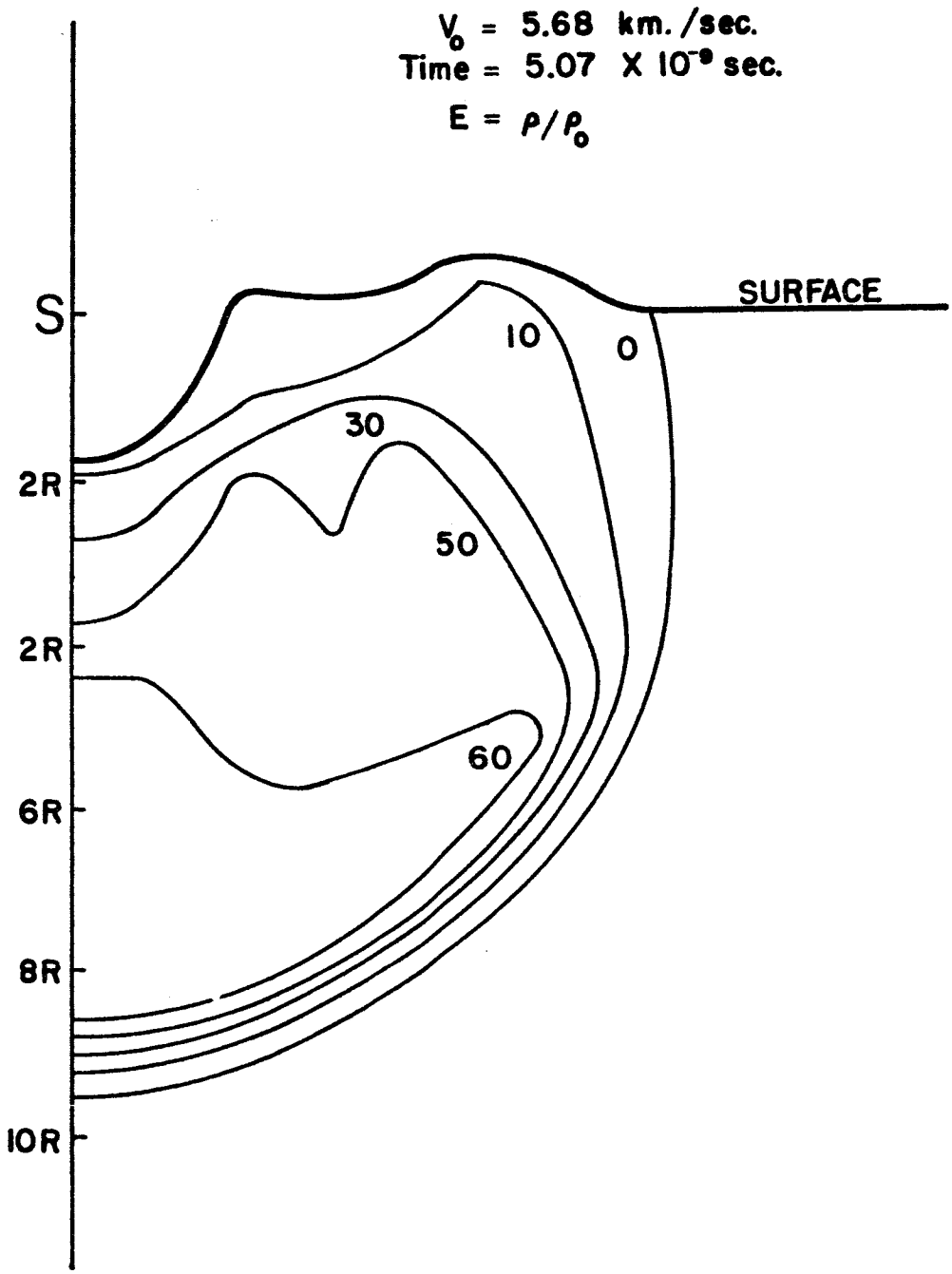

Figure 92. Energy Map (t = 5.07 x 10^{-9} sec) I

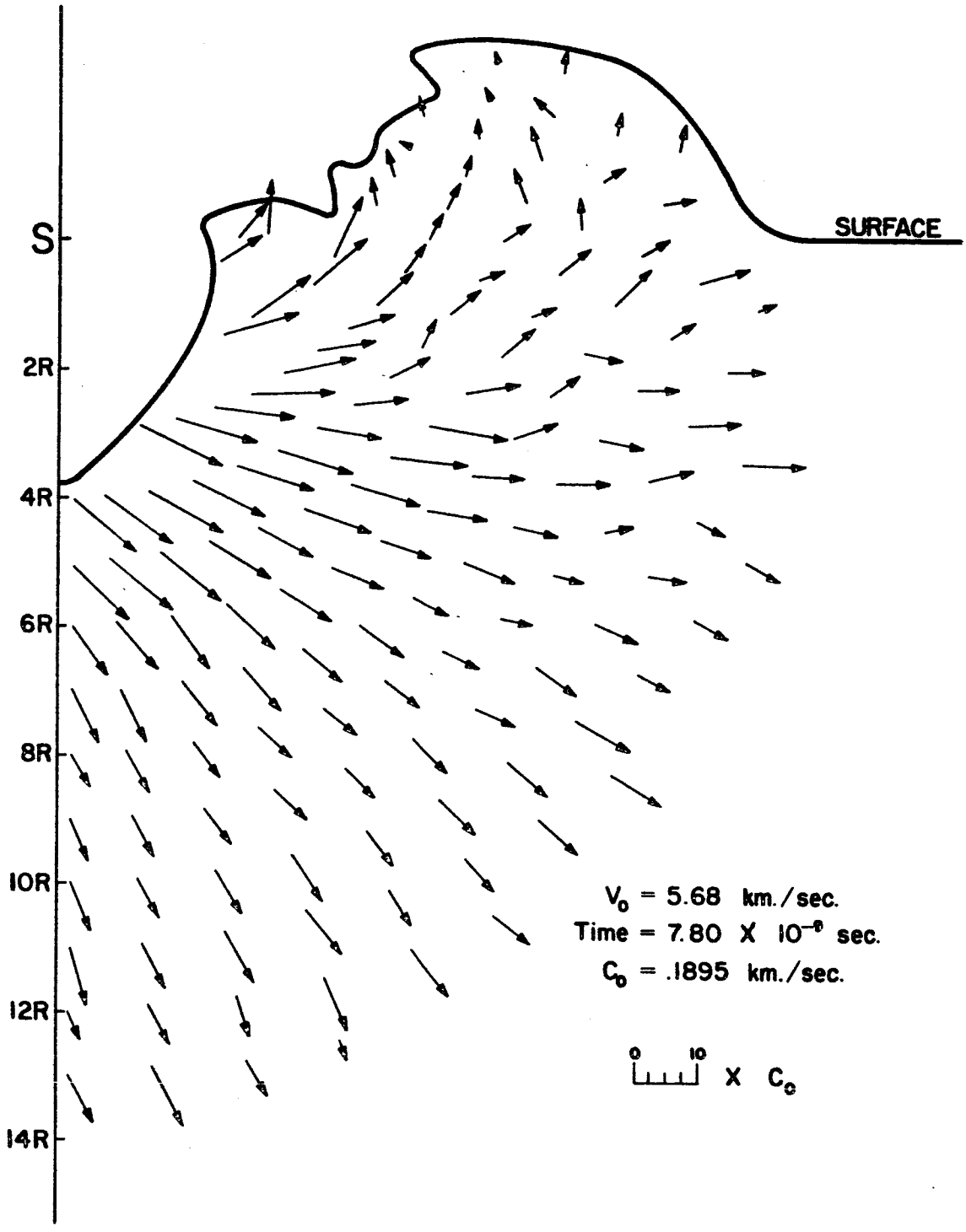

Figure 93. Velocity Map (t = 7.80 x 10^{-9} sec) I

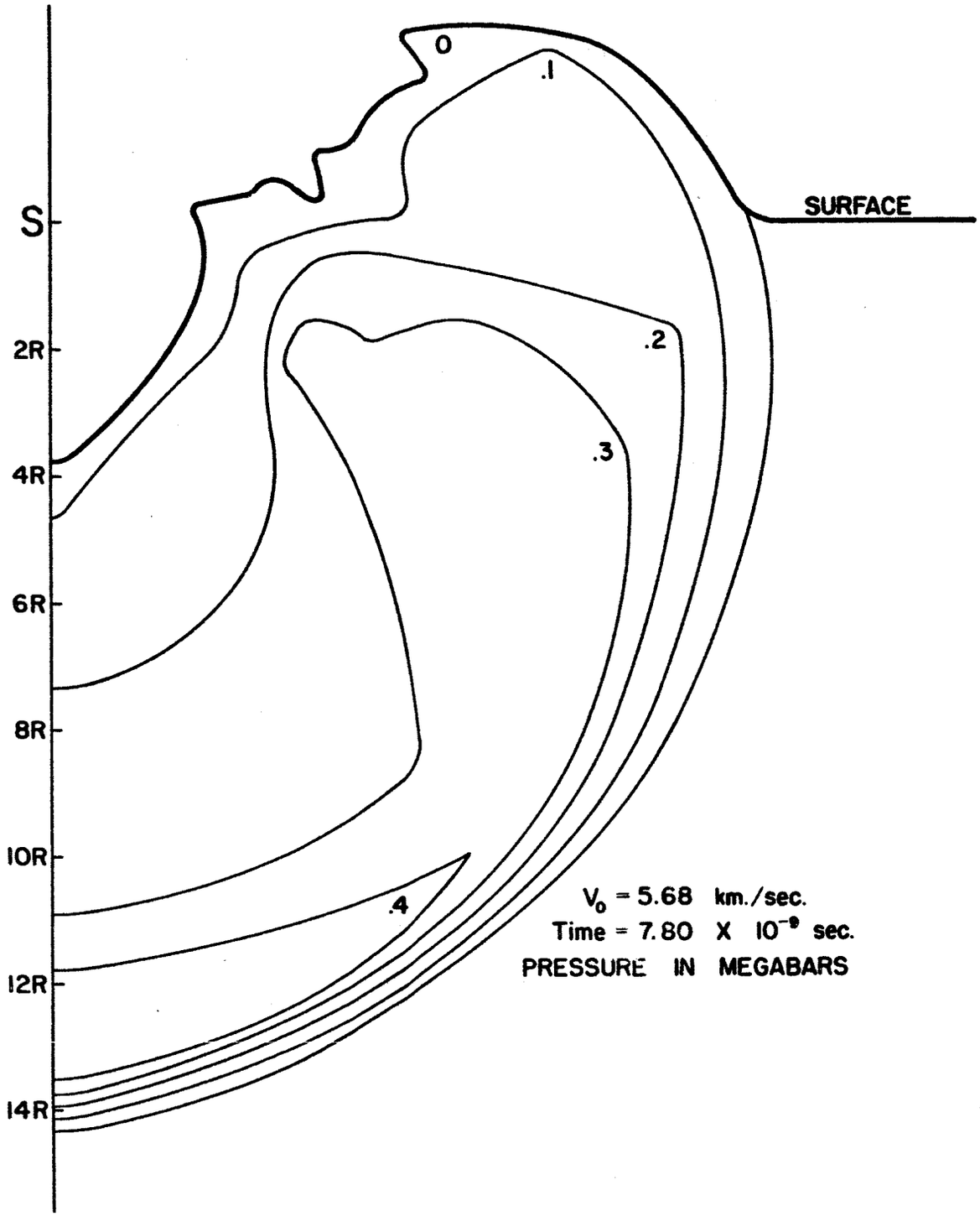

Figure 94. Pressure Map (t = 7.80 x 10^{-9} sec) I

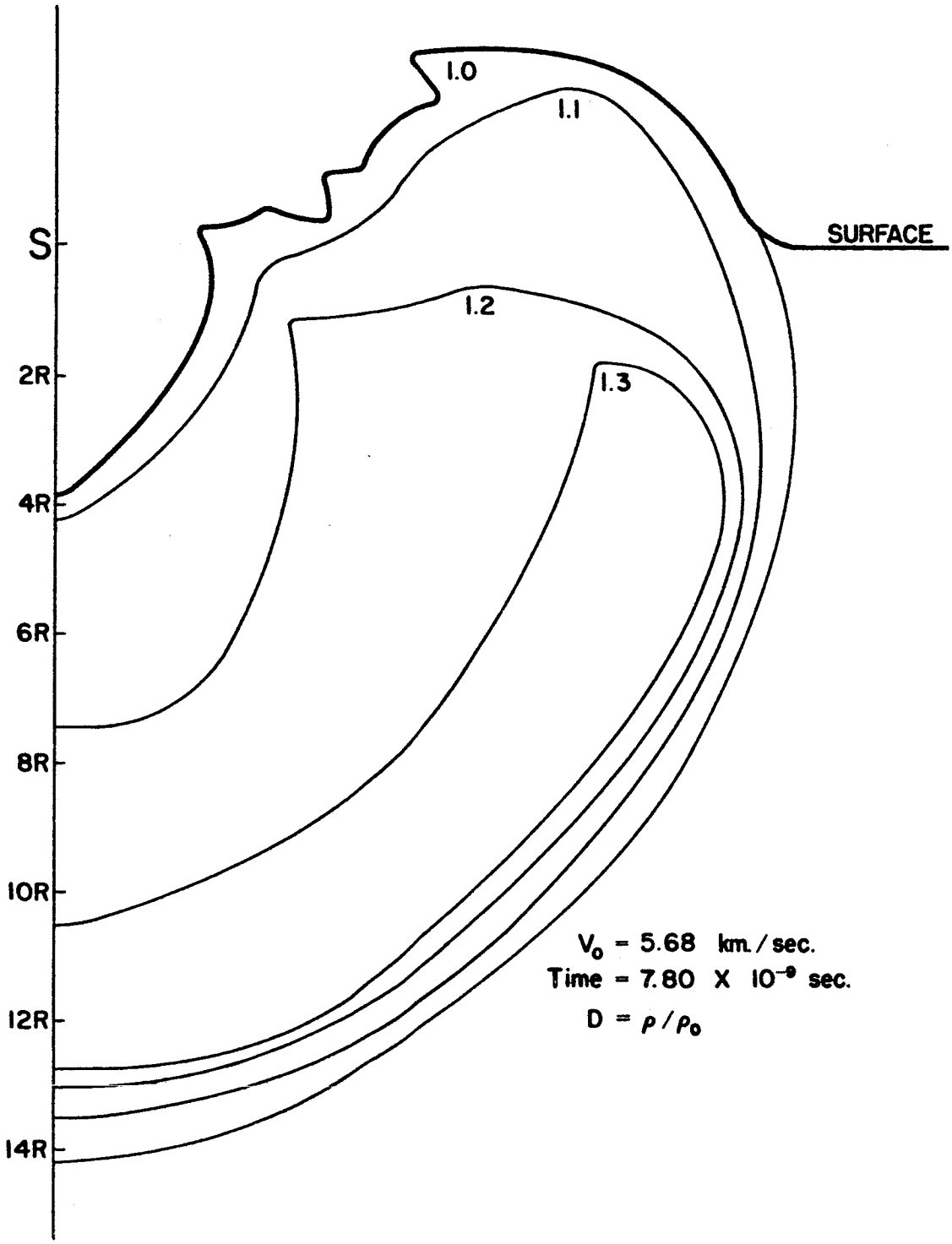

Figure 95. Density Map (t= 7.80 x 10^{-9} sec) I

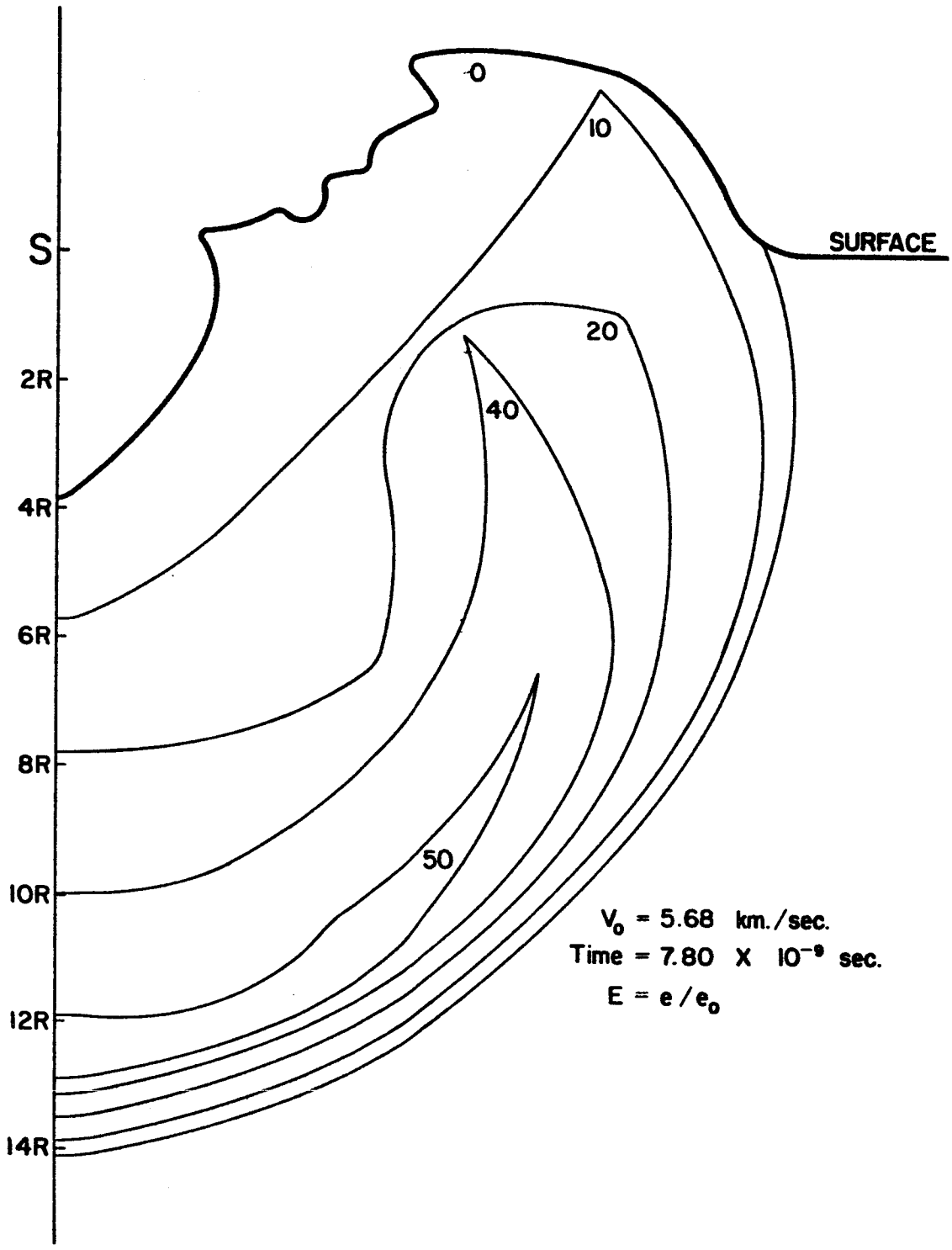

Figure 96. Energy Map (t = 7.80 x 10^{-9} sec) I

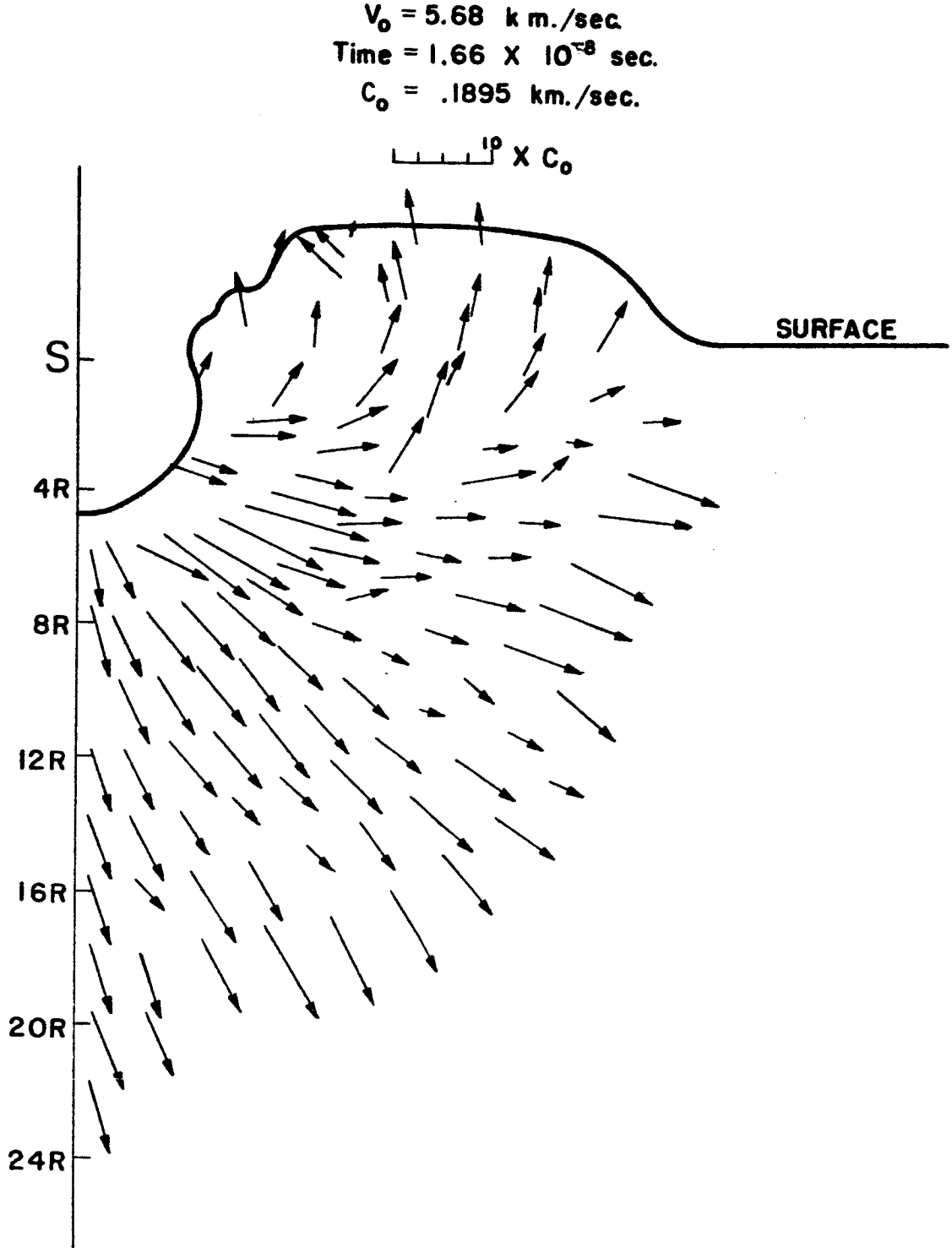

Figure 97. Velocity Map (t = 1.66 x 10^{-8} sec) I

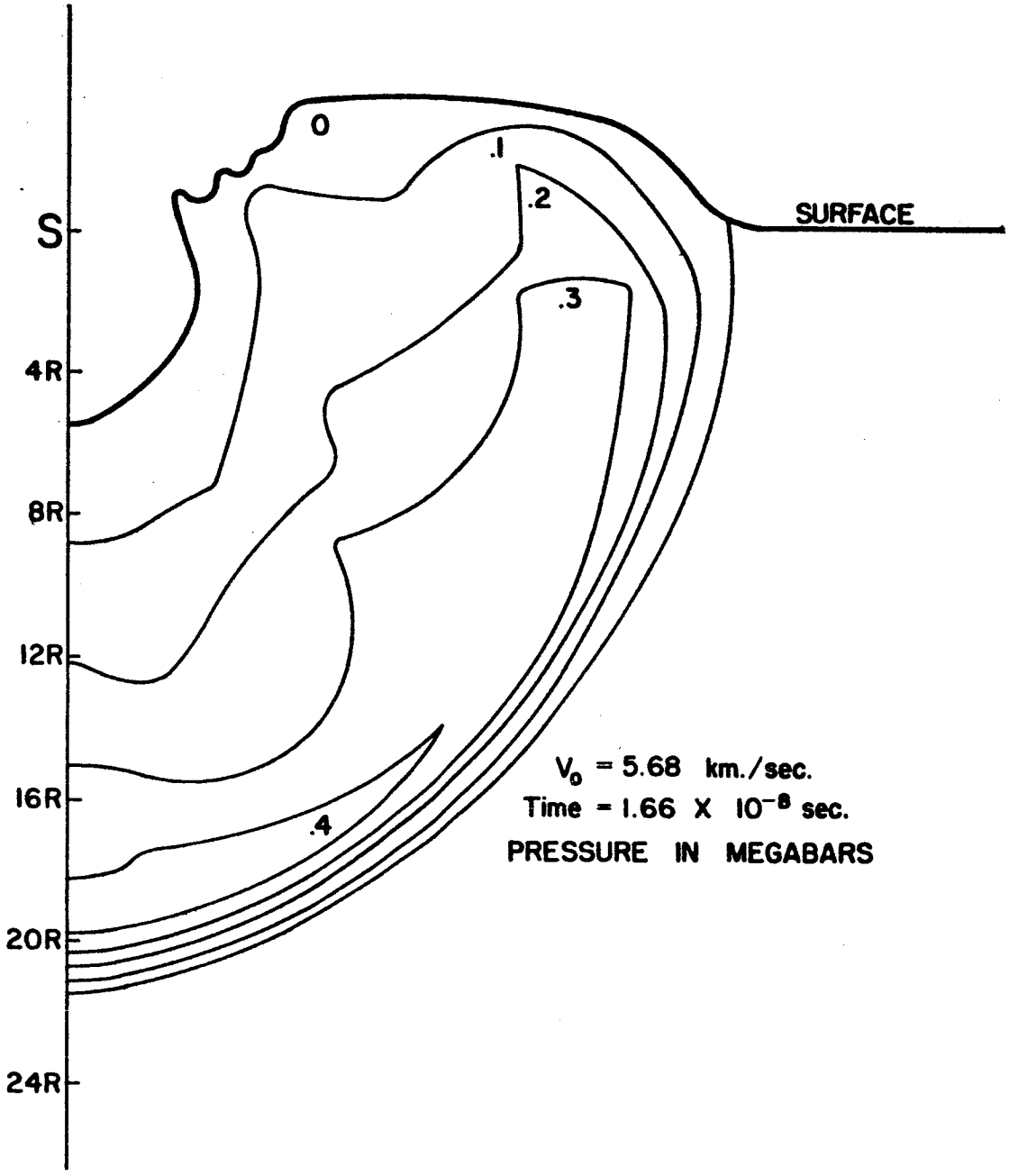

Figure 98. Pressure Map (t = 1.66 x 10^{-8} sec) I

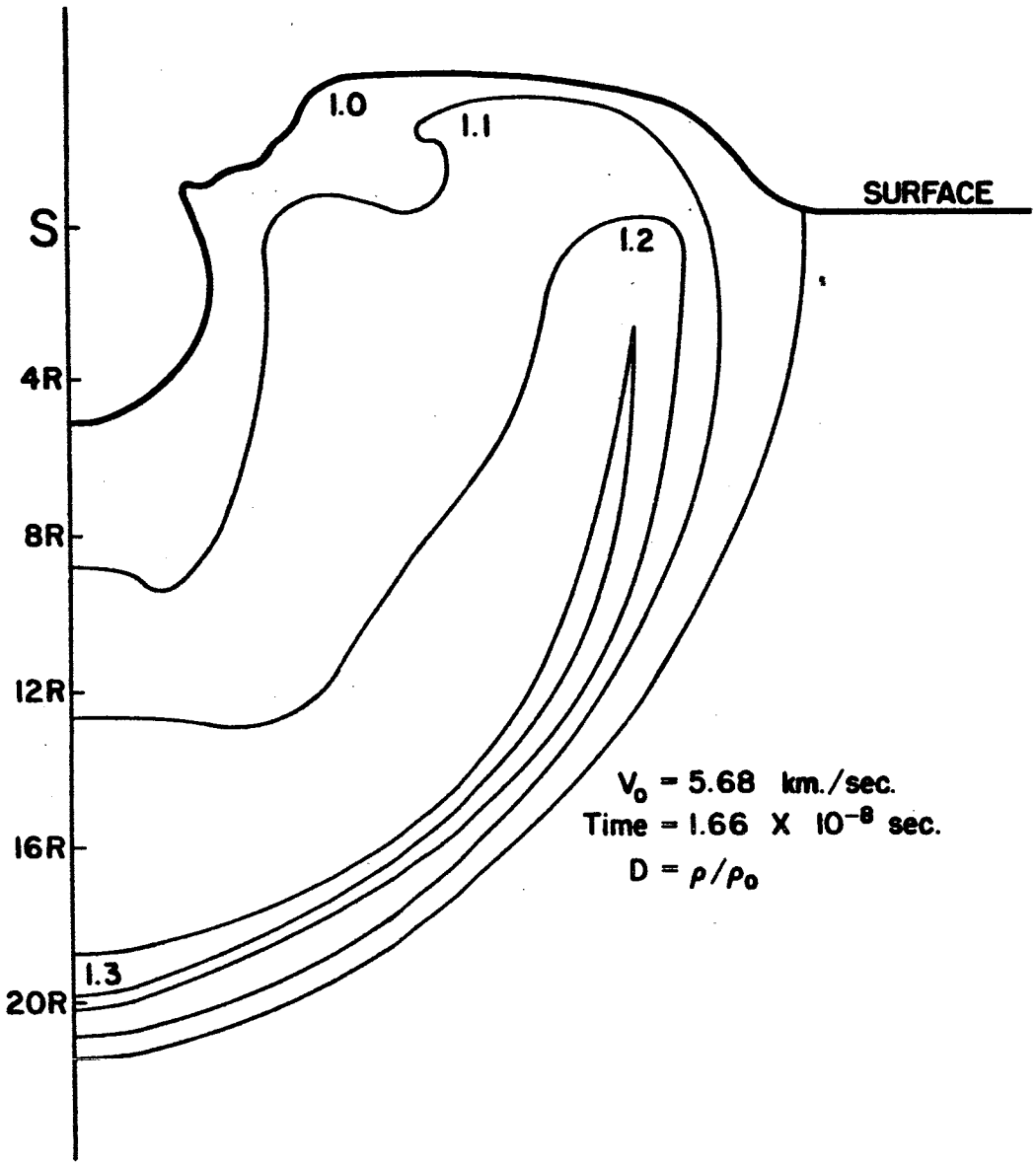

Figure 99. Density Map (t = 1.66 x 10^{-8} sec) I

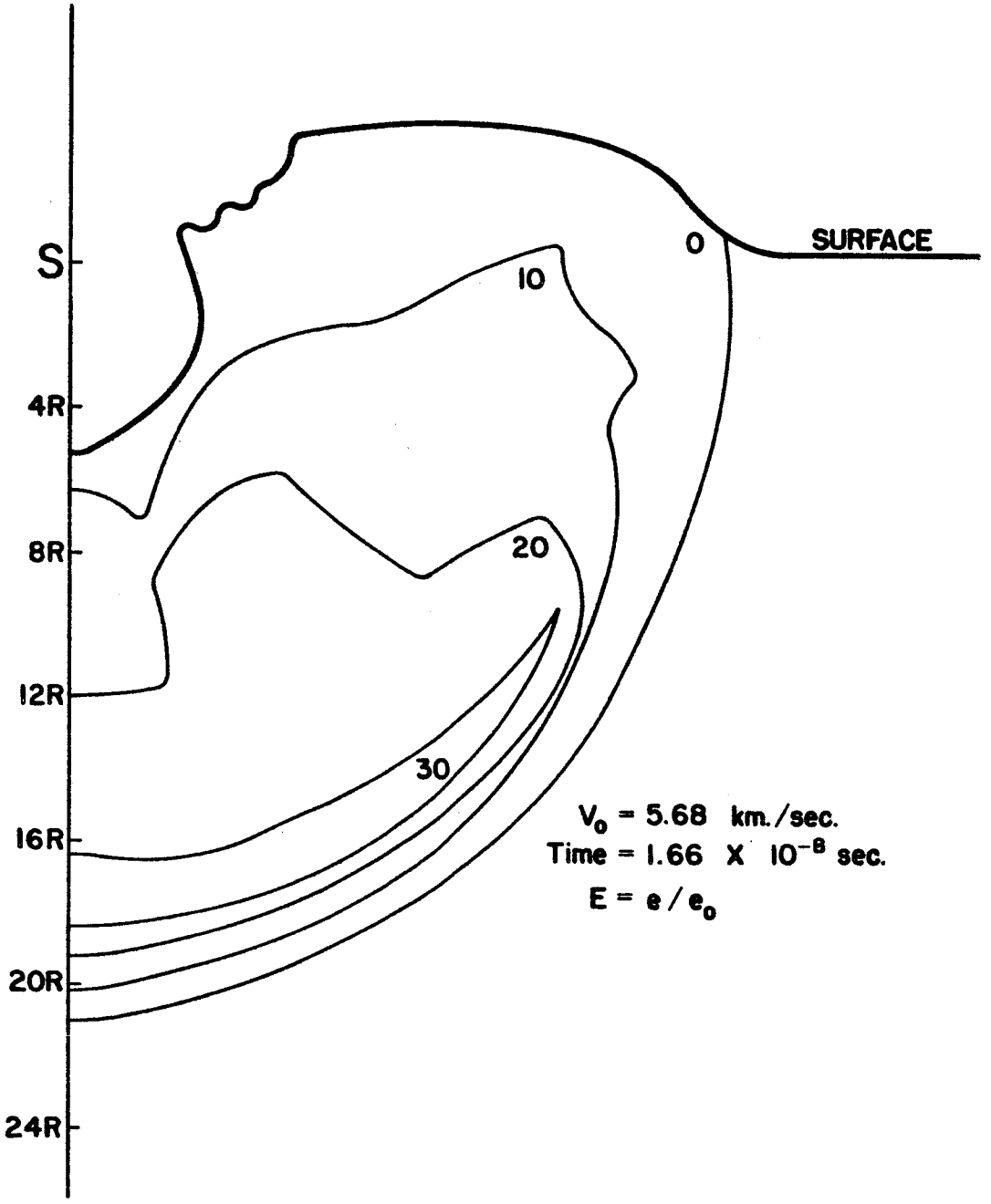

Figure 100. Energy Map (t = 1.66 x 10^{-8} sec) I

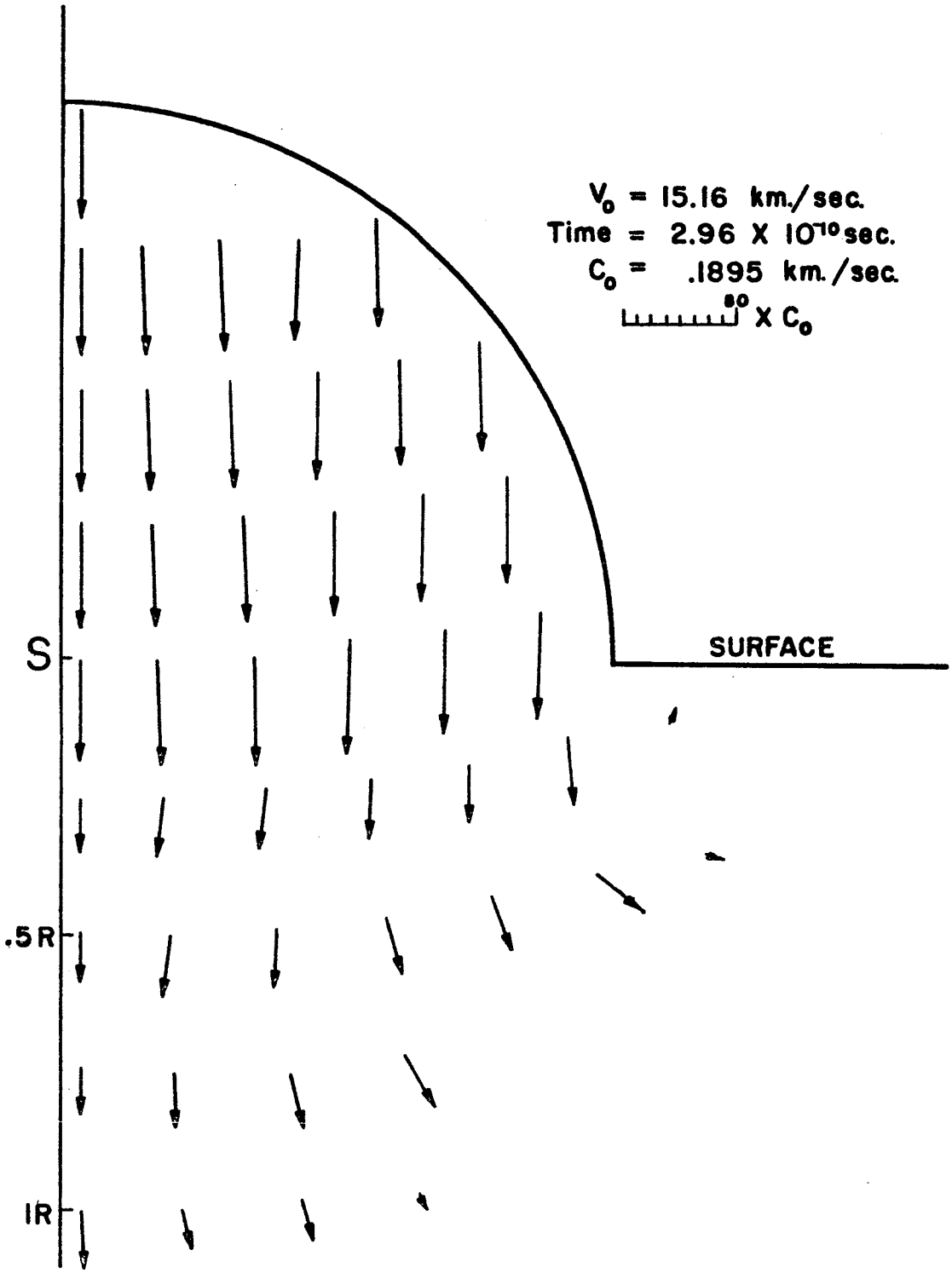

Figure 101. Velocity Map (t = .296 x 10^{-9} sec) II

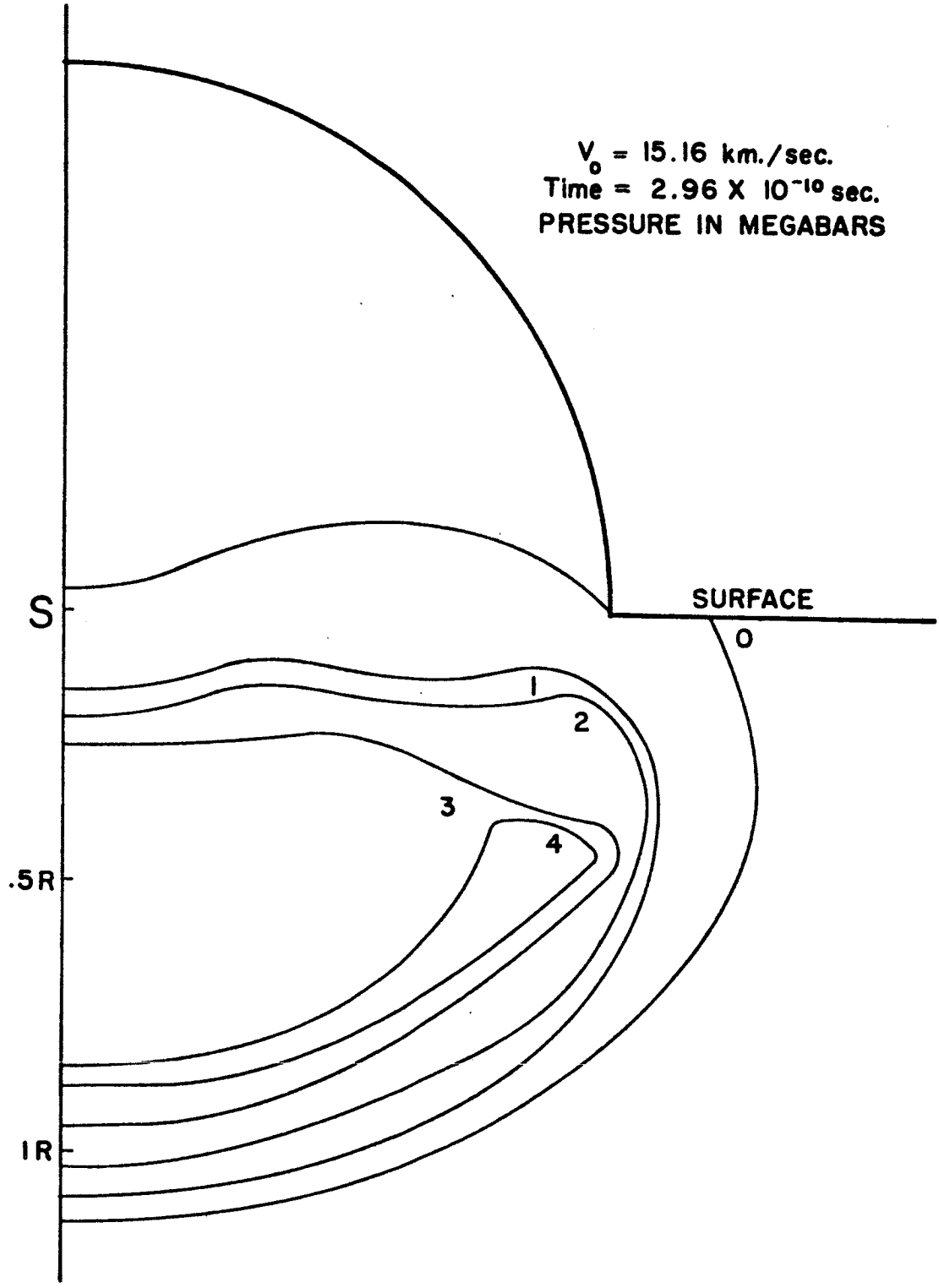

Figure 102. Pressure Map (t = .296 x 10^{-9} sec) II

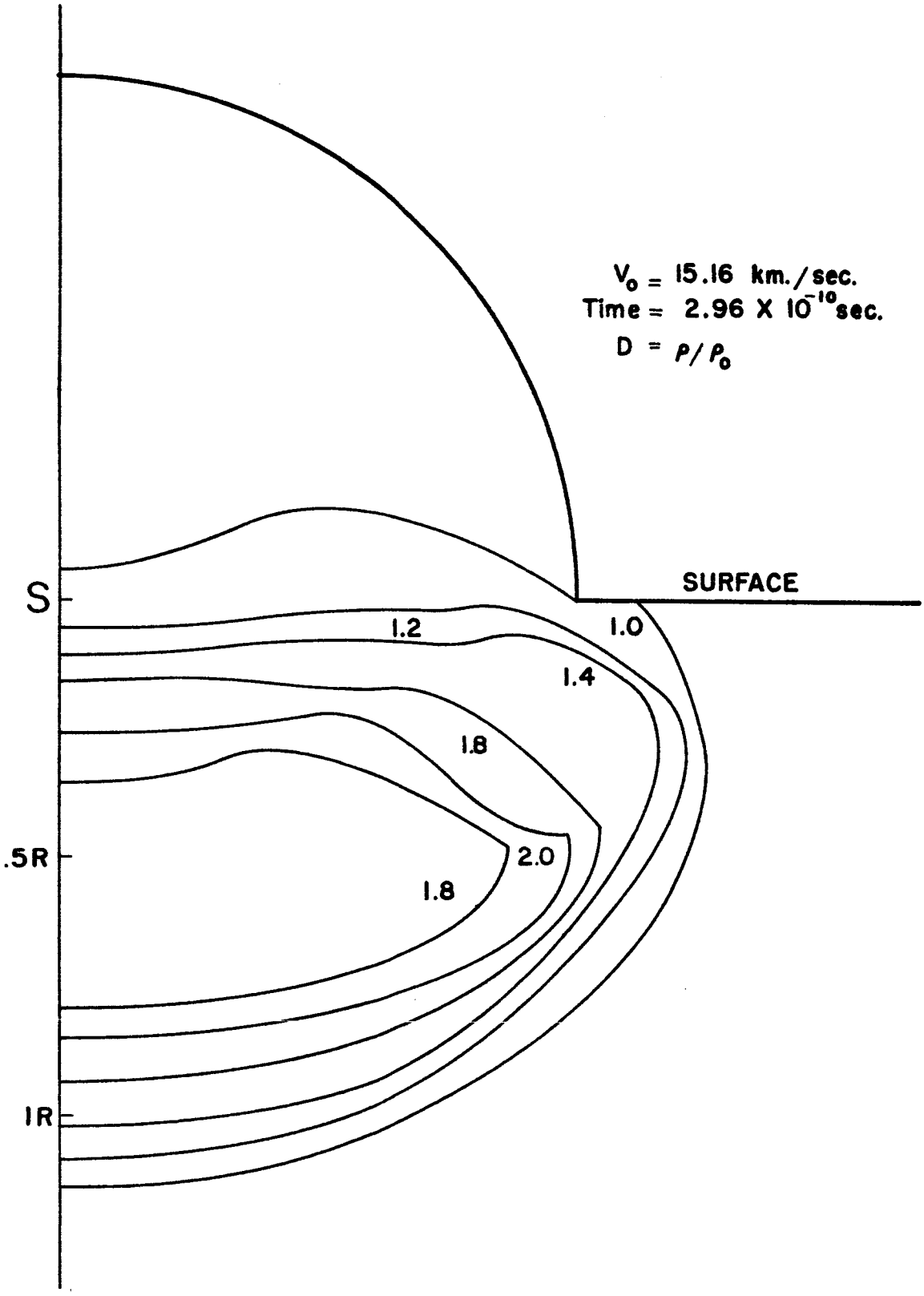

Figure 103. Density Map (t = .296 x 10^{-9} sec) II

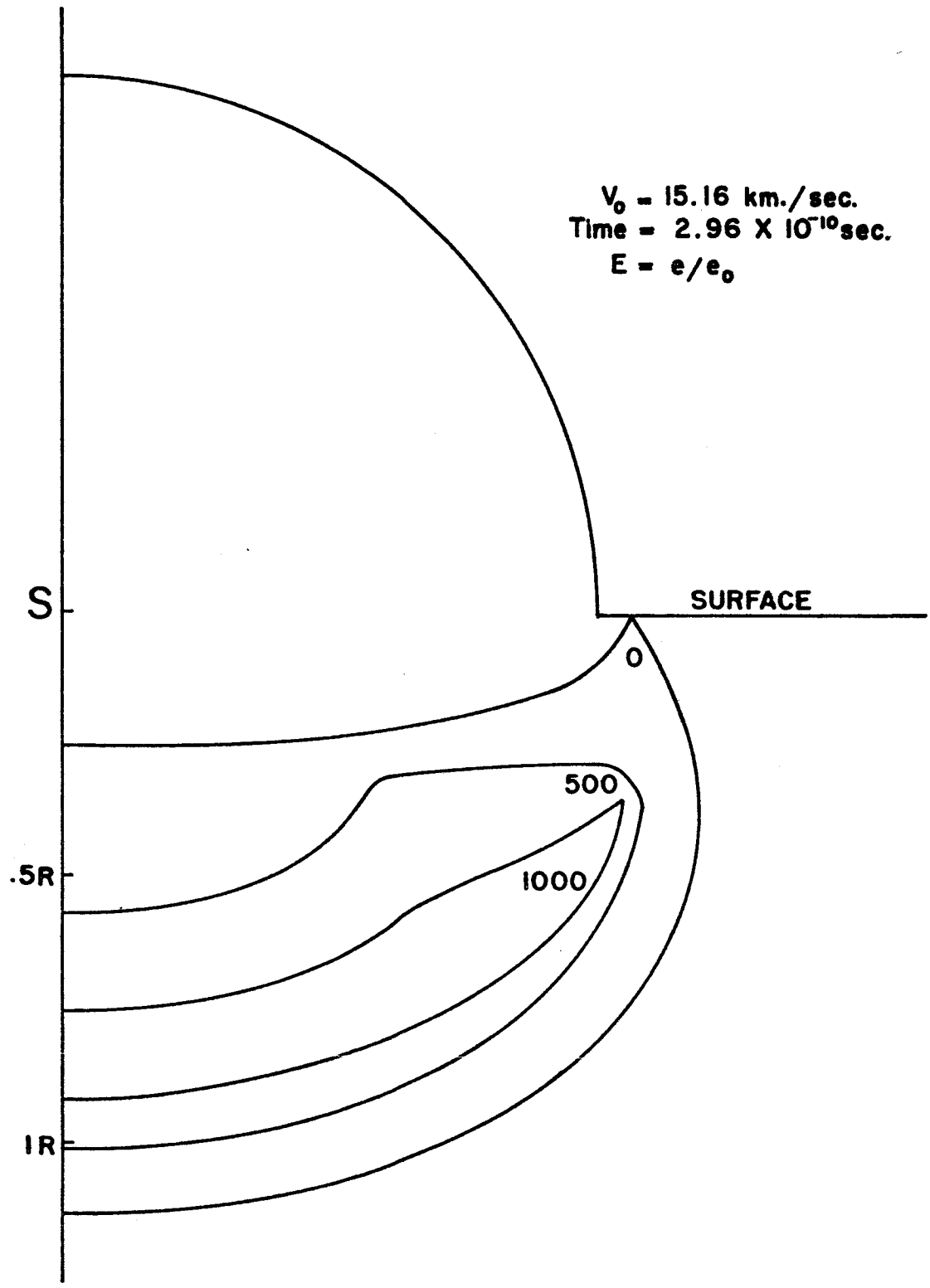

Figure 104. Energy Map (t = .296 x 10^{-9} sec) II

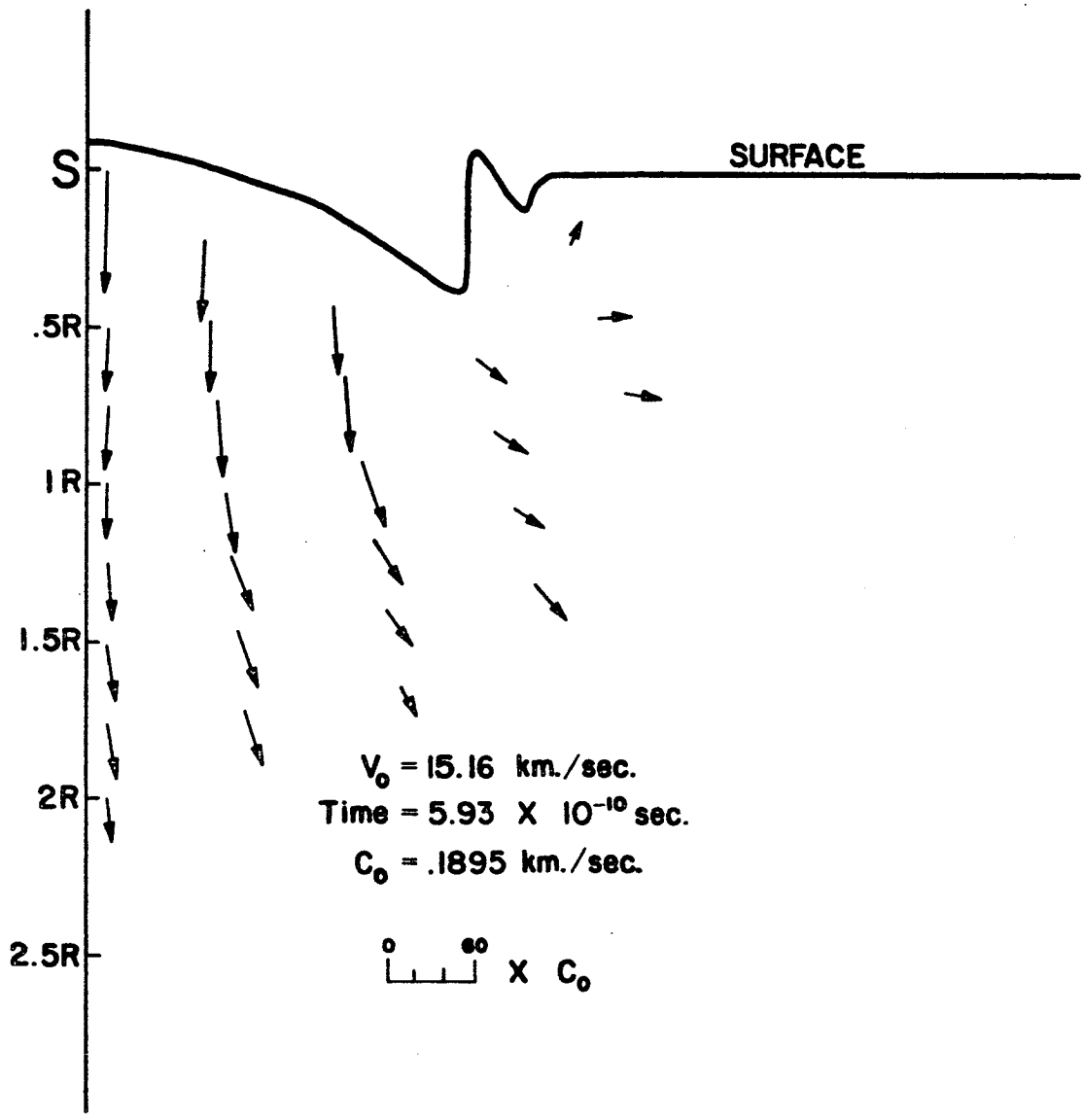

Figure 105. Velocity Map (t = .593 x 10^{-9} sec) II

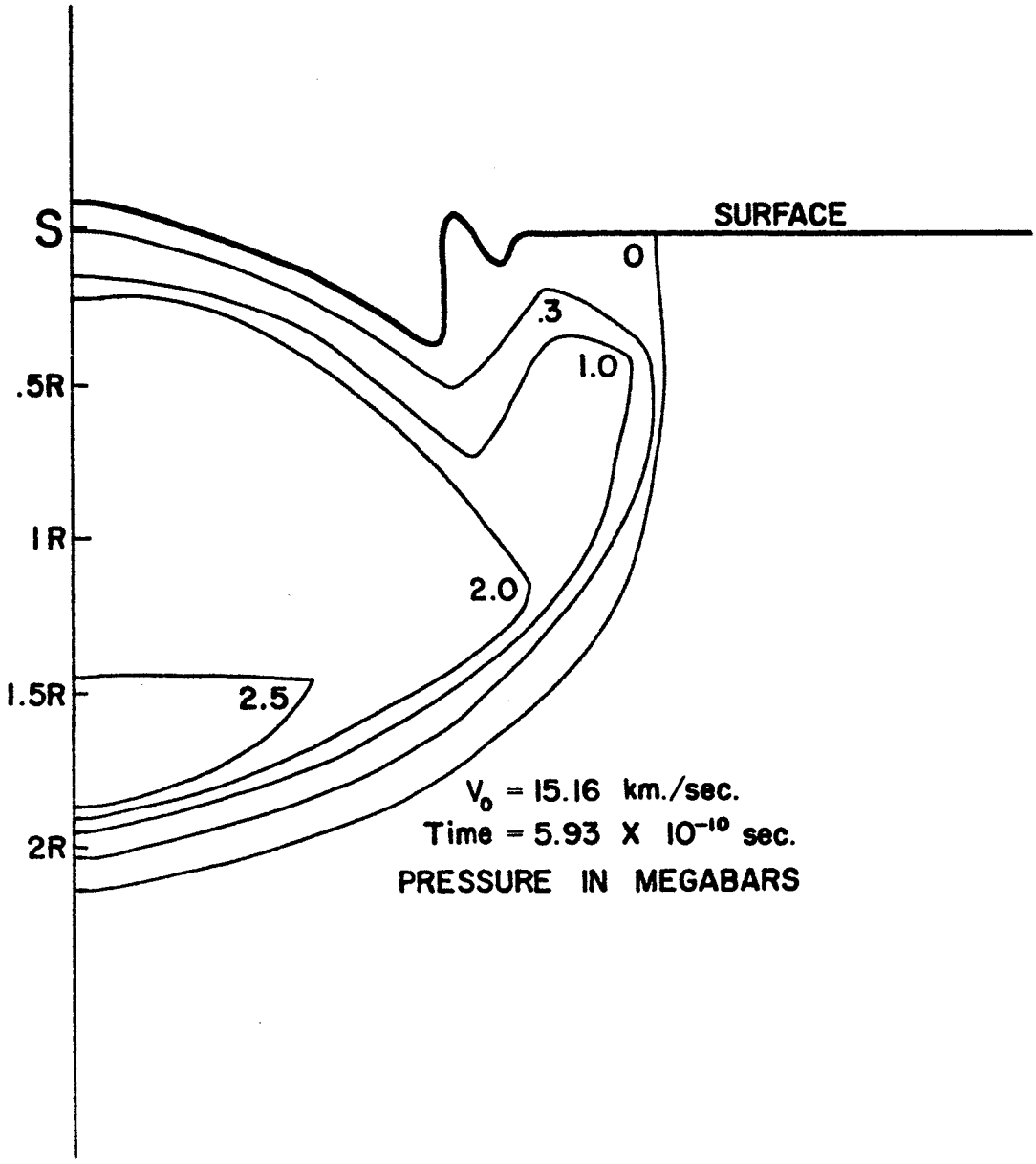

Figure 106. Pressure Map (t = .593 x 10^{-9} sec) II

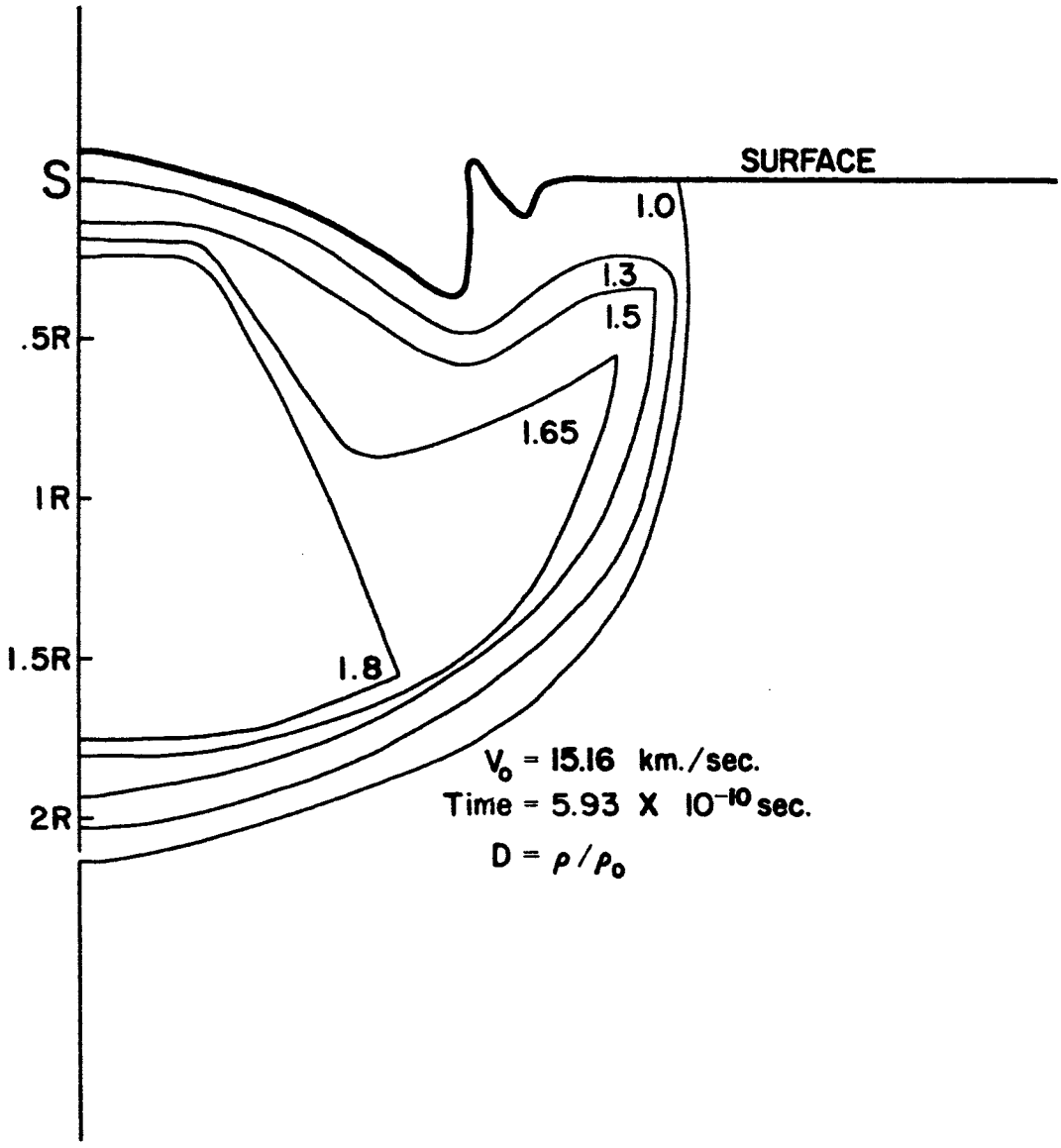

Figure 107. Density Map (t = .593 x 10^{-9}. sec) II

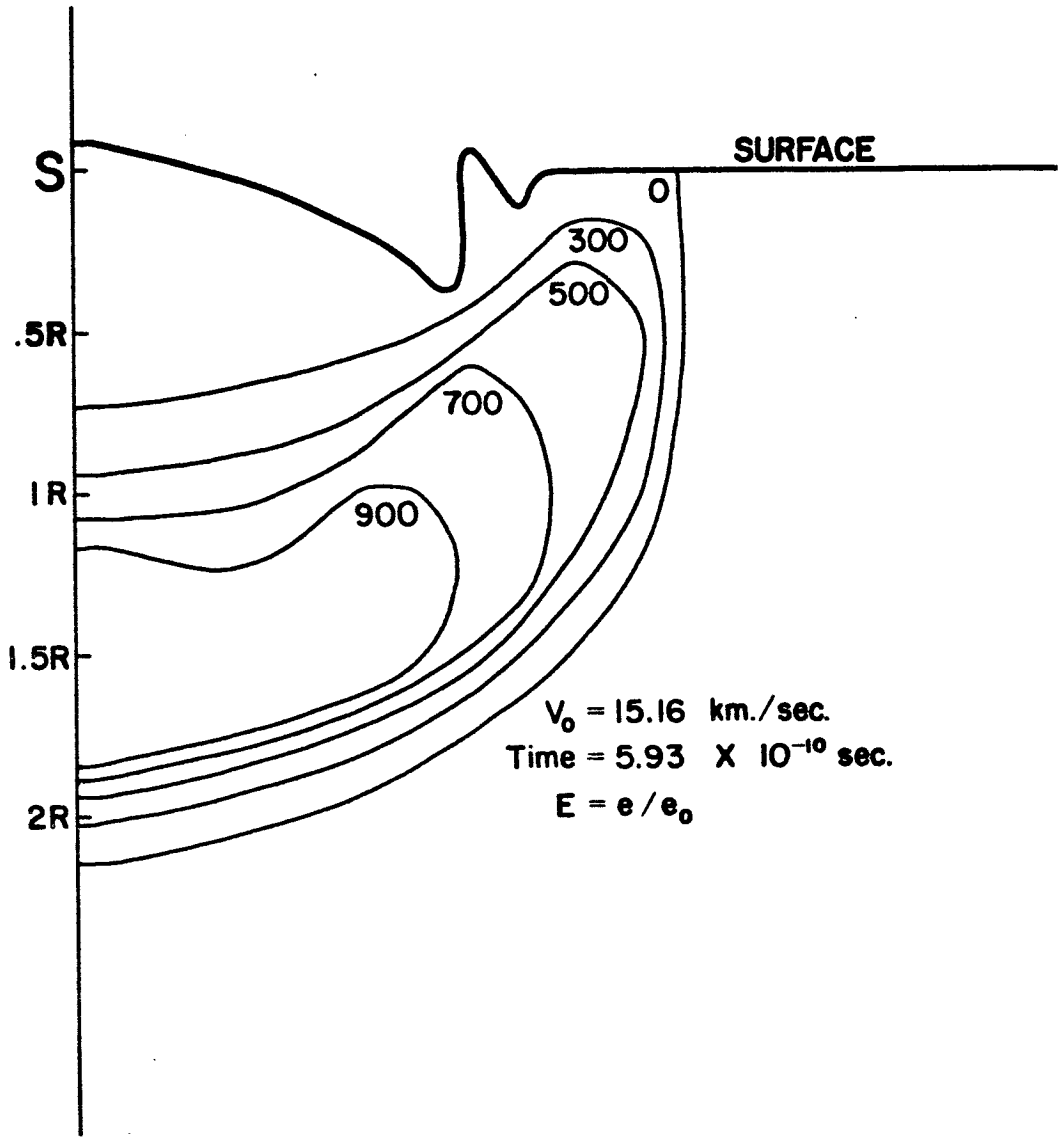

Figure 108. Energy Map (t = .593 x 10^{-9} sec) II

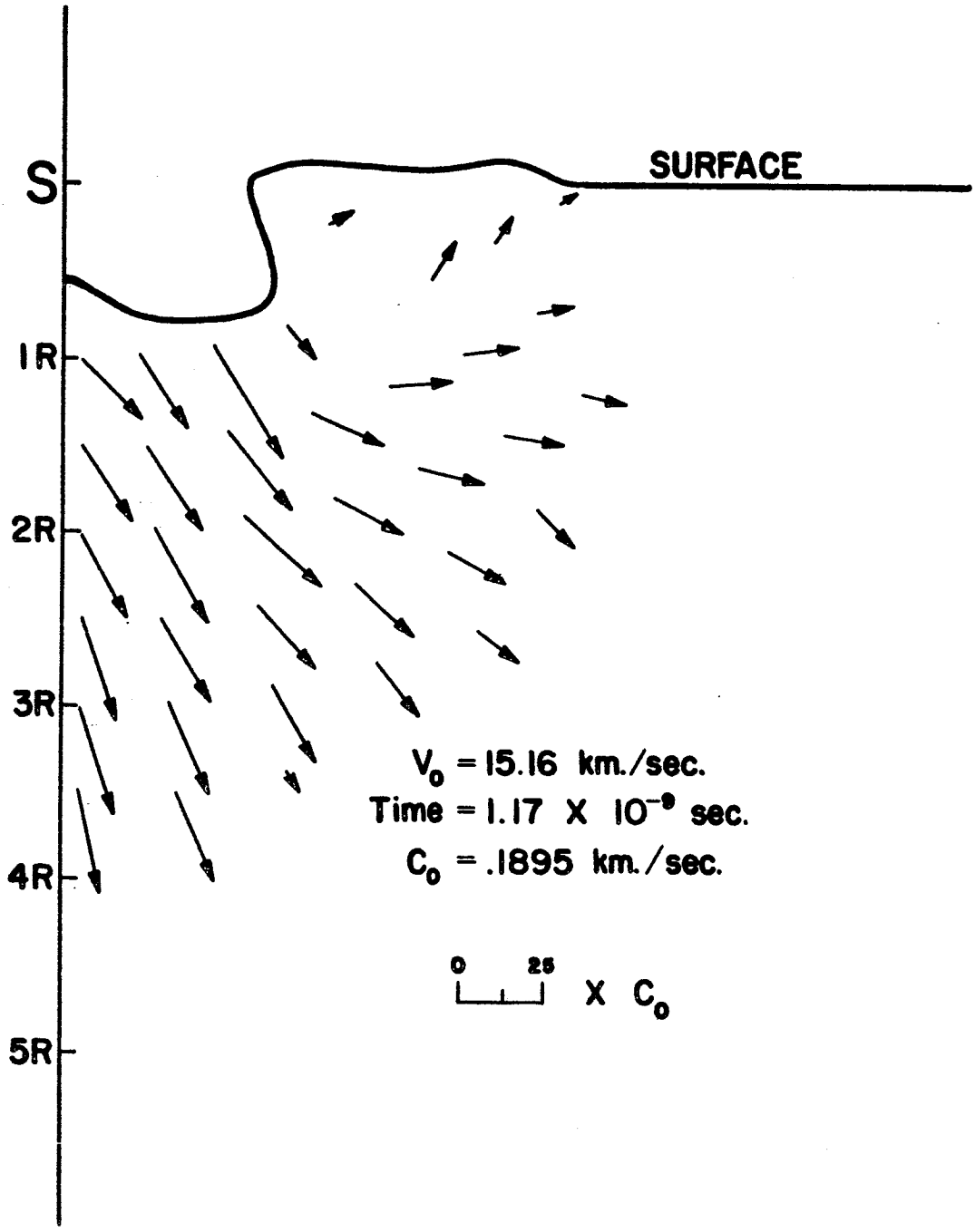

Figure 109. Velocity Map (t = 1.17 x 10^{-9} sec) II

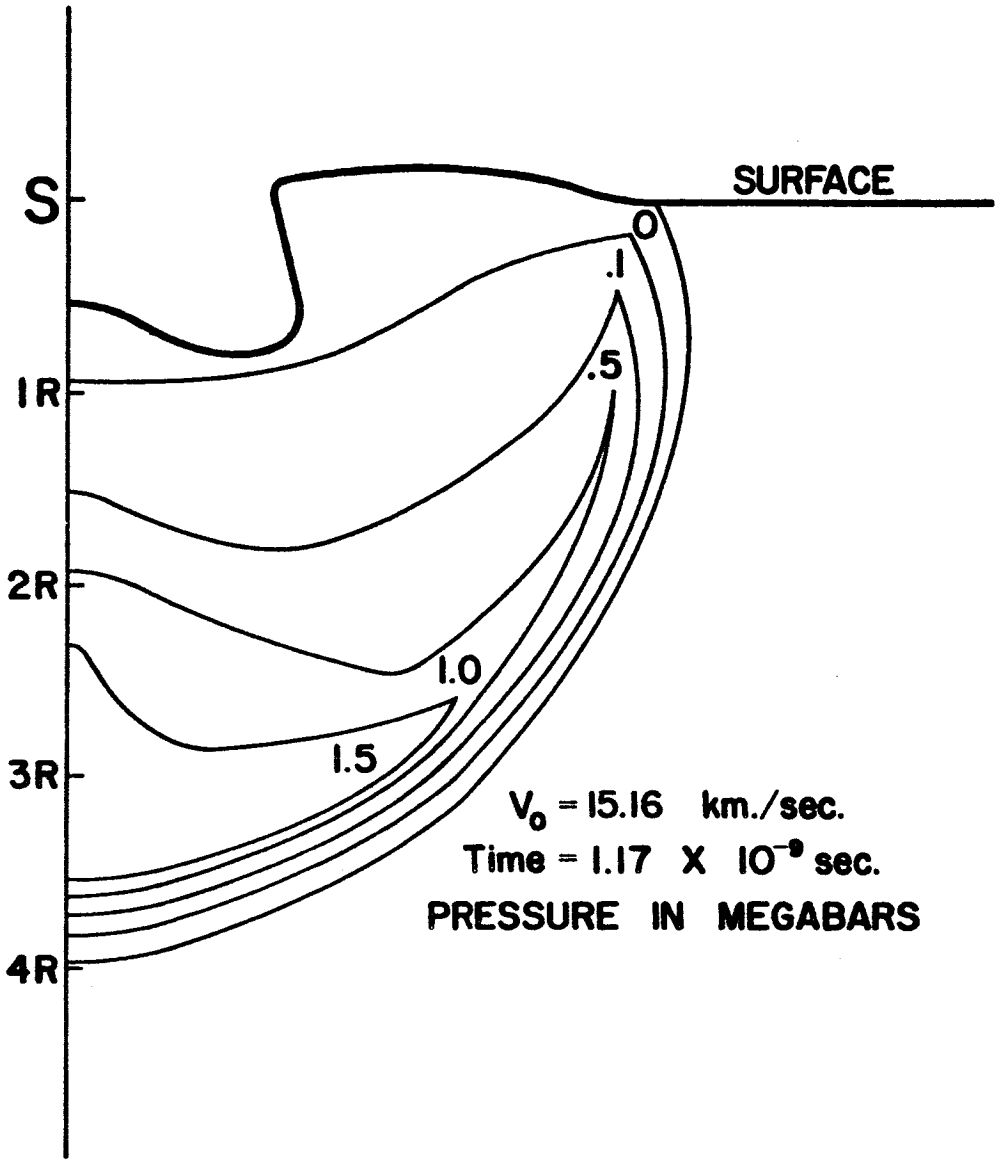

Figure 110. Pressure Map (t = 1.17 x 10^{-9} sec) II

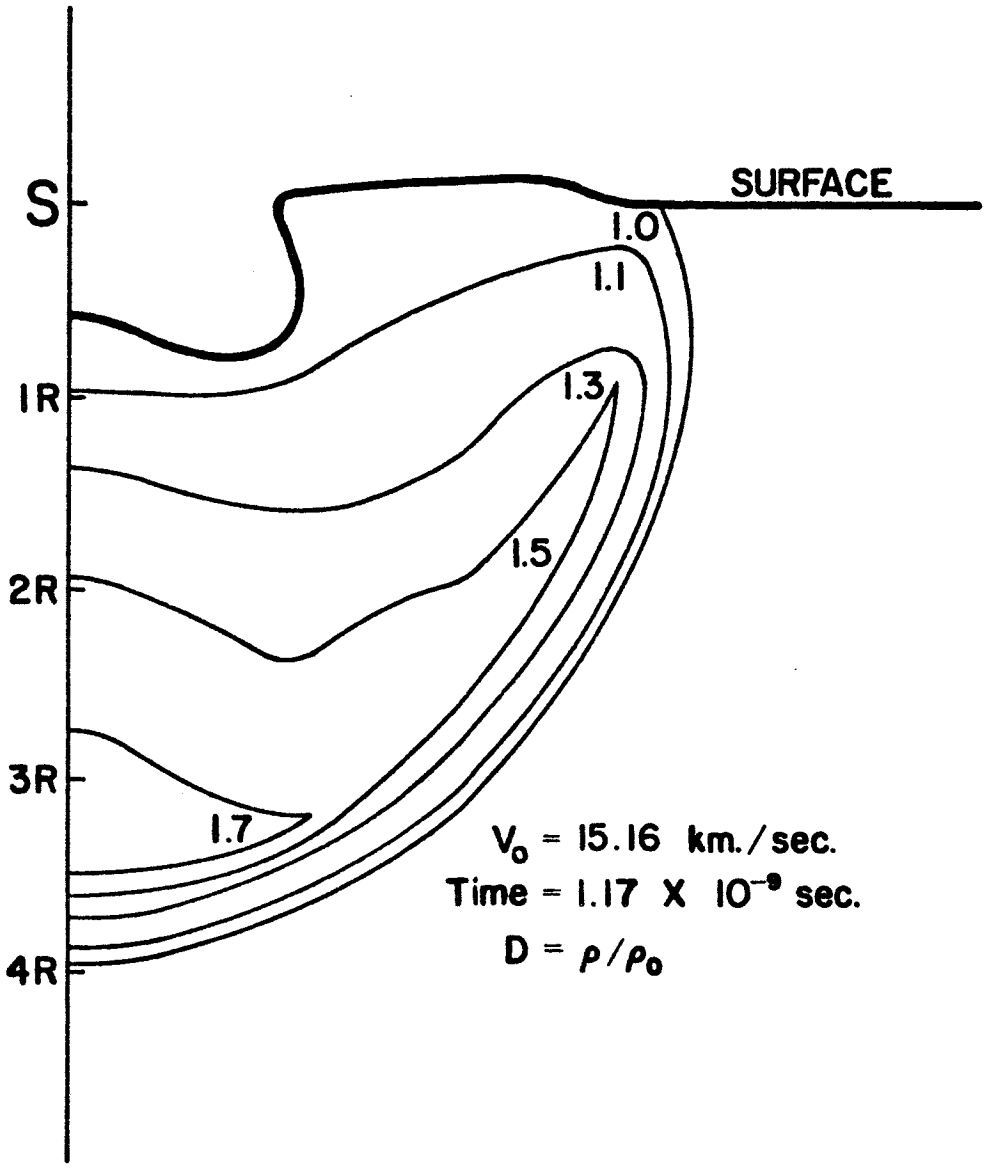

Figure 111. Density Map (t = 1.17 x 10^{-9} sec) II

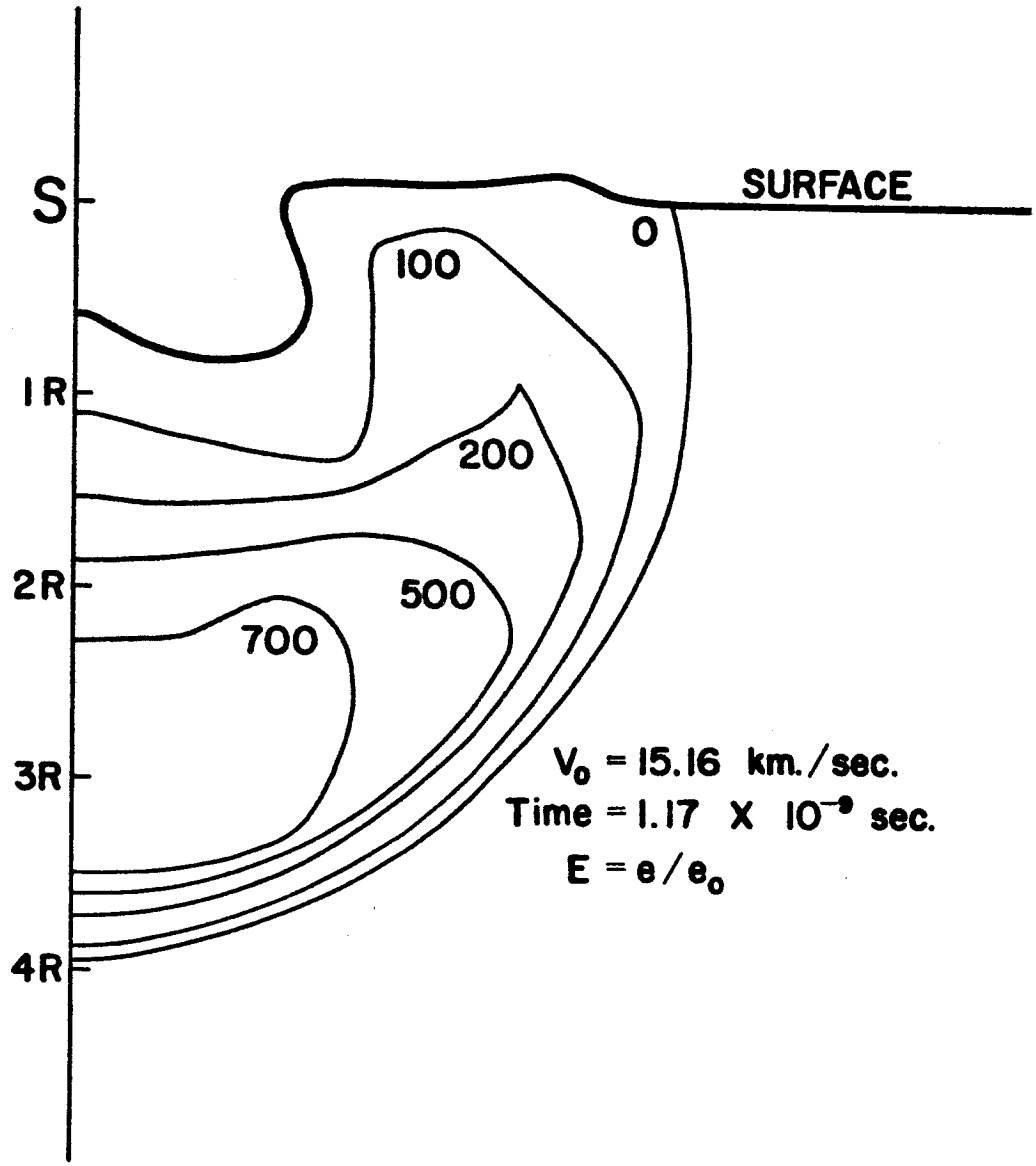

Figure 112. Energy Map (t = 1.17 x 10^{-9} sec) II

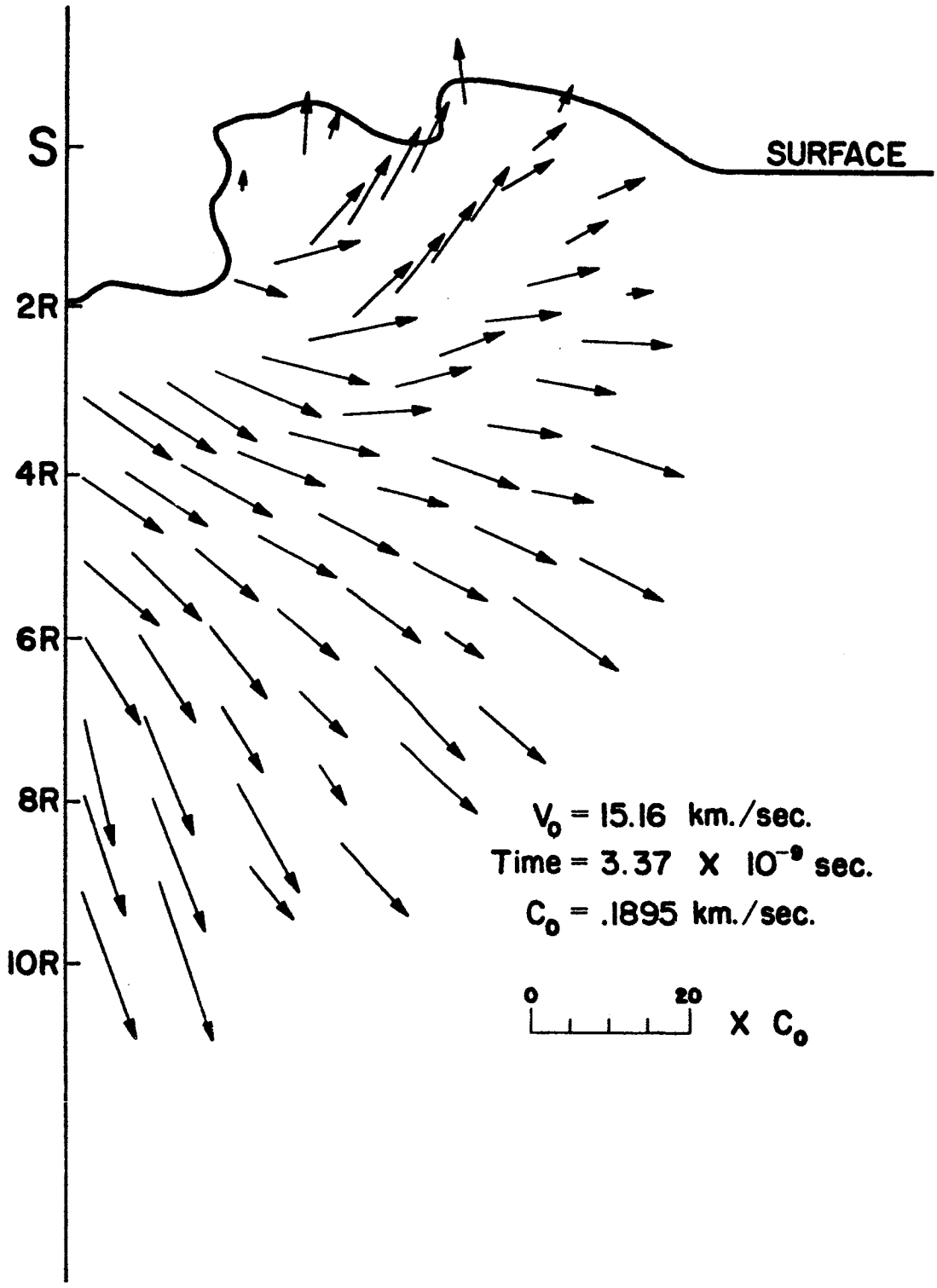

Figure 113. Velocity Map (t = 3.37 x 10^{-9} sec) II

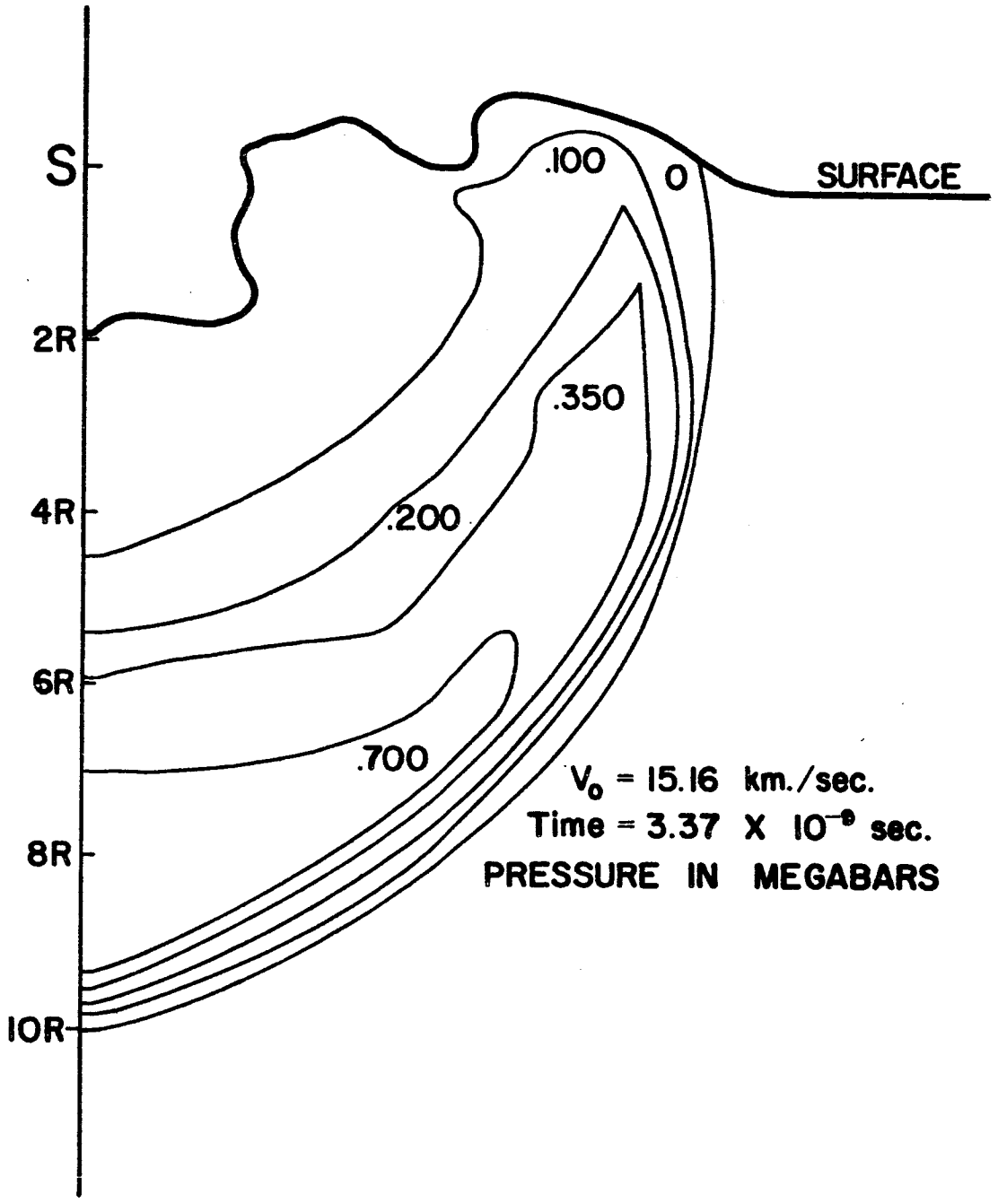

Figure 114. Pressure Map (t = 3.37 x 10^{-9} sec) II

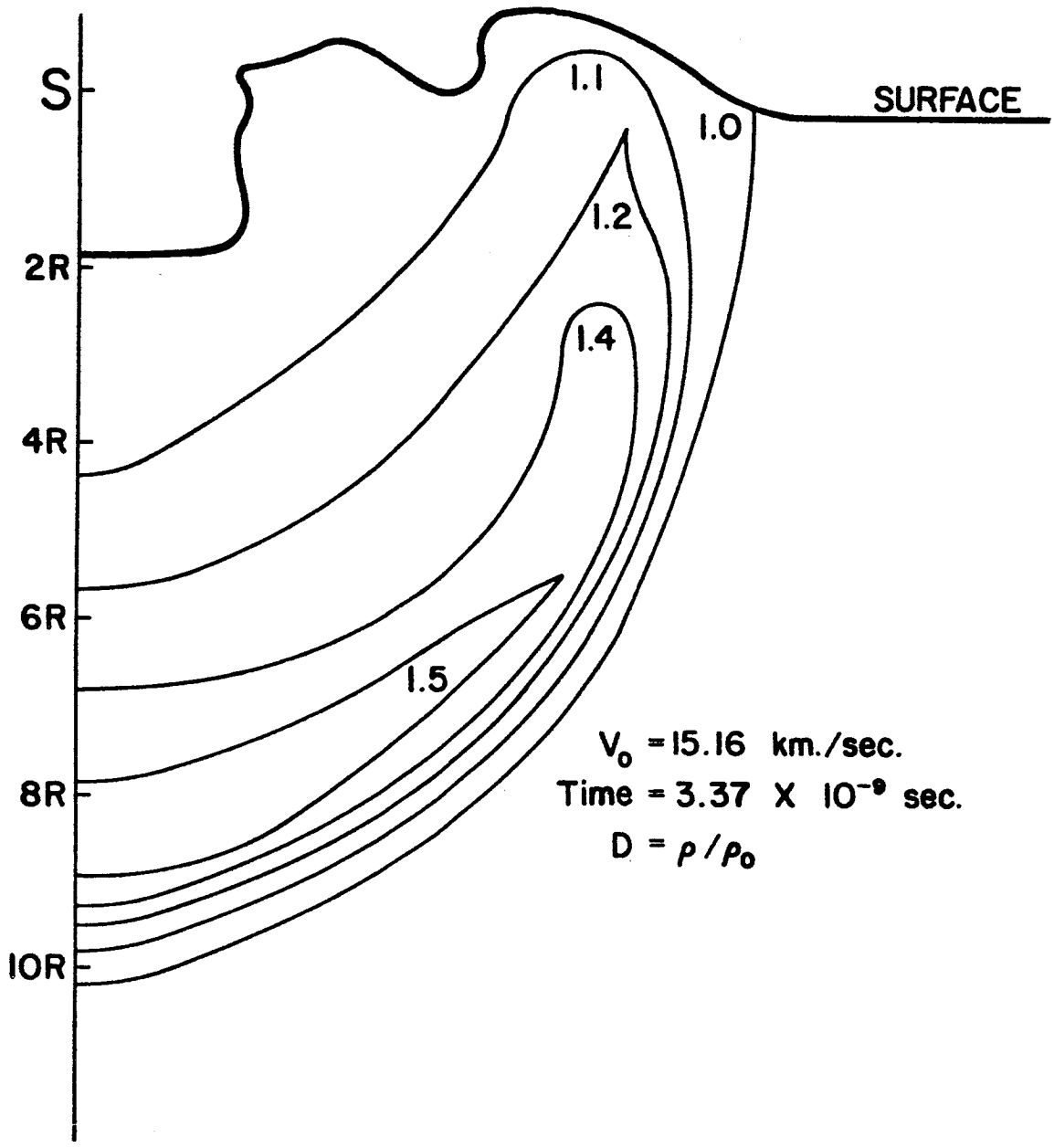

Figure 115. Density Map (t = 3.37 x 10^{-9} sec) II

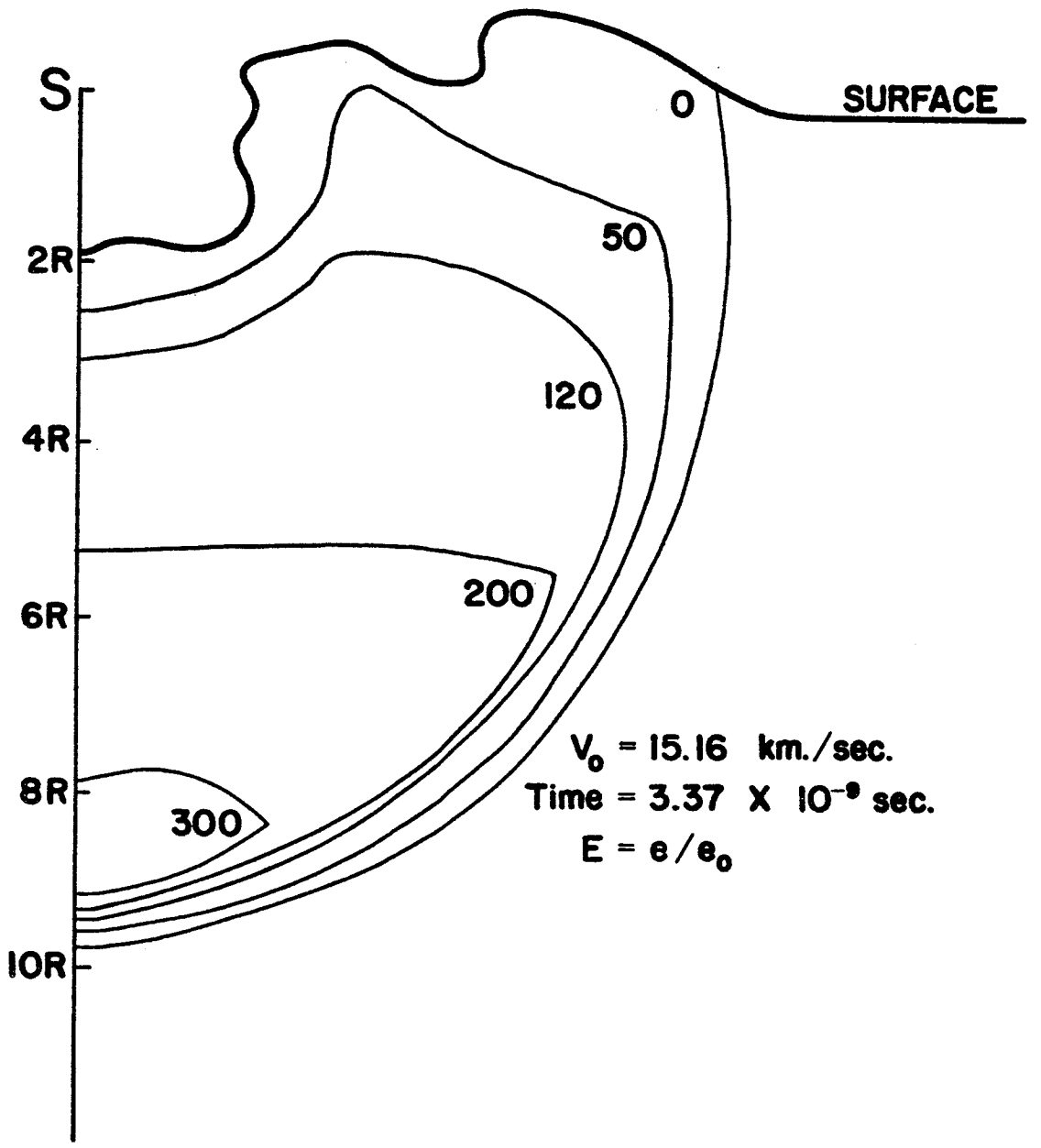

Figure 116. Energy Map (t = 3.37 x 10^{-9} sec) II

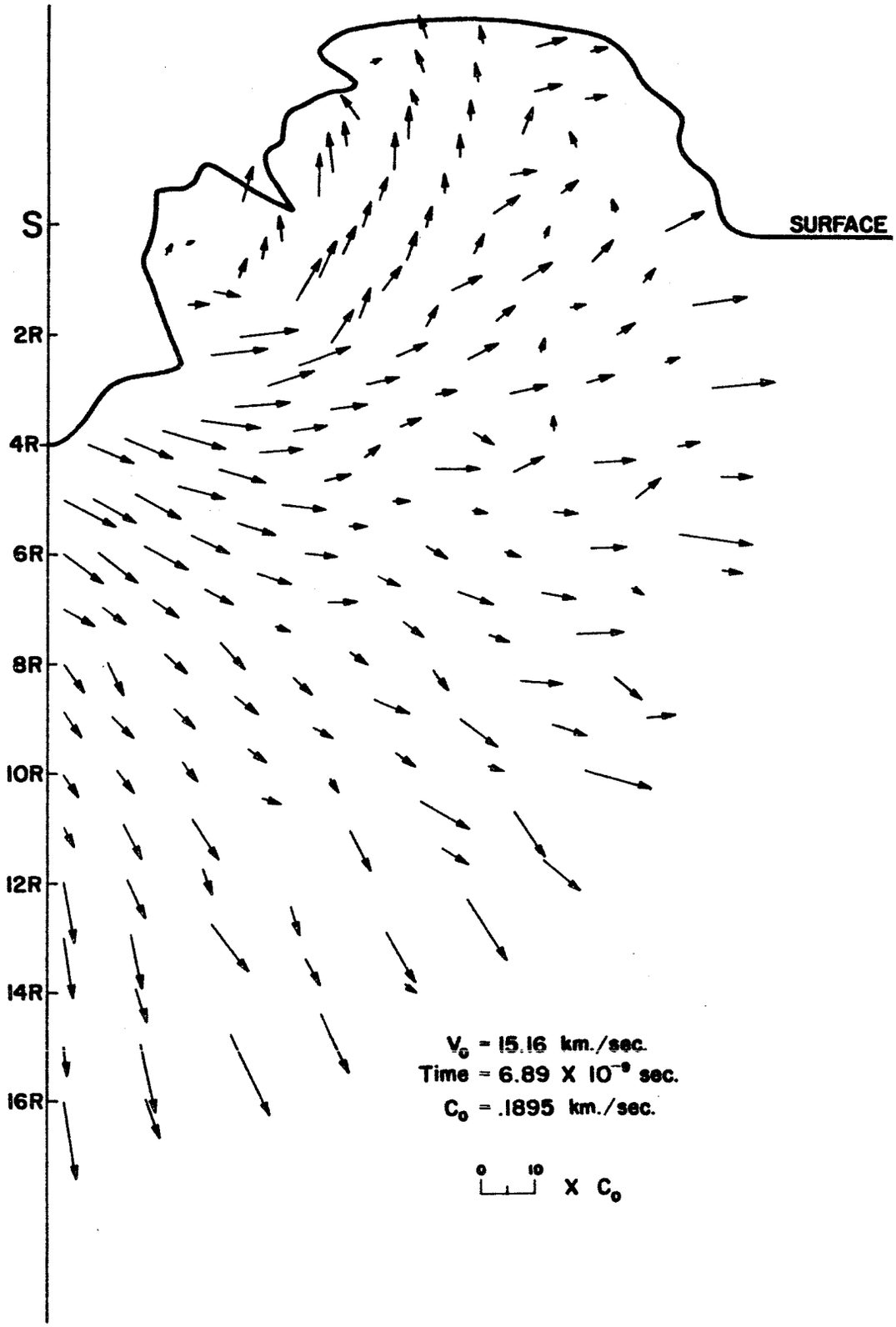

Figure 117. Velocity Map (t = 6.89 x 10^{-9} sec) II

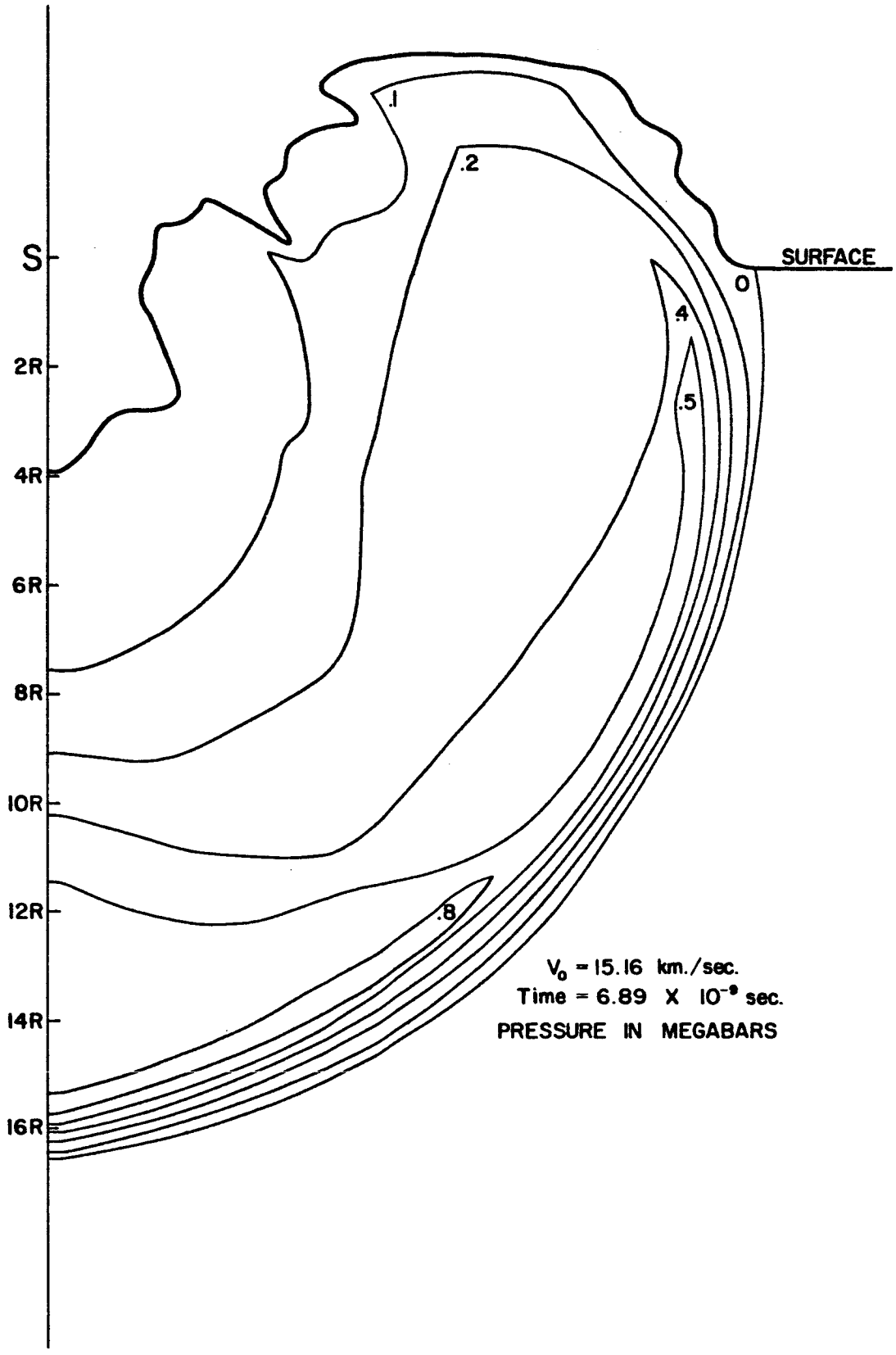

Figure 118. Pressure Map (t = 6.89 x 10^{-9} sec) II

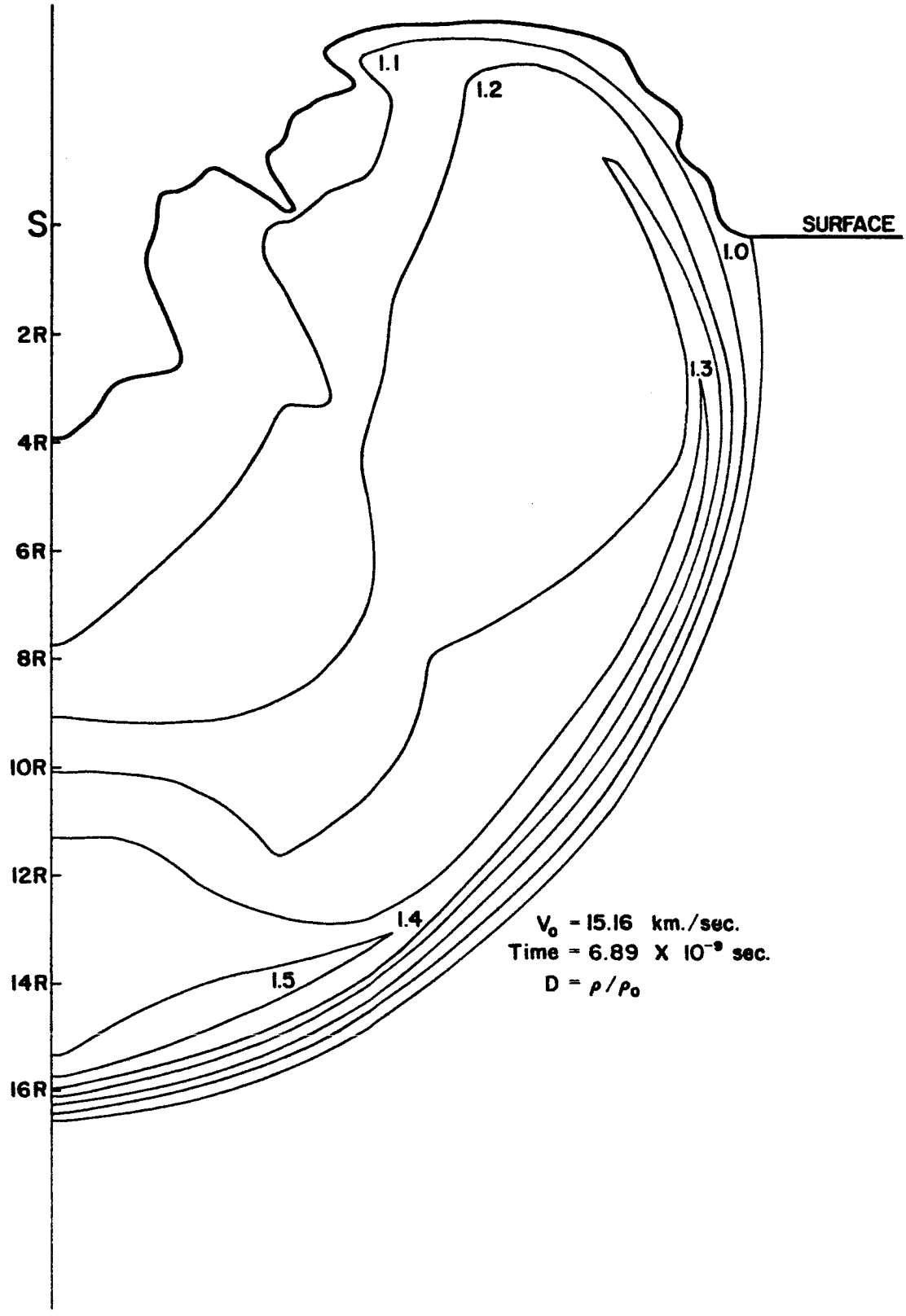

Figure 119. Density Map (t = 6.89 x 10^{-9} sec) II

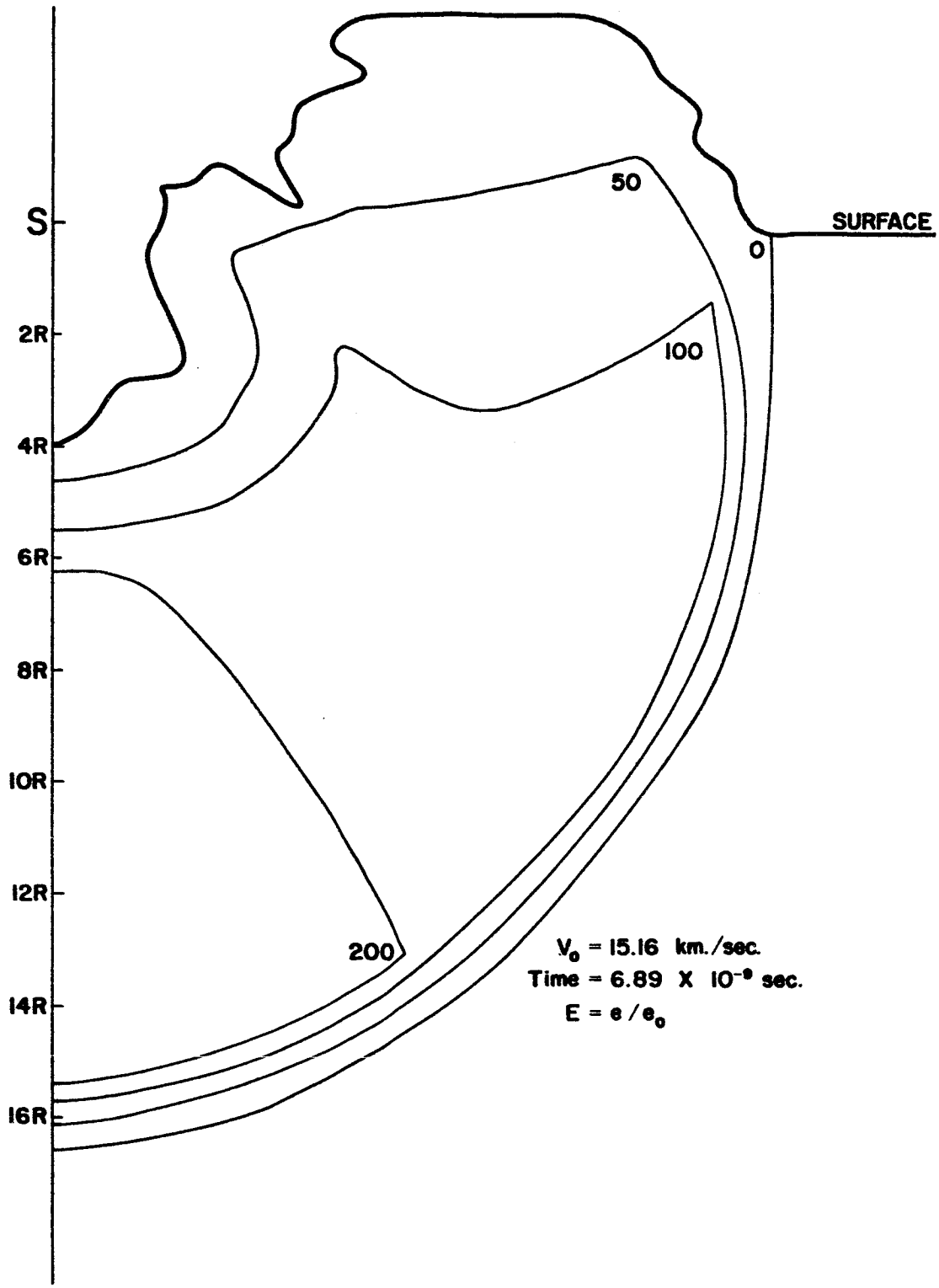

Figure 120. Energy Map (t = 6.89 x 10^{-9} sec) II

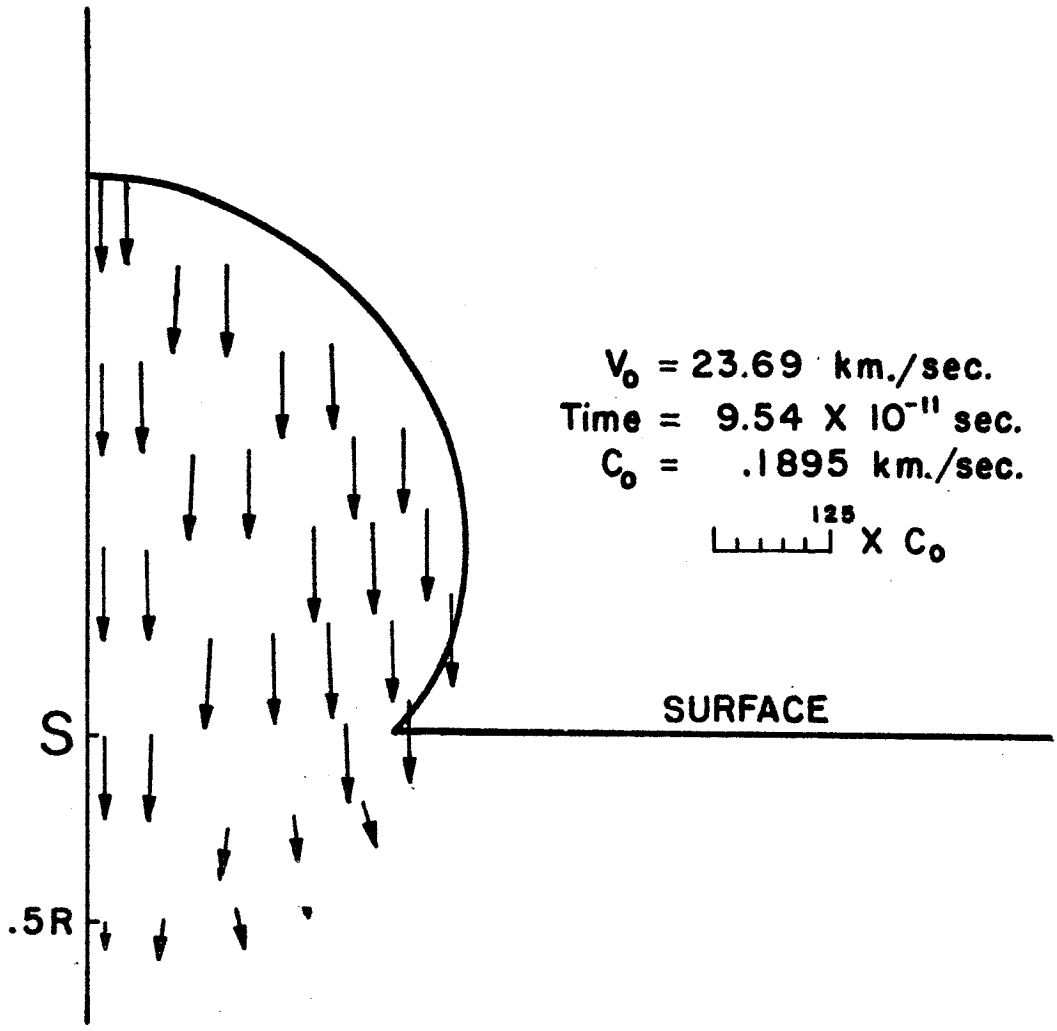

Figure 121. Velocity Map (t = 9.54 x 10^{-11} sec) III

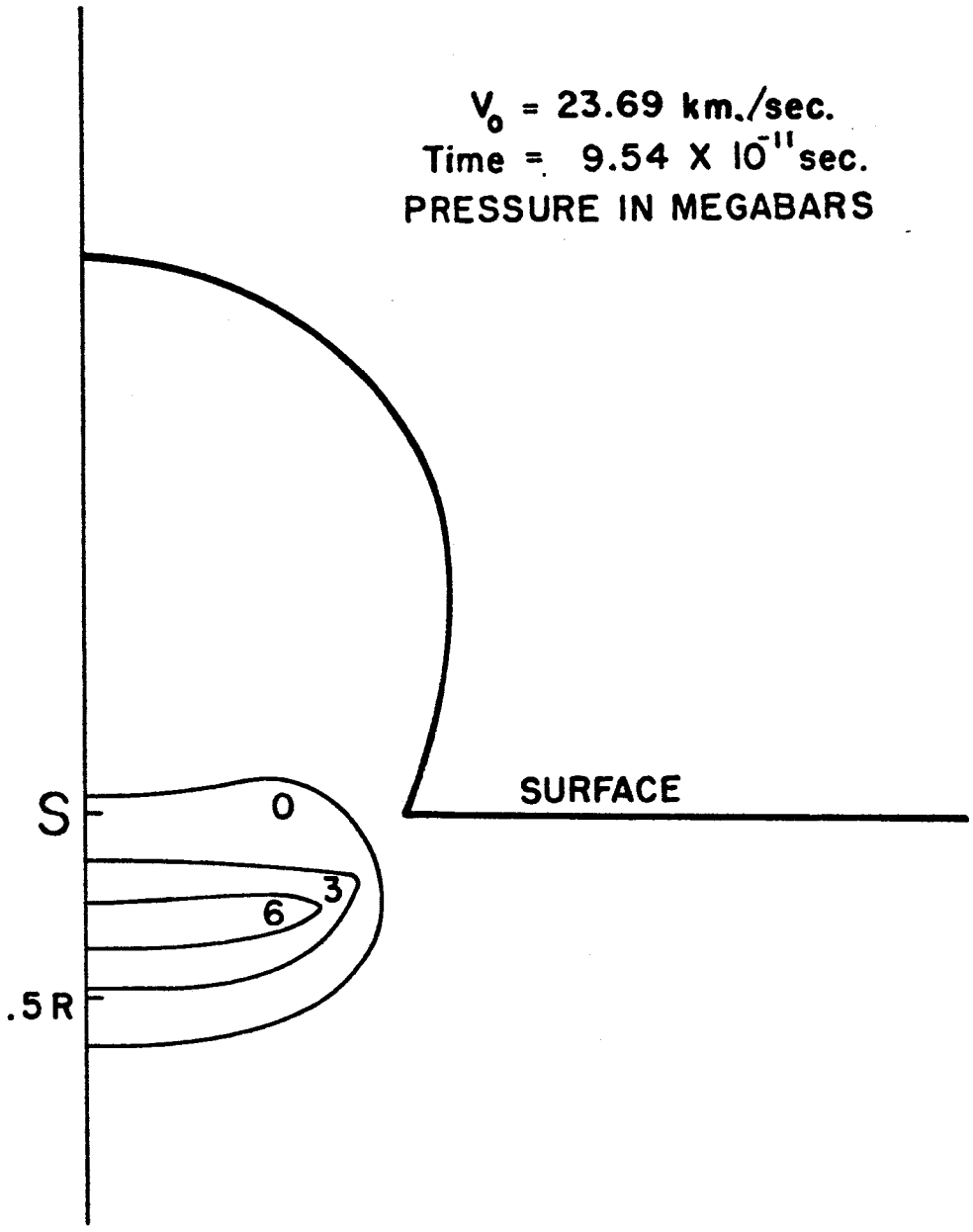

Figure 122. Pressure Map (t = 9.54 x 10^{-11} sec) III

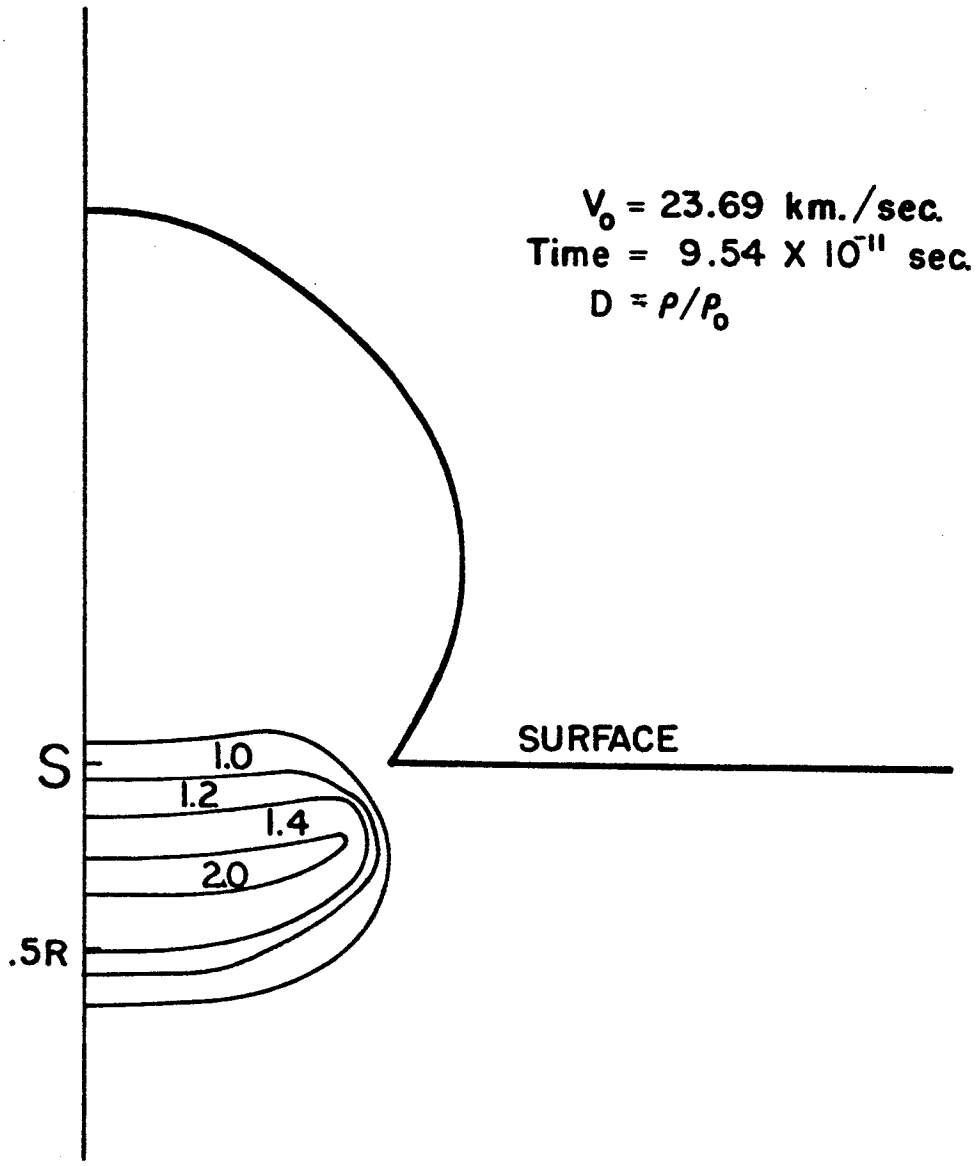

Figure 123. Density Map (t = 9.54 x 10^{-11} sec) III

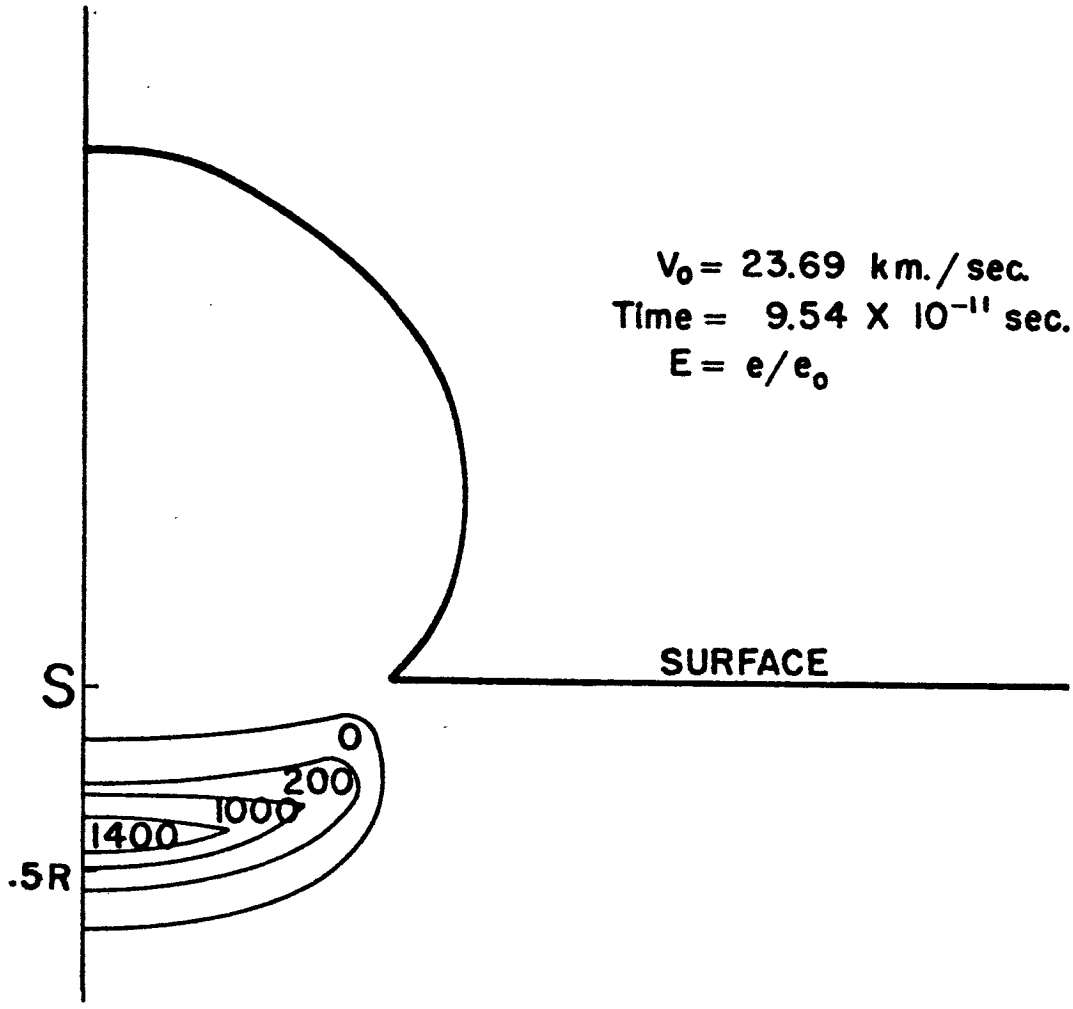

Figure 124. Energy Map (t = 9.54 x 10^{-11} sec) III

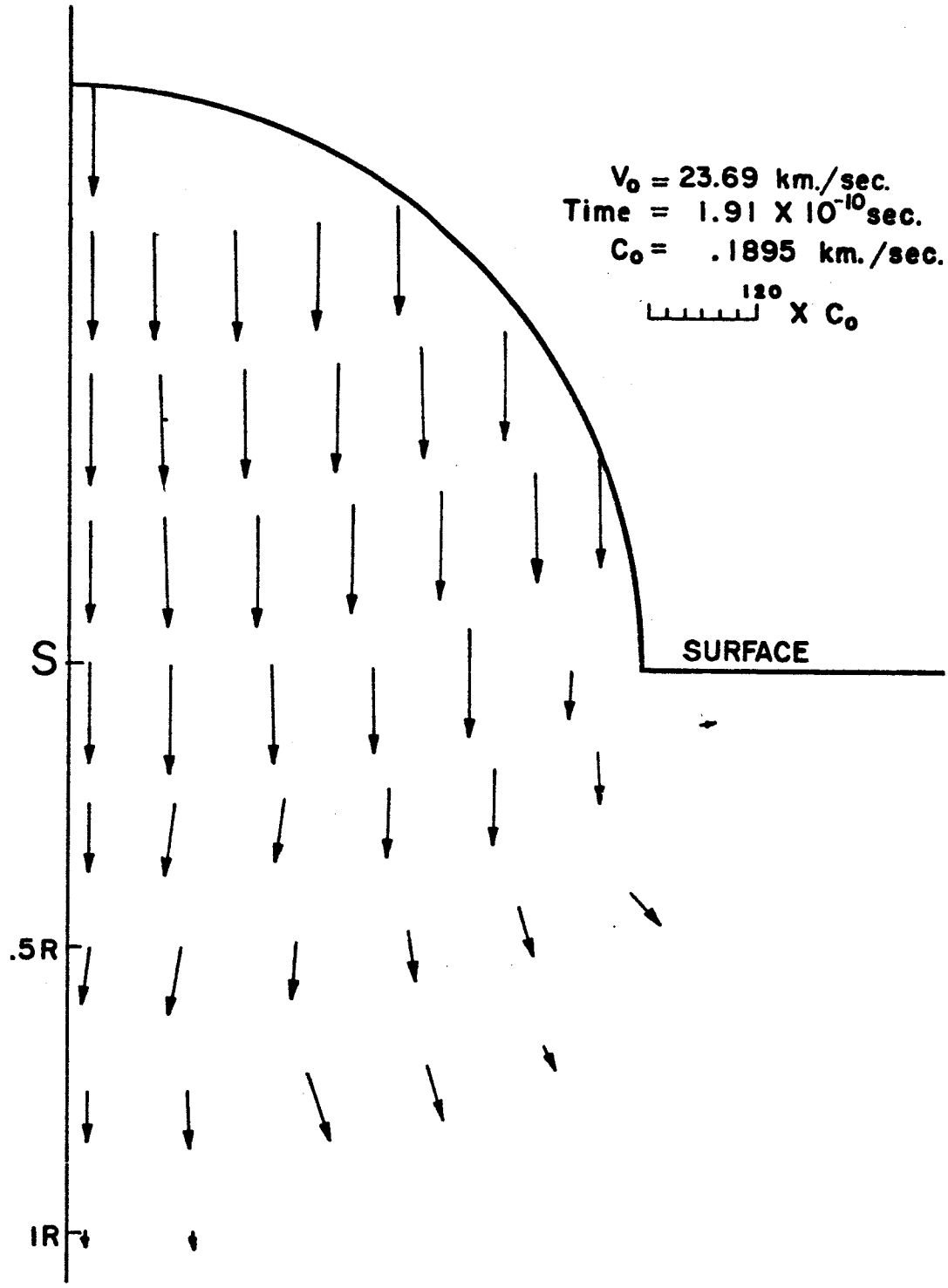

Figure 125. Velocity Map (t = 1.91 x 10^{-10} sec) III

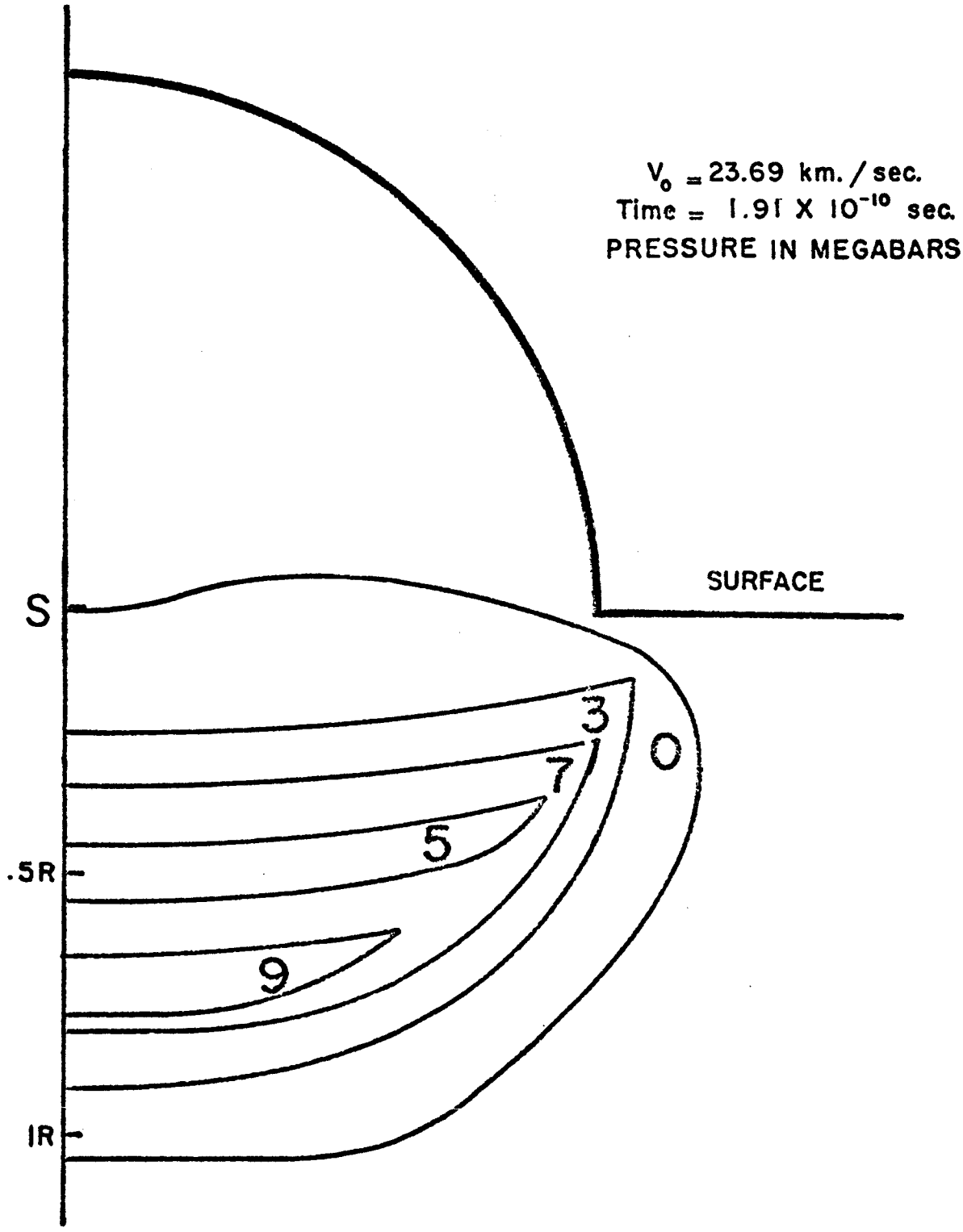

Figure 126. Pressure Map (t = 1.91 x 10^{-10} sec) III

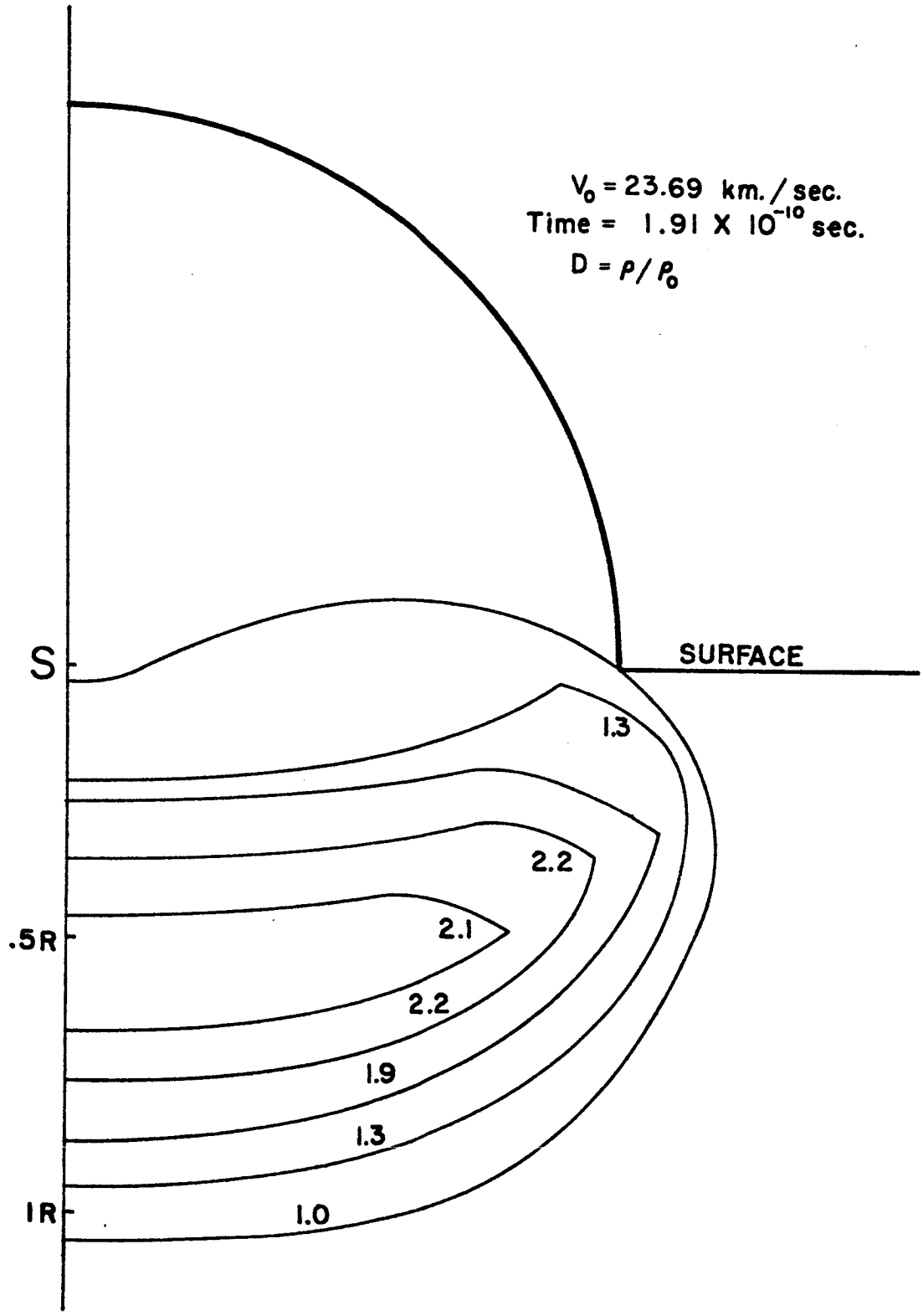

Figure 127. Density Map ($t = 1.91 \times 10^{-10}$ sec) III

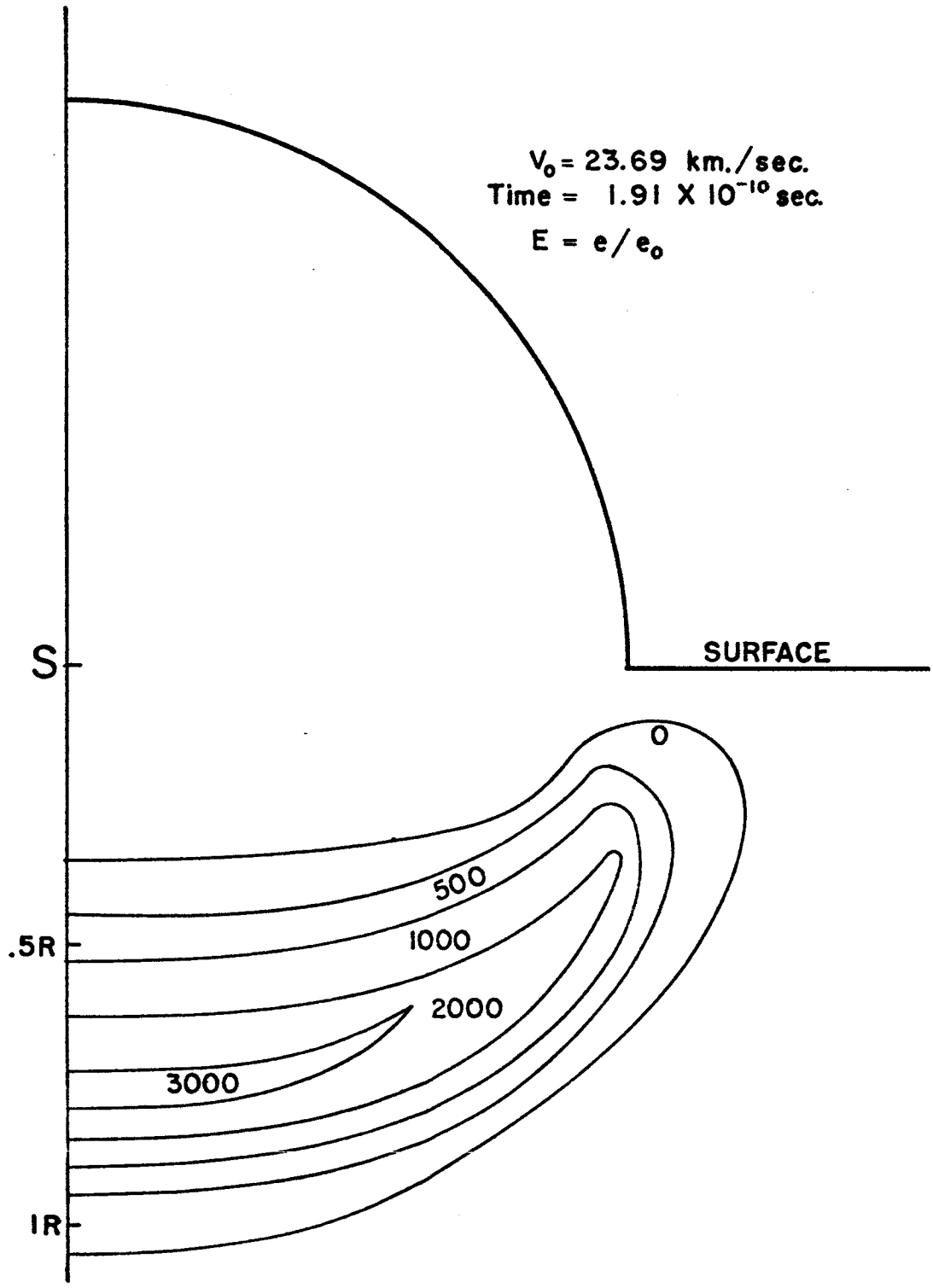

Figure 128. Energy Map (t = 1.91 x 10^{-10} sec) III

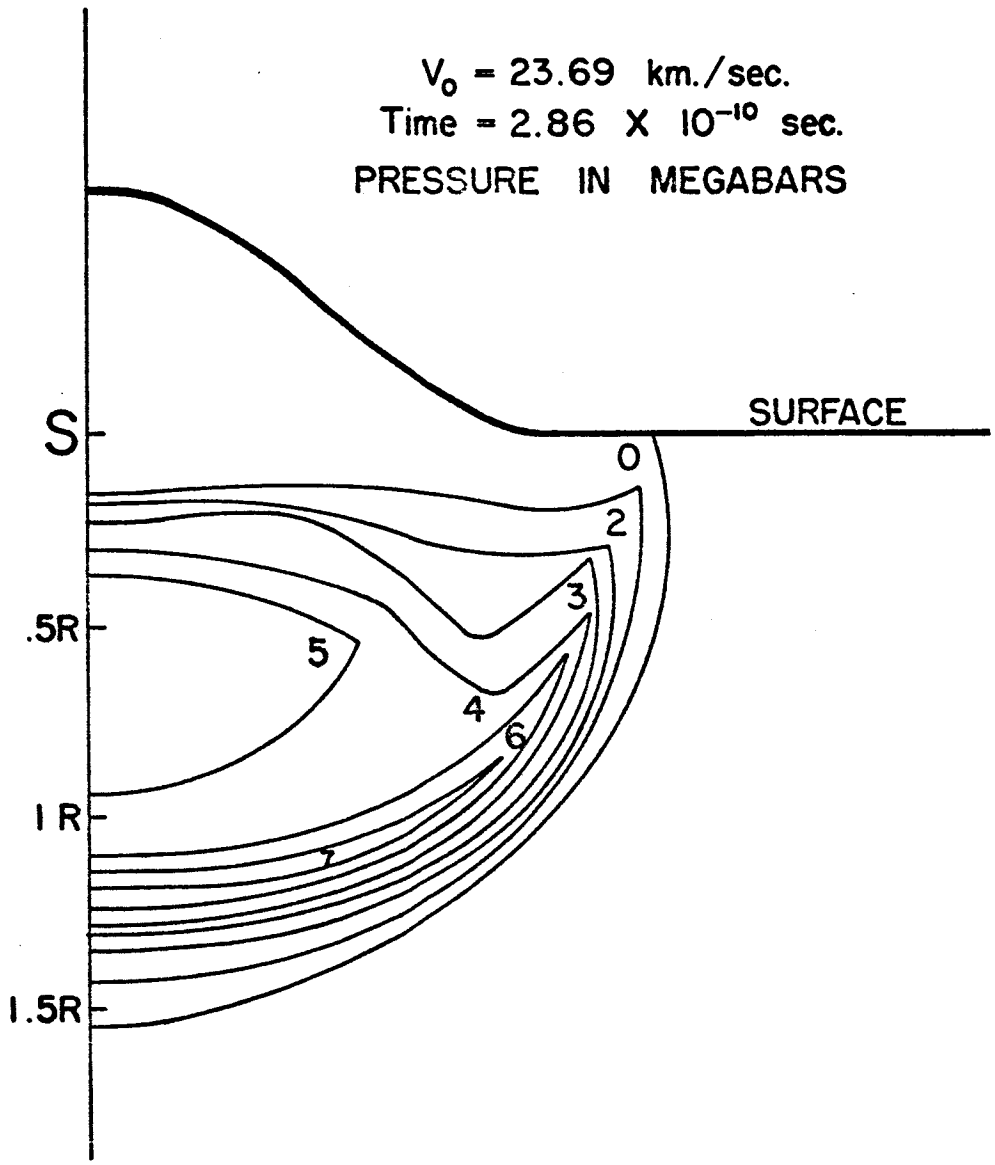

Figure 129. Pressure Map (t = 2.86 x 10^{-10} sec) III

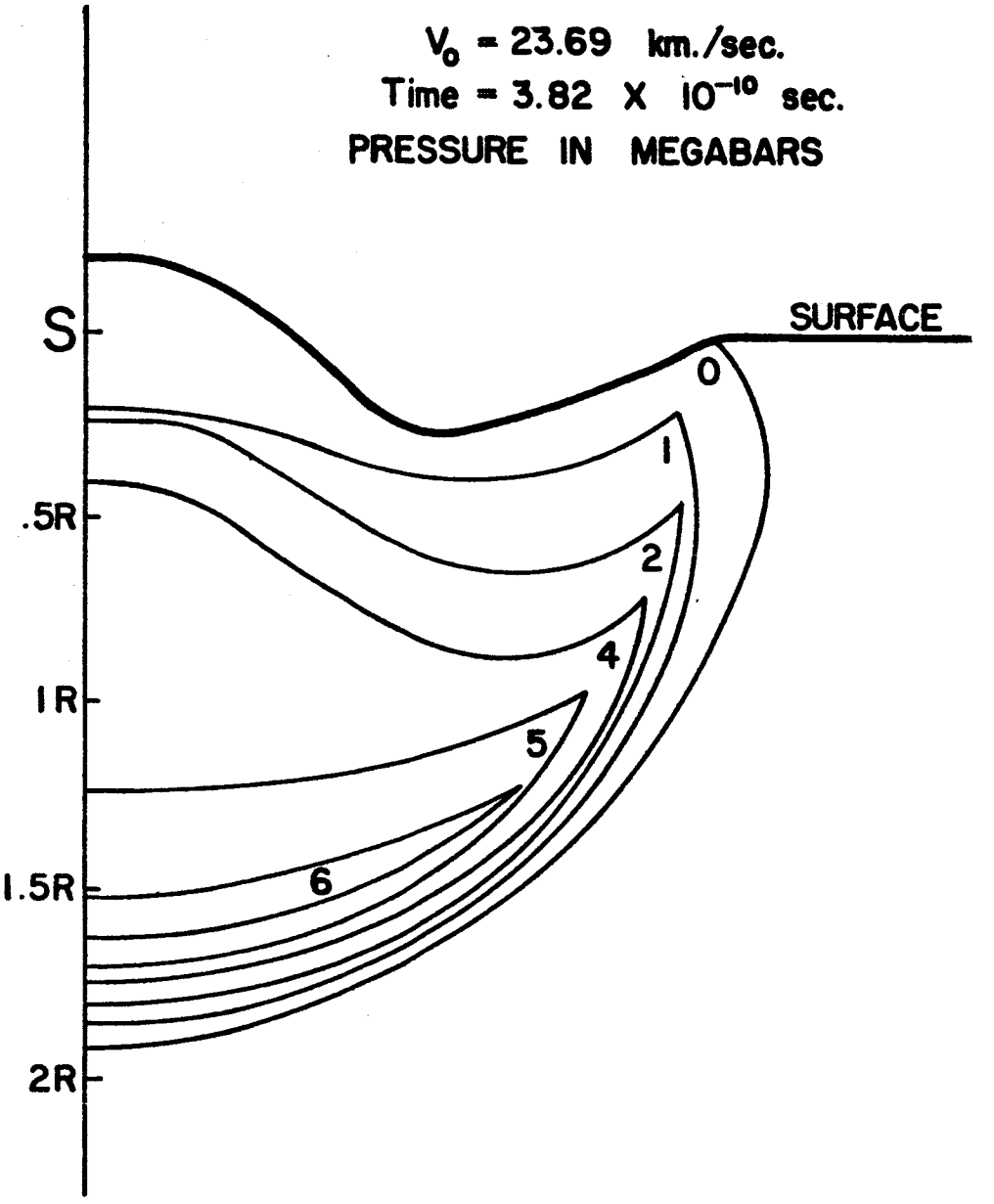

Figure 130. Pressure Map (t = 3.82 x 10^{-10} sec) III

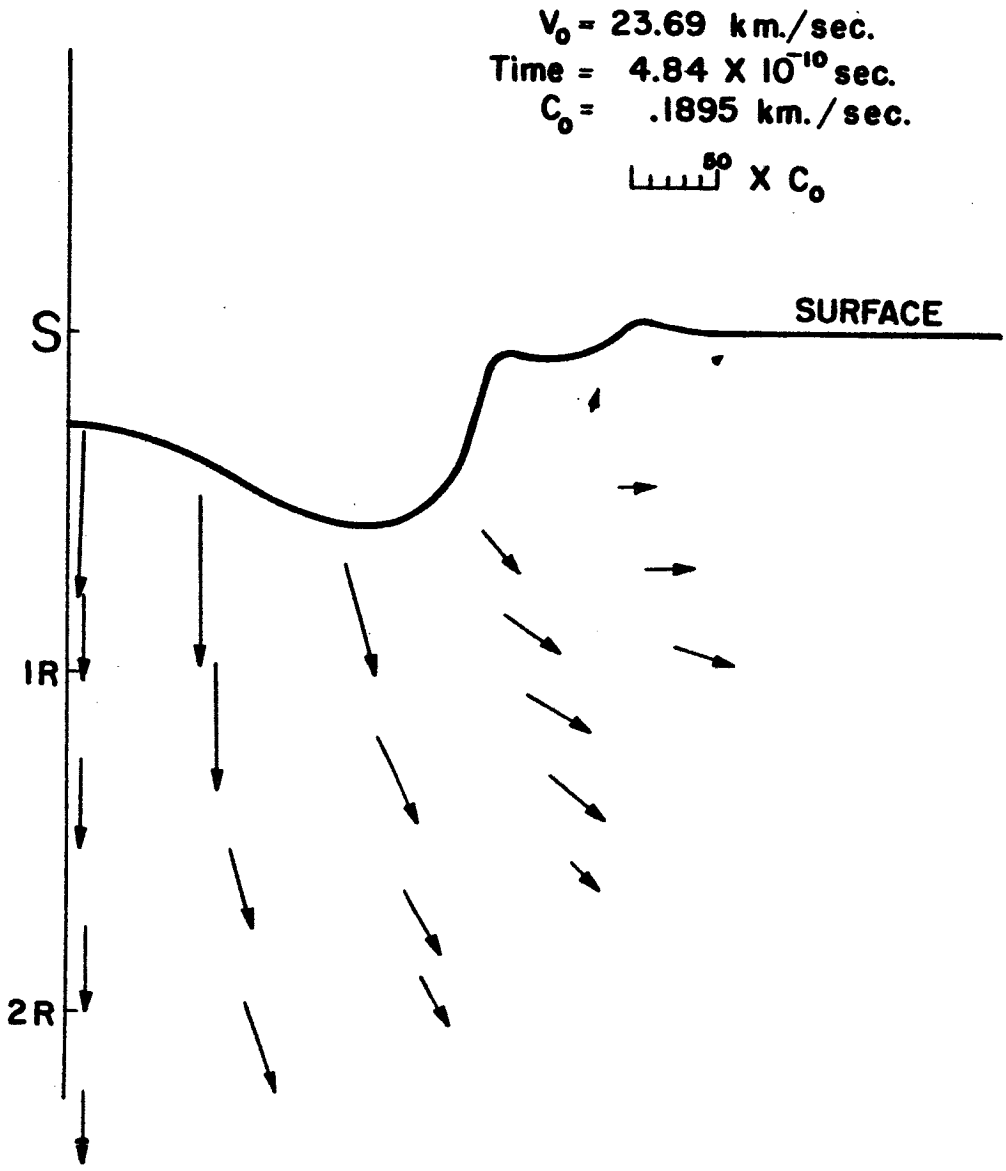

Figure 131. Velocity Map (t = 4.84 x 10^{-10} sec) III

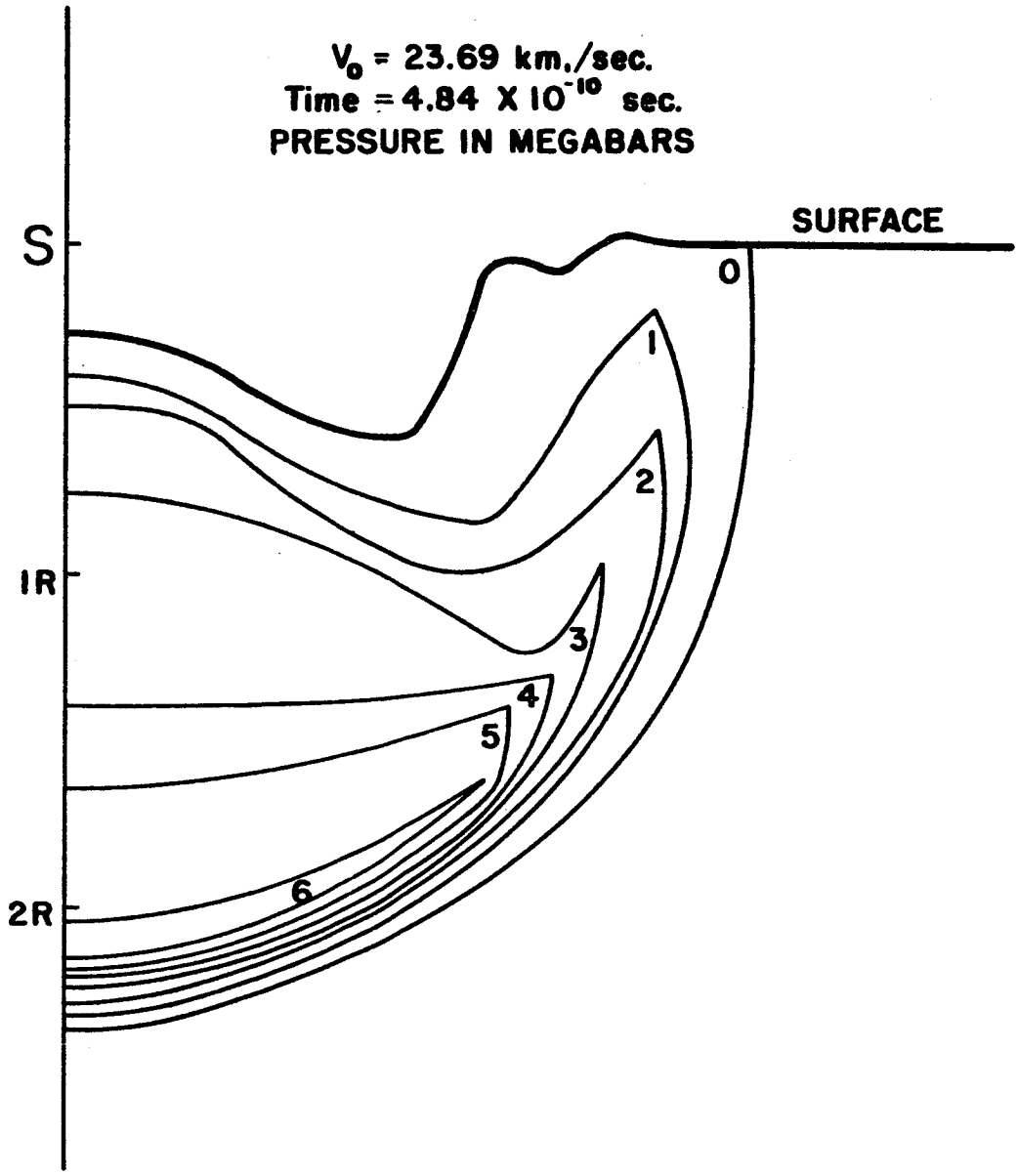

Figure 132. Pressure Map (t = 4.84 x 10^{-10} sec) III

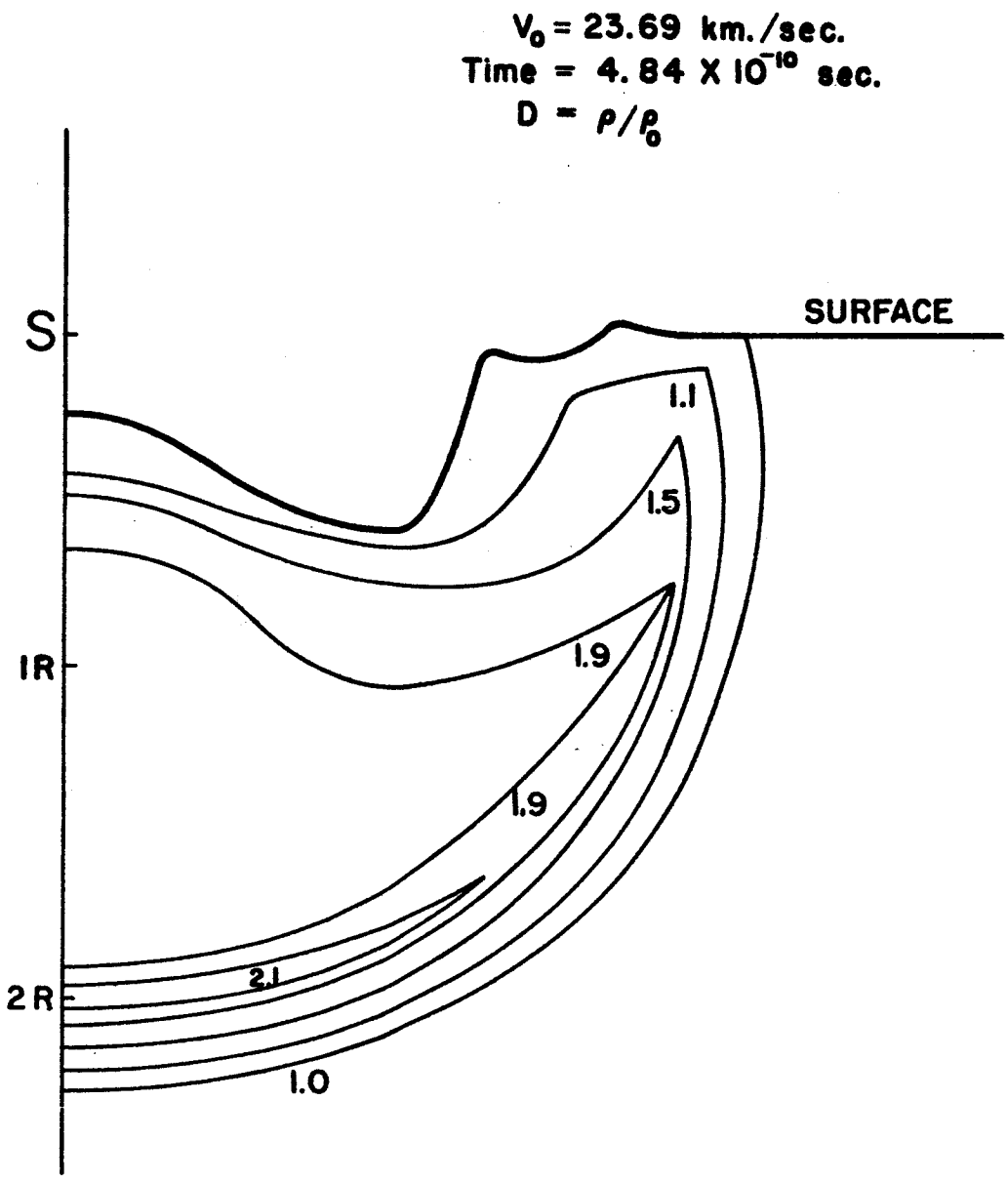

Figure 133. Density Map (t = 4.84 x 10^{-10} sec) III

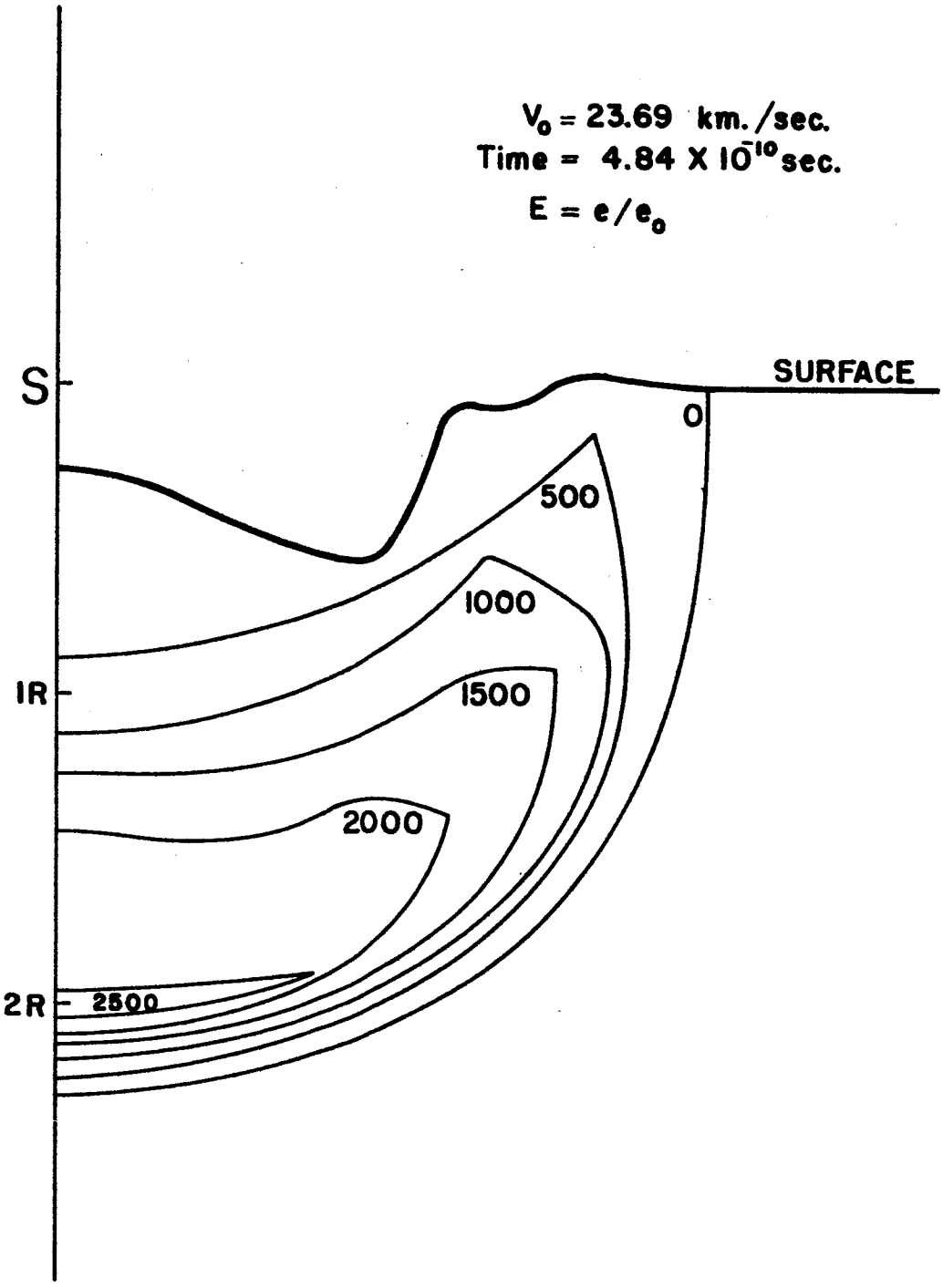

Figure 134. Energy Map (t = 4.84 x 10^{-10} sec) III

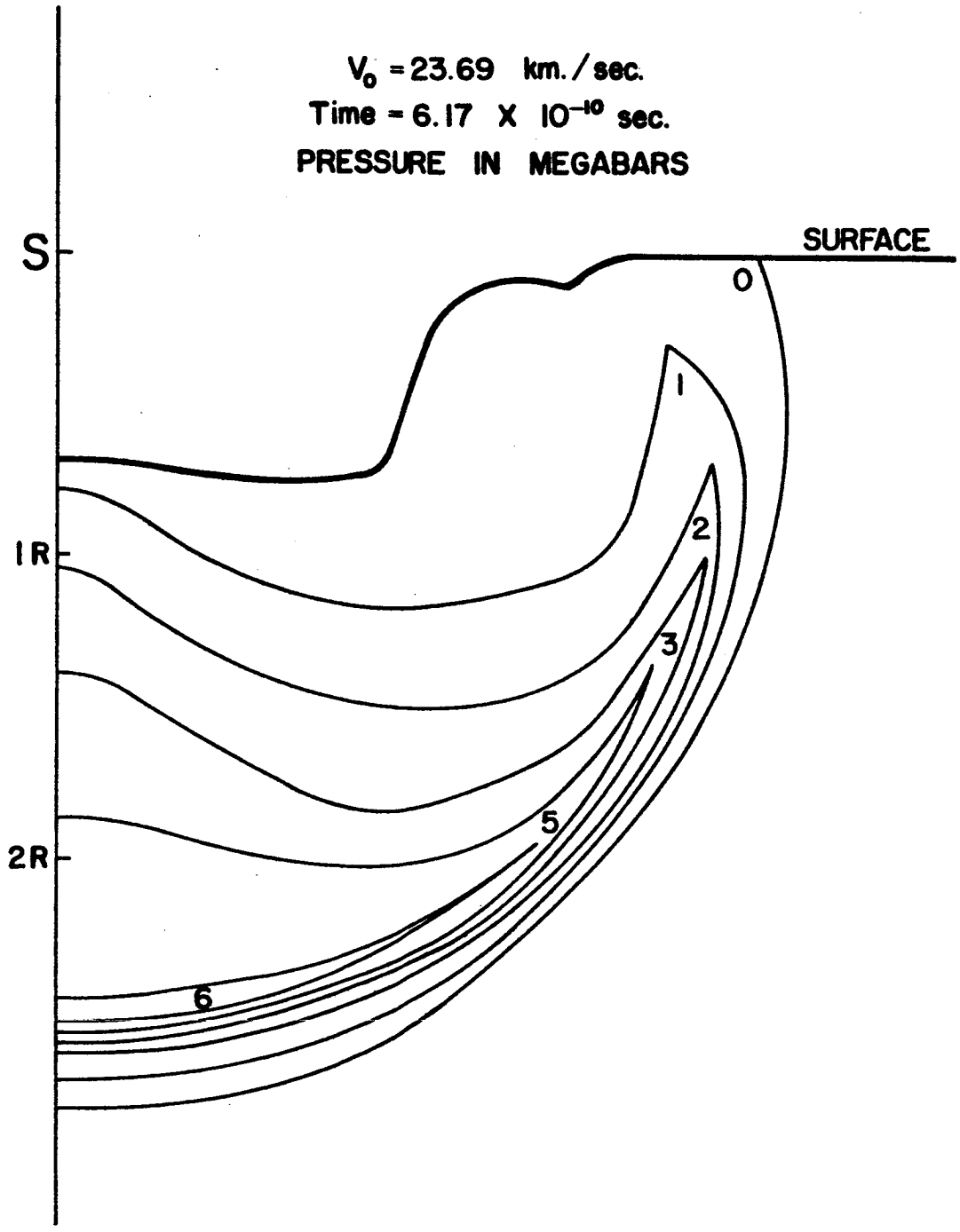

Figure 135. Pressure Map (t = 6.17 x 10^{-10} sec) III

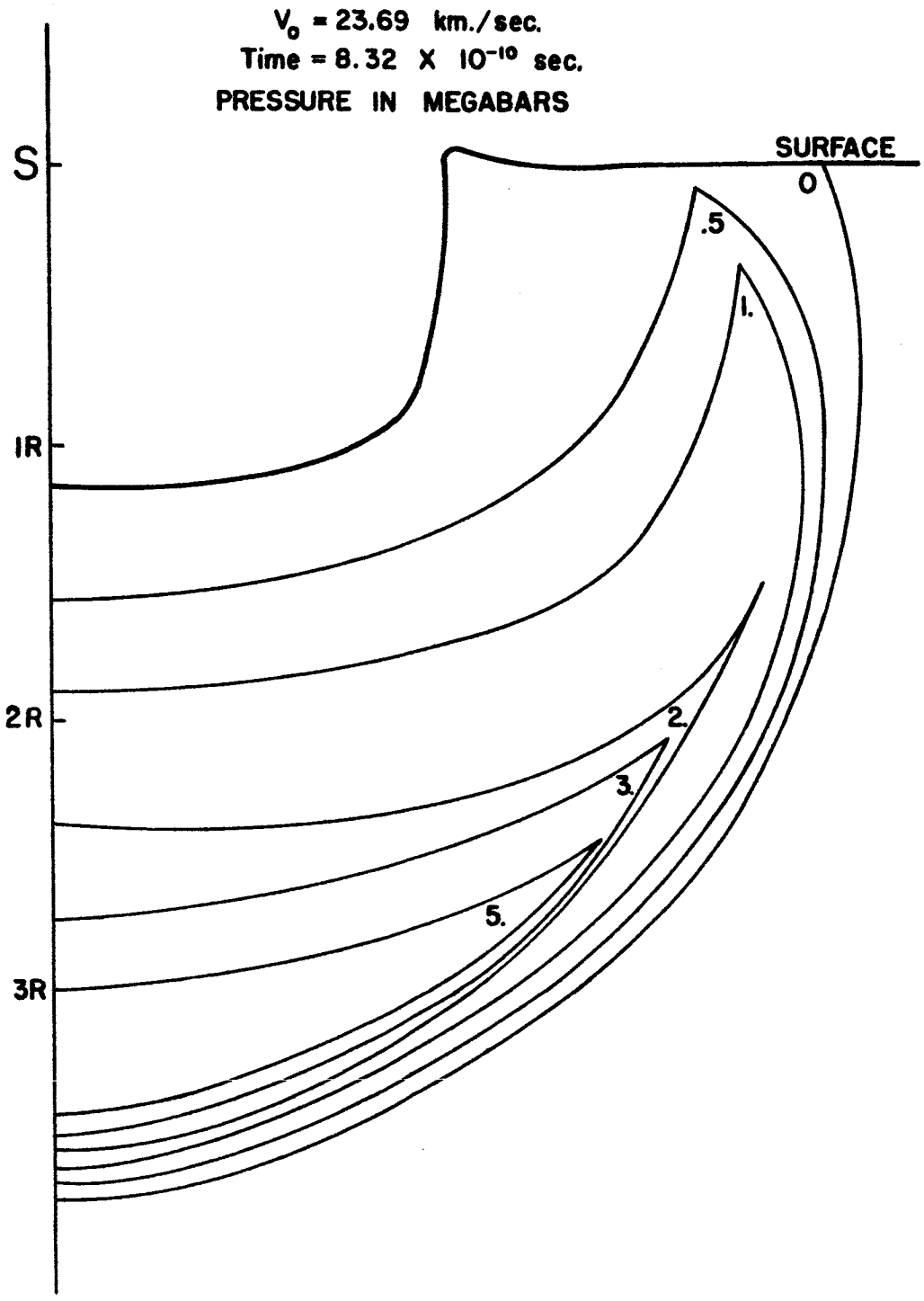

Figure 136. Pressure Map (t = 8.32 x 10^{-10} sec) III

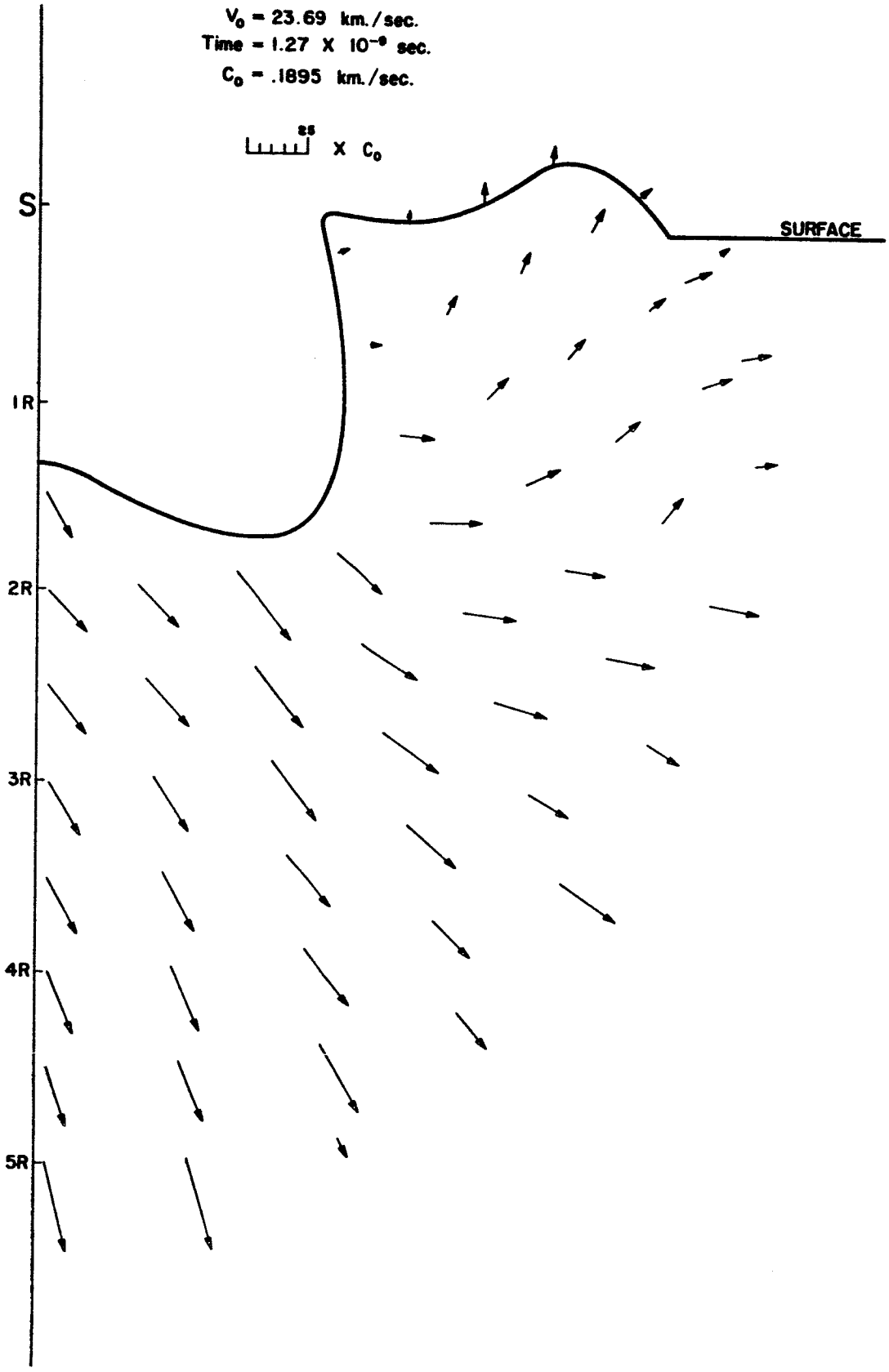

Figure 137. Velocity Map (t = 1.27 x 10^{-9} sec) III

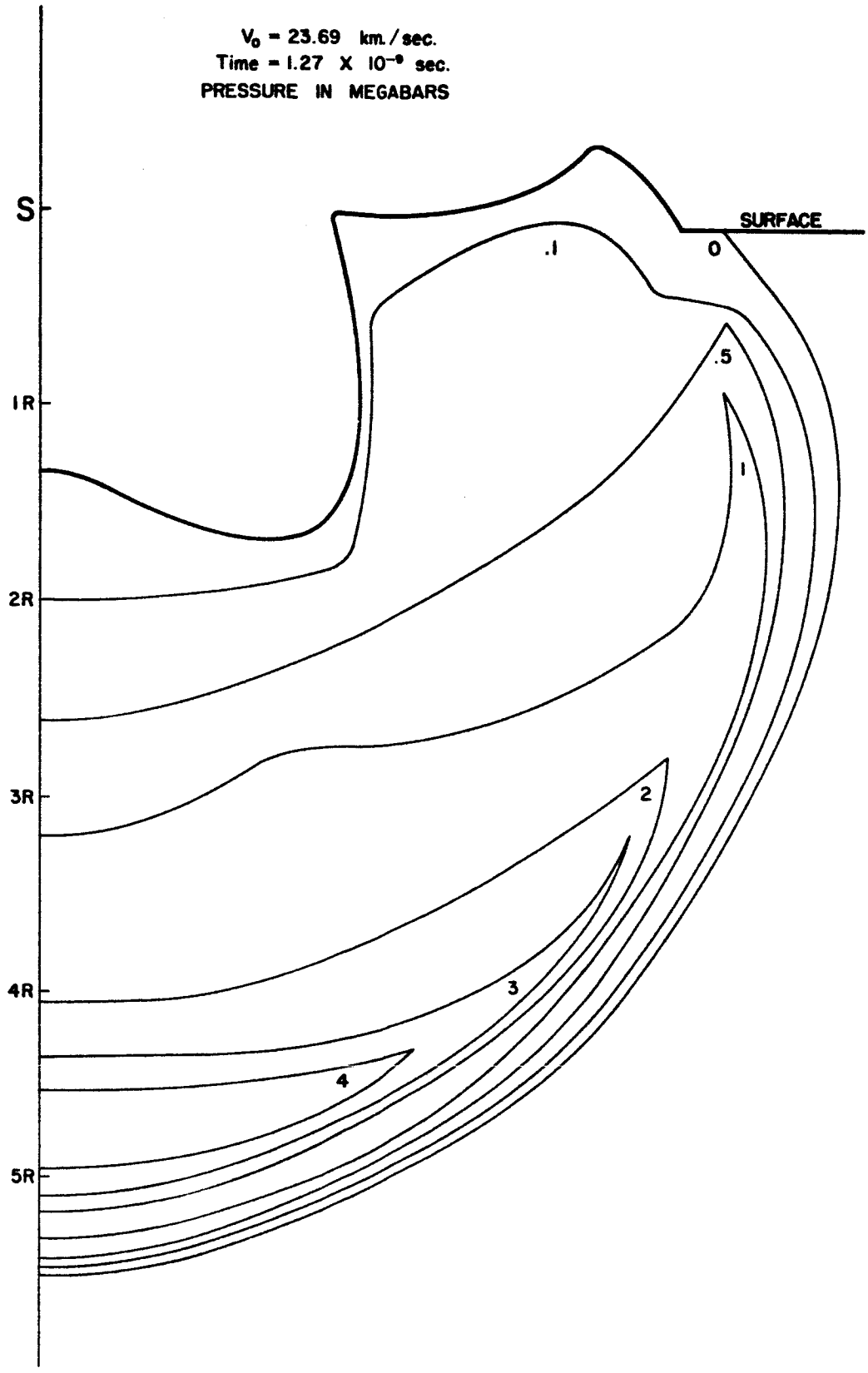

Figure 138. Pressure Map (t = 1.27 x 10^{-9} sec) III

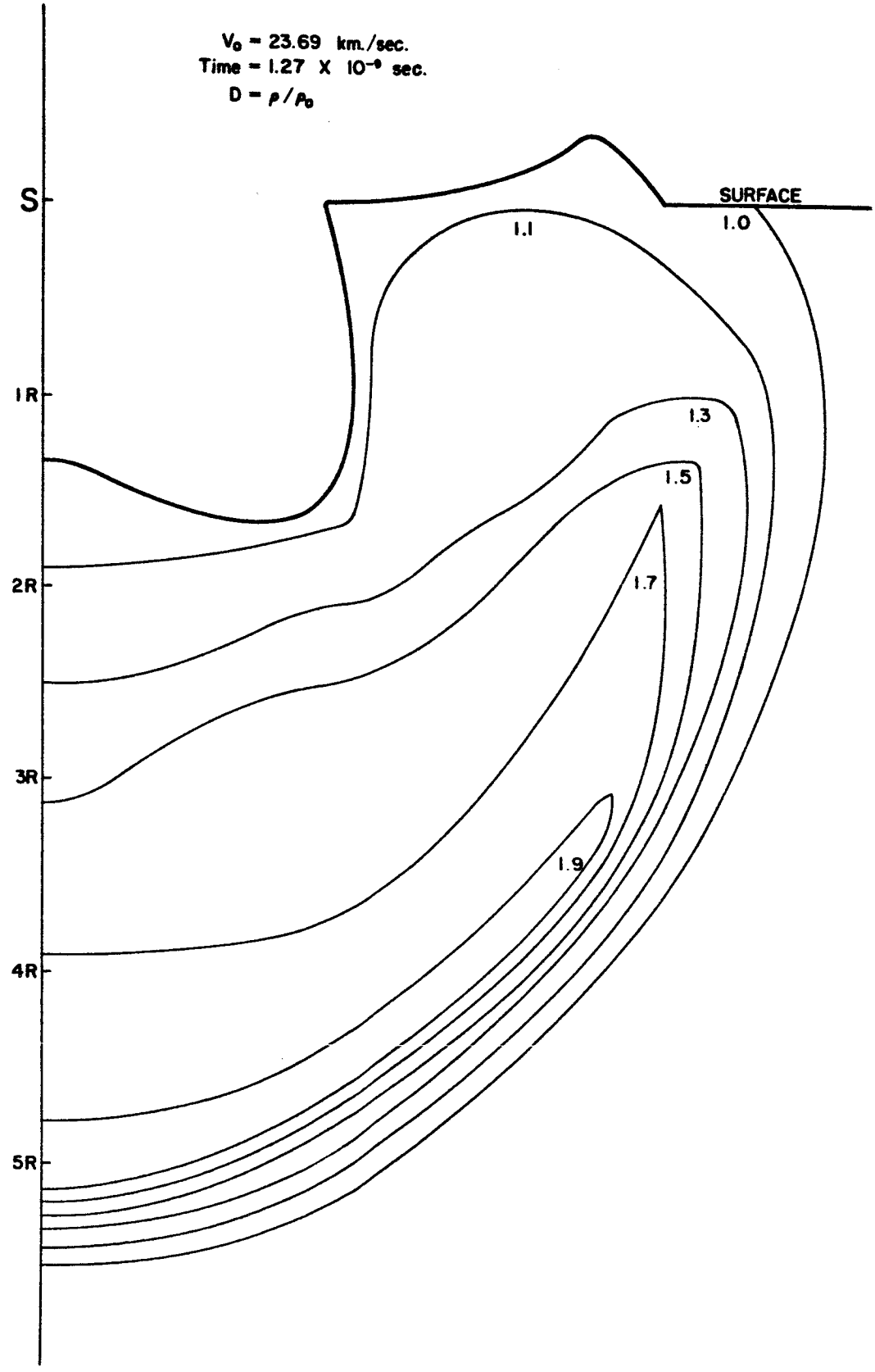

Figure 139. Density Map (t = 1.27 x 10^{-9} sec) III

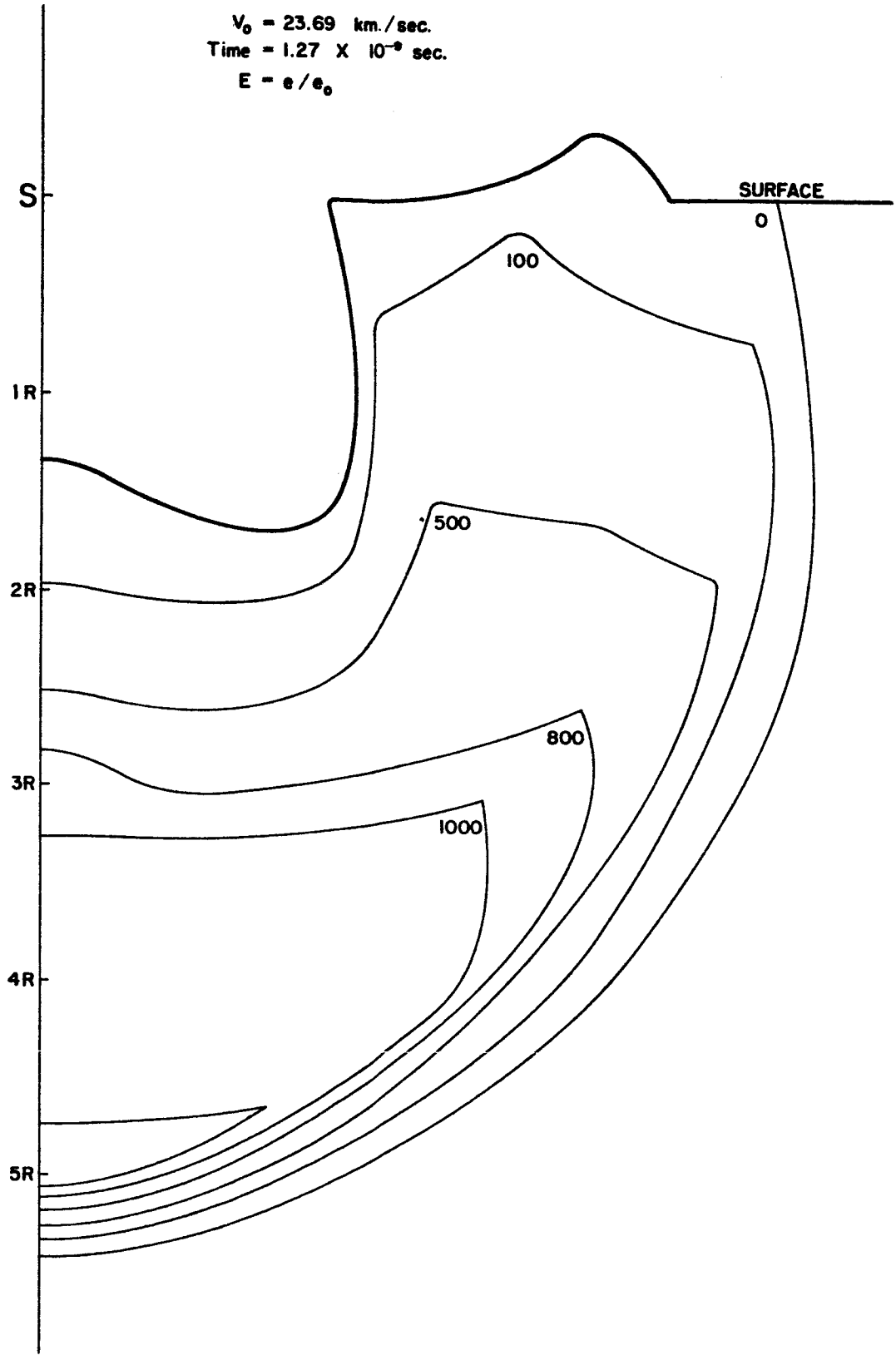

Figure 140. Energy Map (t = 1.27 x 10^{-9} sec) III

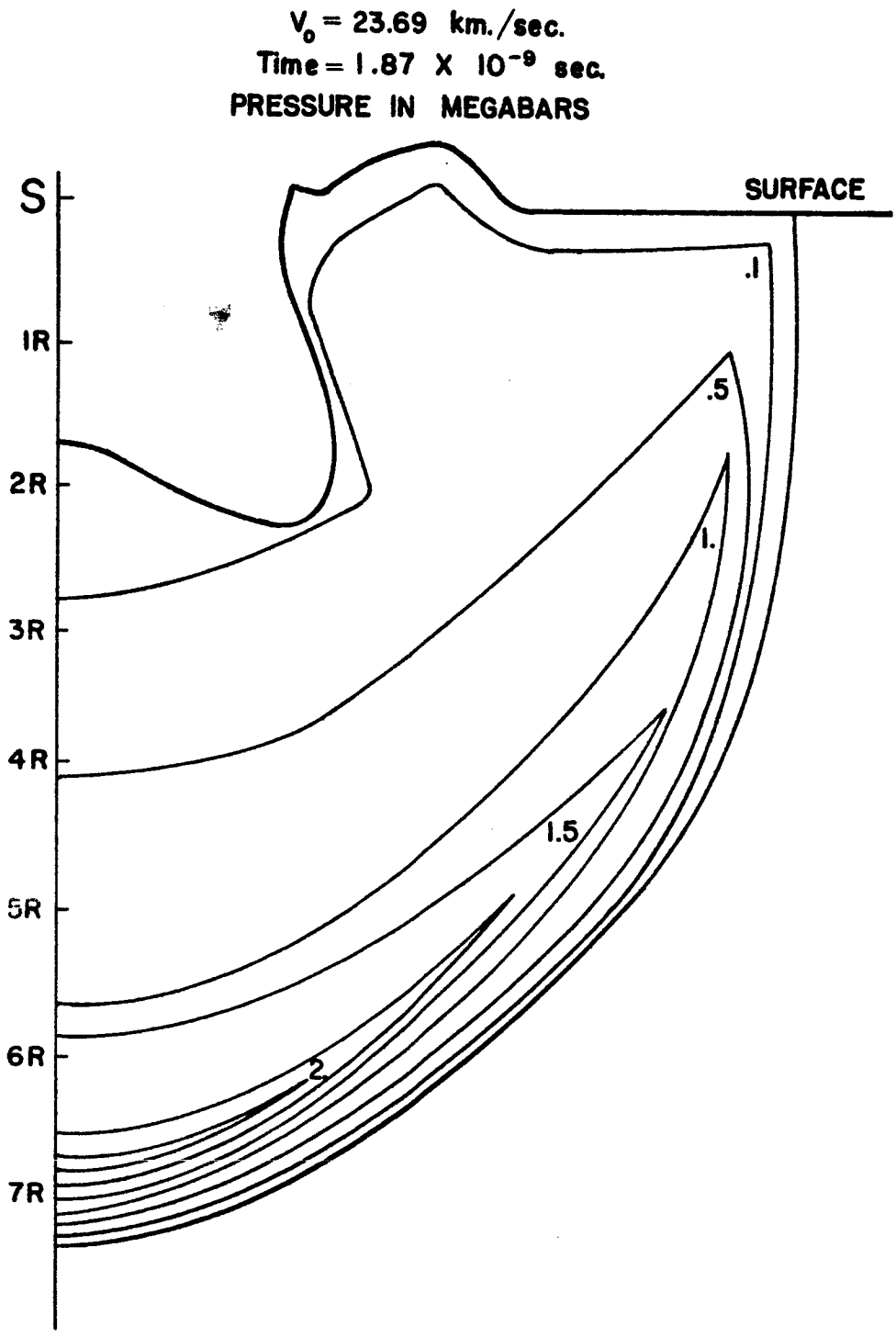

Figure 141. Pressure Map (t = 1.87 x 10^{-9} sec) III

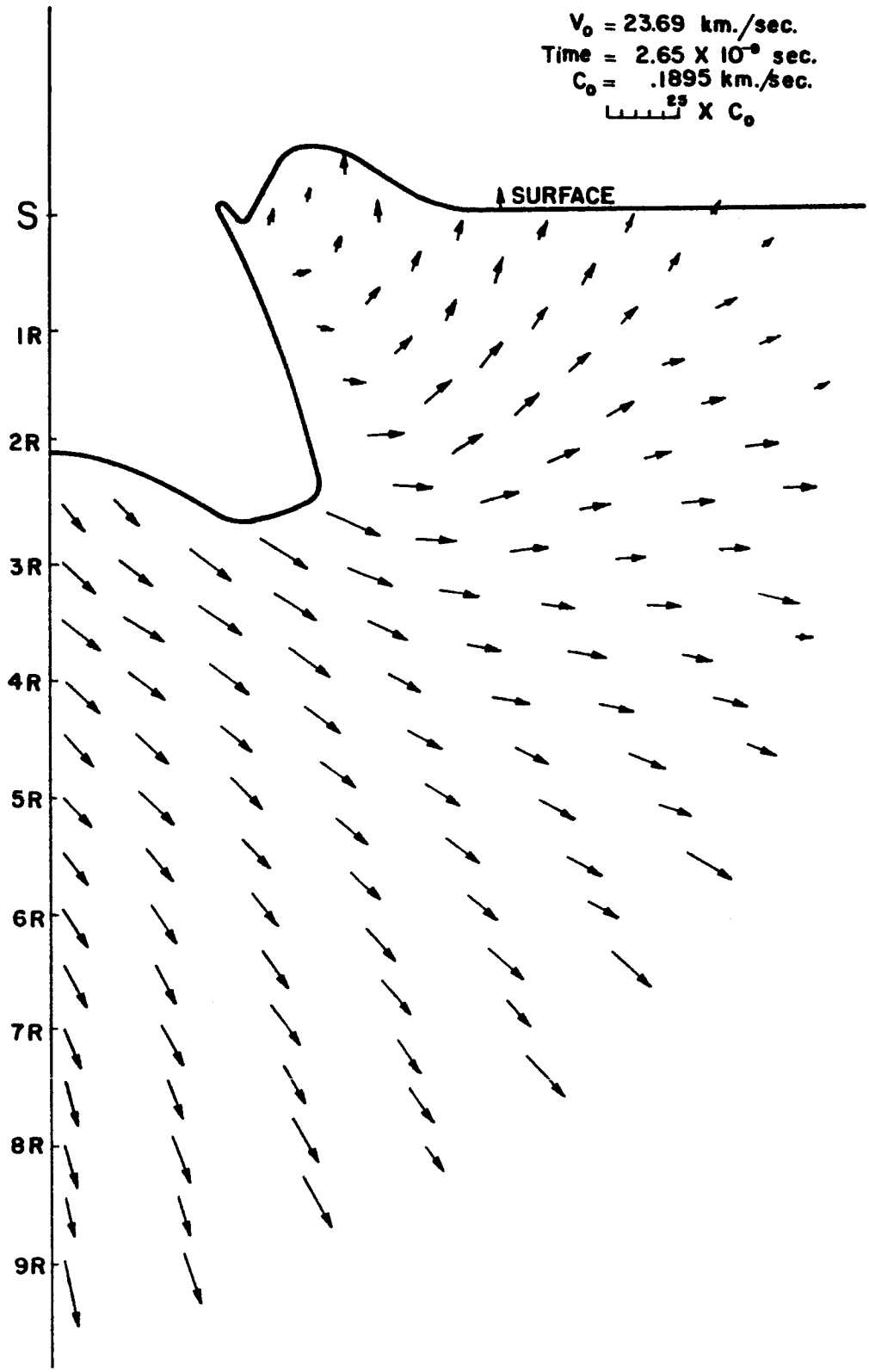

Figure 142. Velocity Map (t = 2.65 x 10^{-9} sec) III

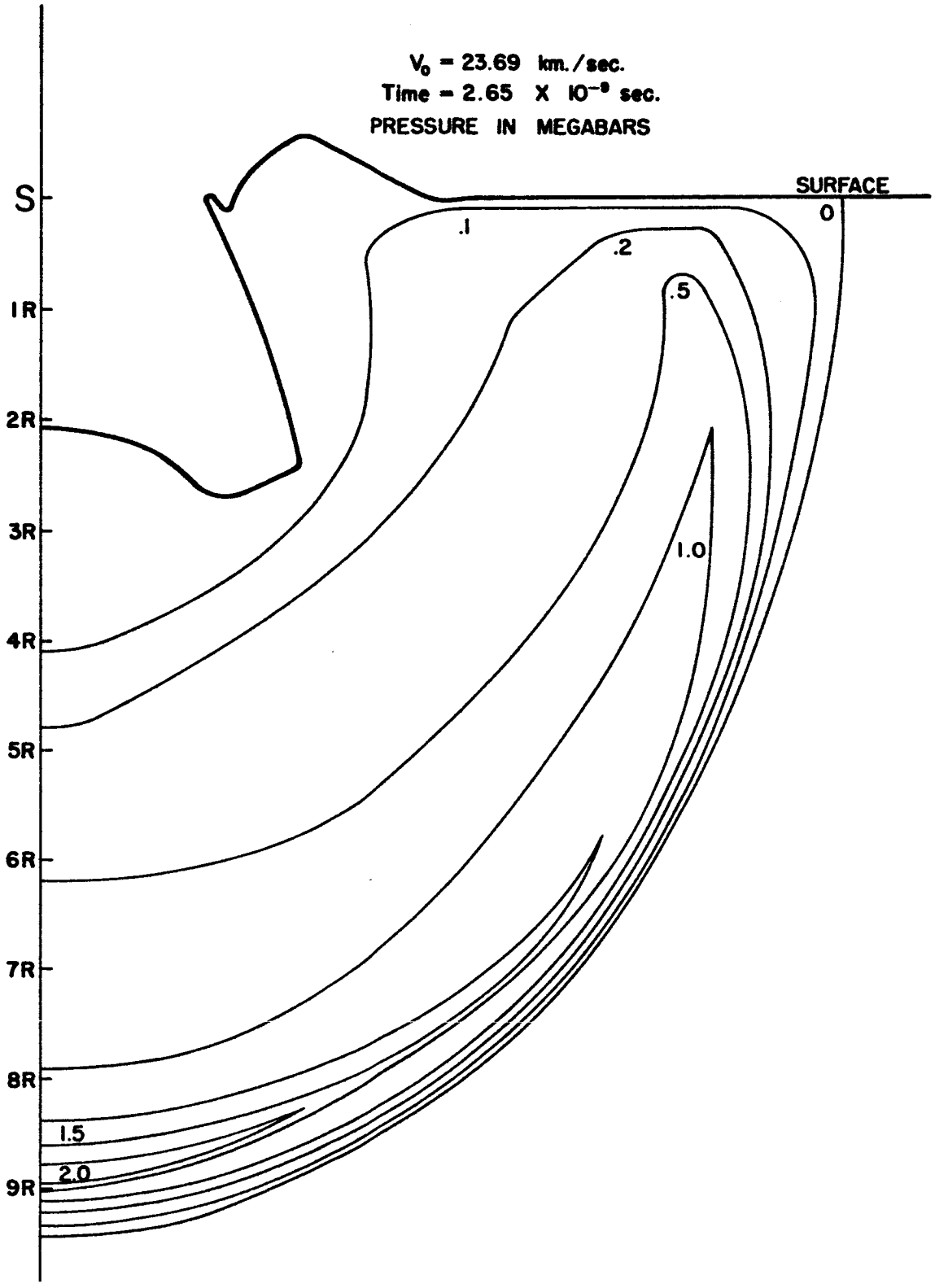

Figure 143. Pressure Map (t = 2.65 x 10^{-9} sec) III

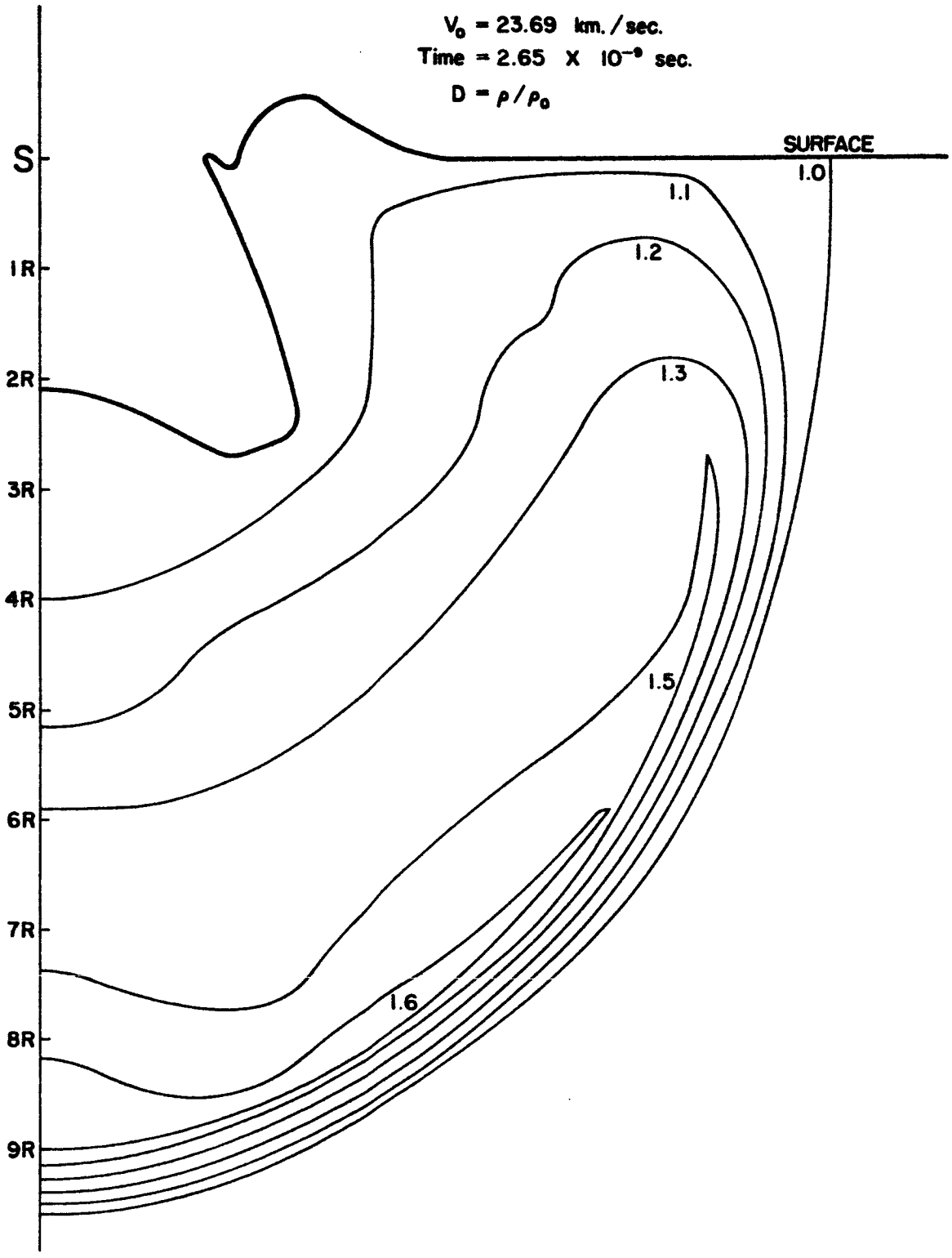

Figure 144. Density Map (t = 2.65 x 10^{-9} sec) III

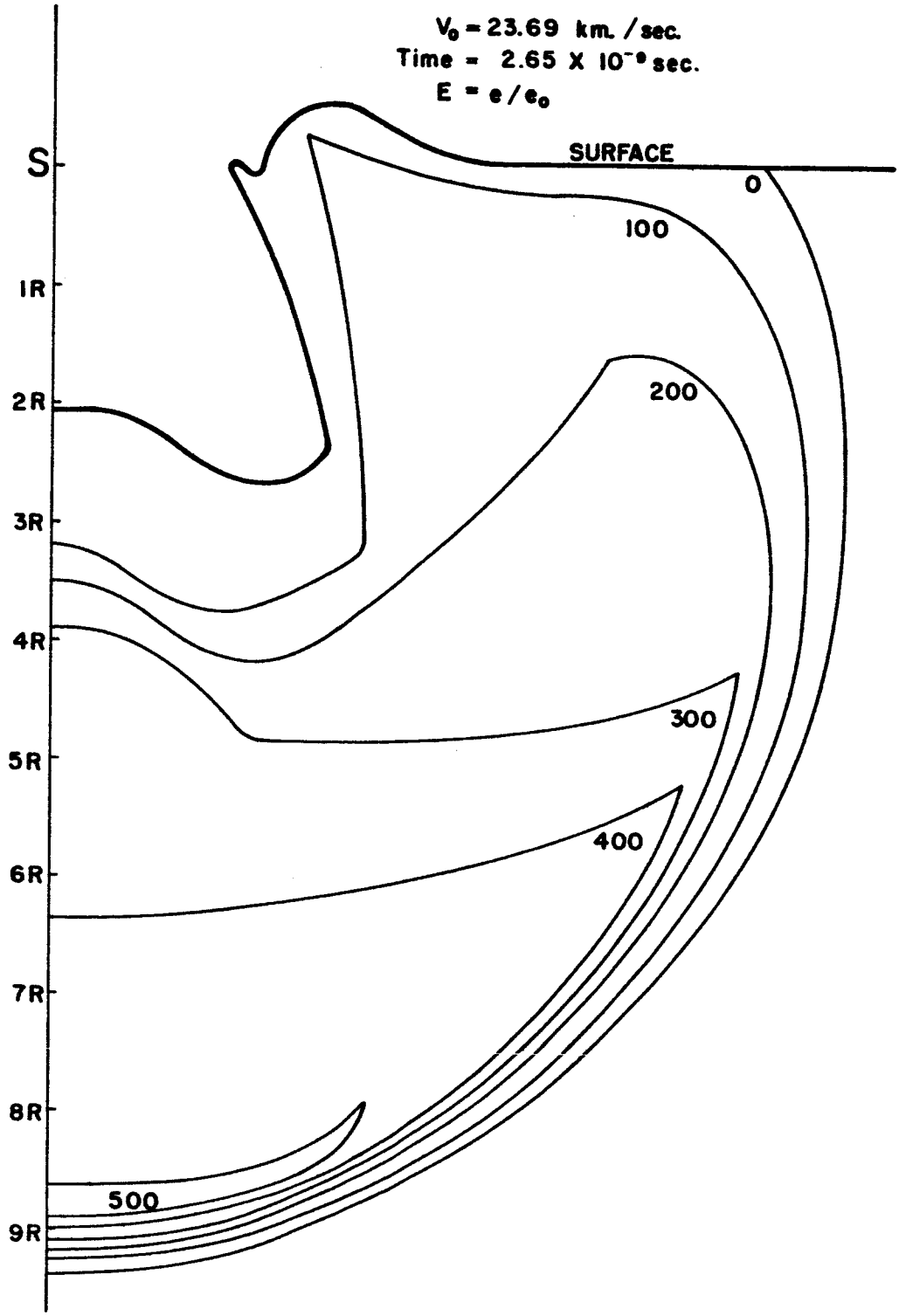

Figure 145. Energy Map (t = 2.65 x 10^{-9} sec) III

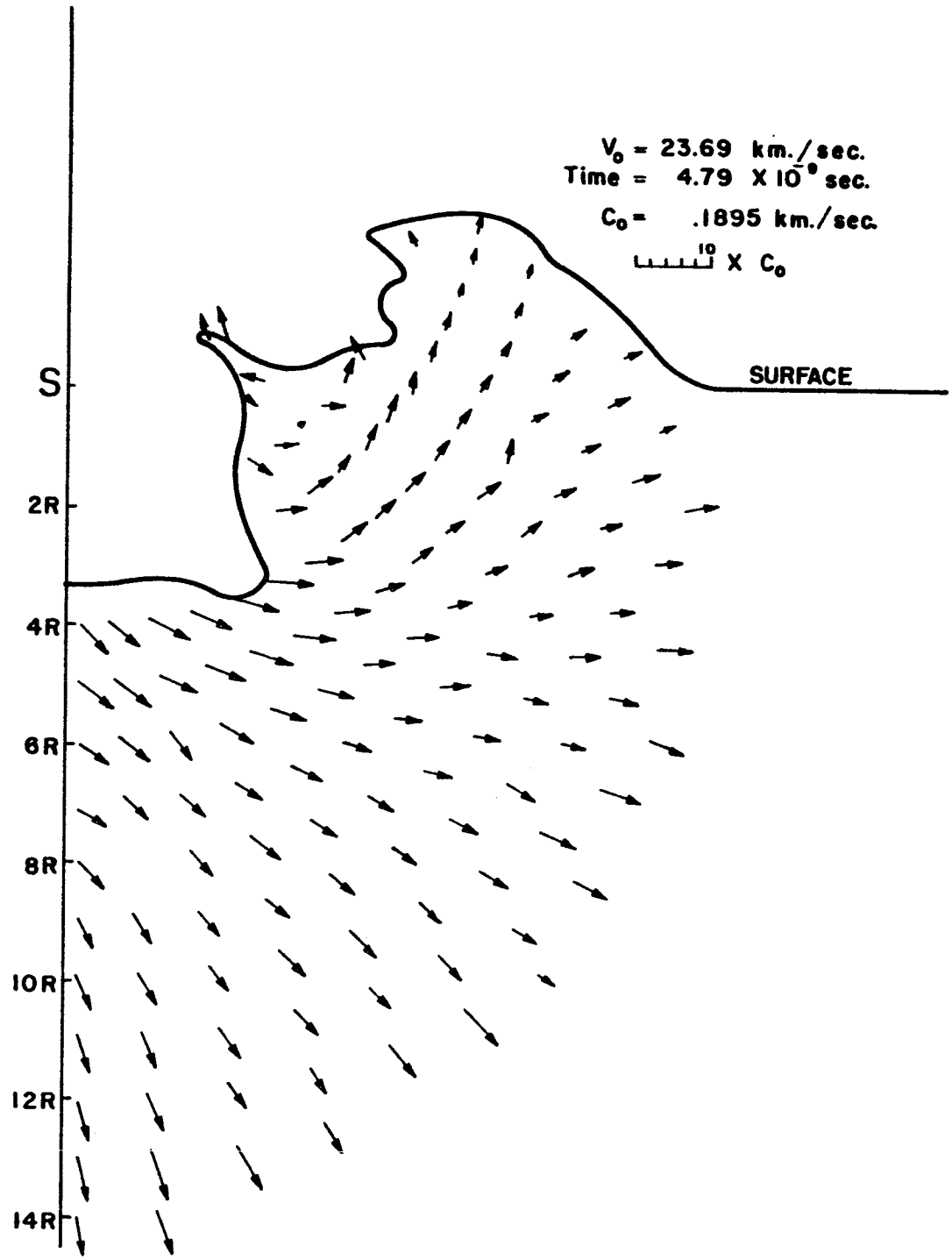

Figure 146. Velocity Map (t = 4.79 x 10^{-9} sec) III

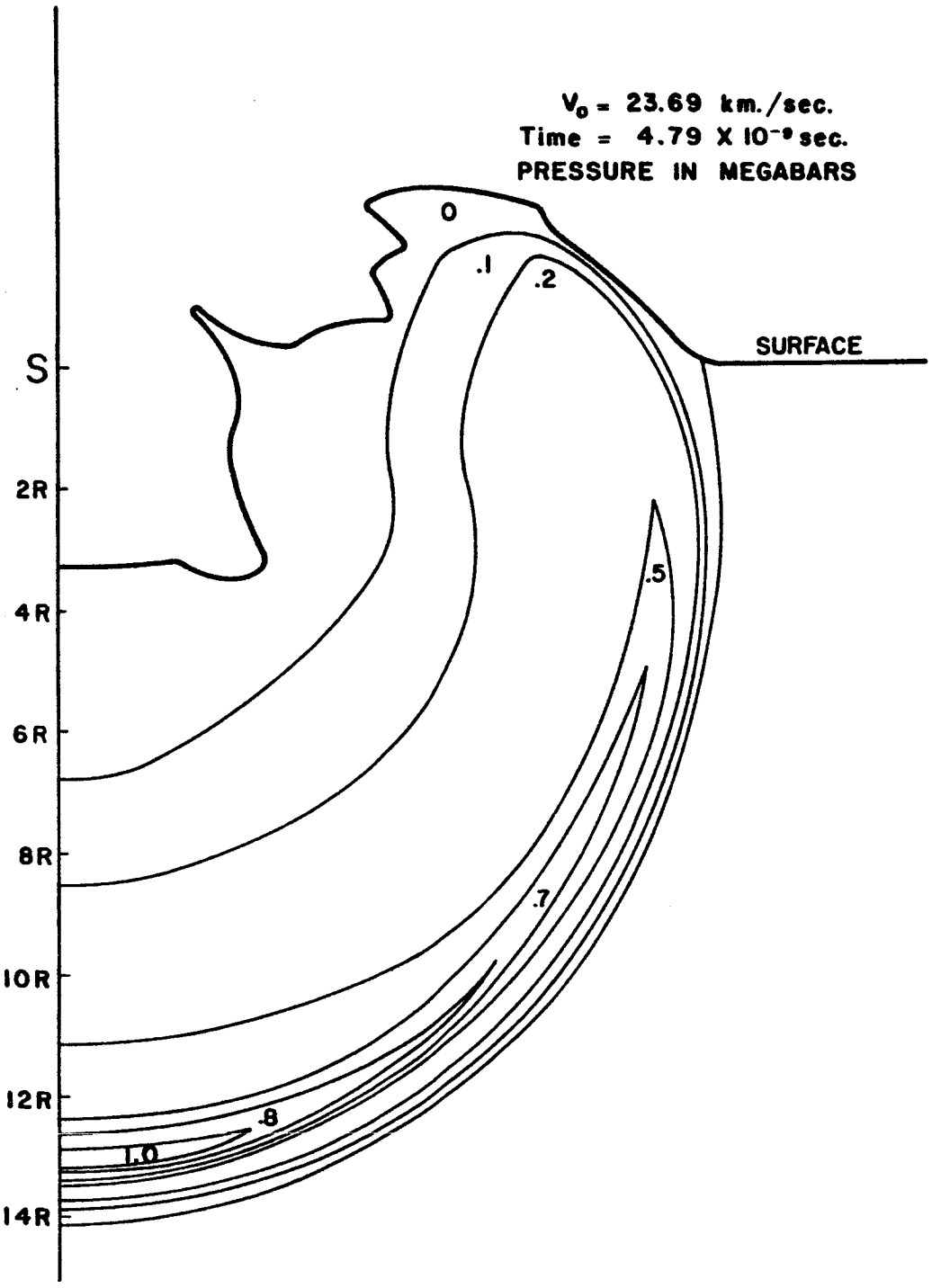

Figure 147. Pressure Map (t = 4.79 x 10^{-9} sec) III

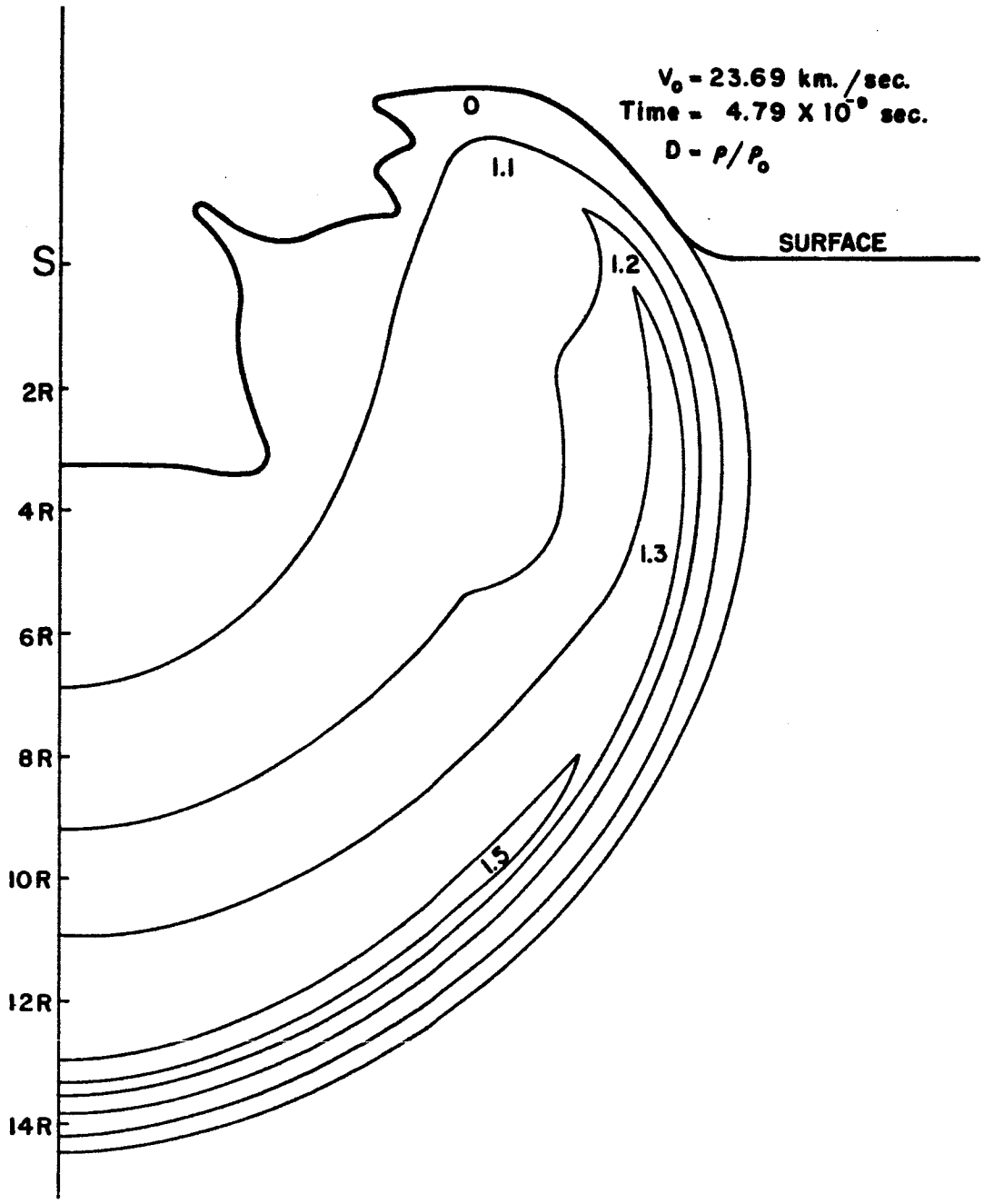

Figure 148. Density Map (t = 4.79 x 10^{-9} sec) III

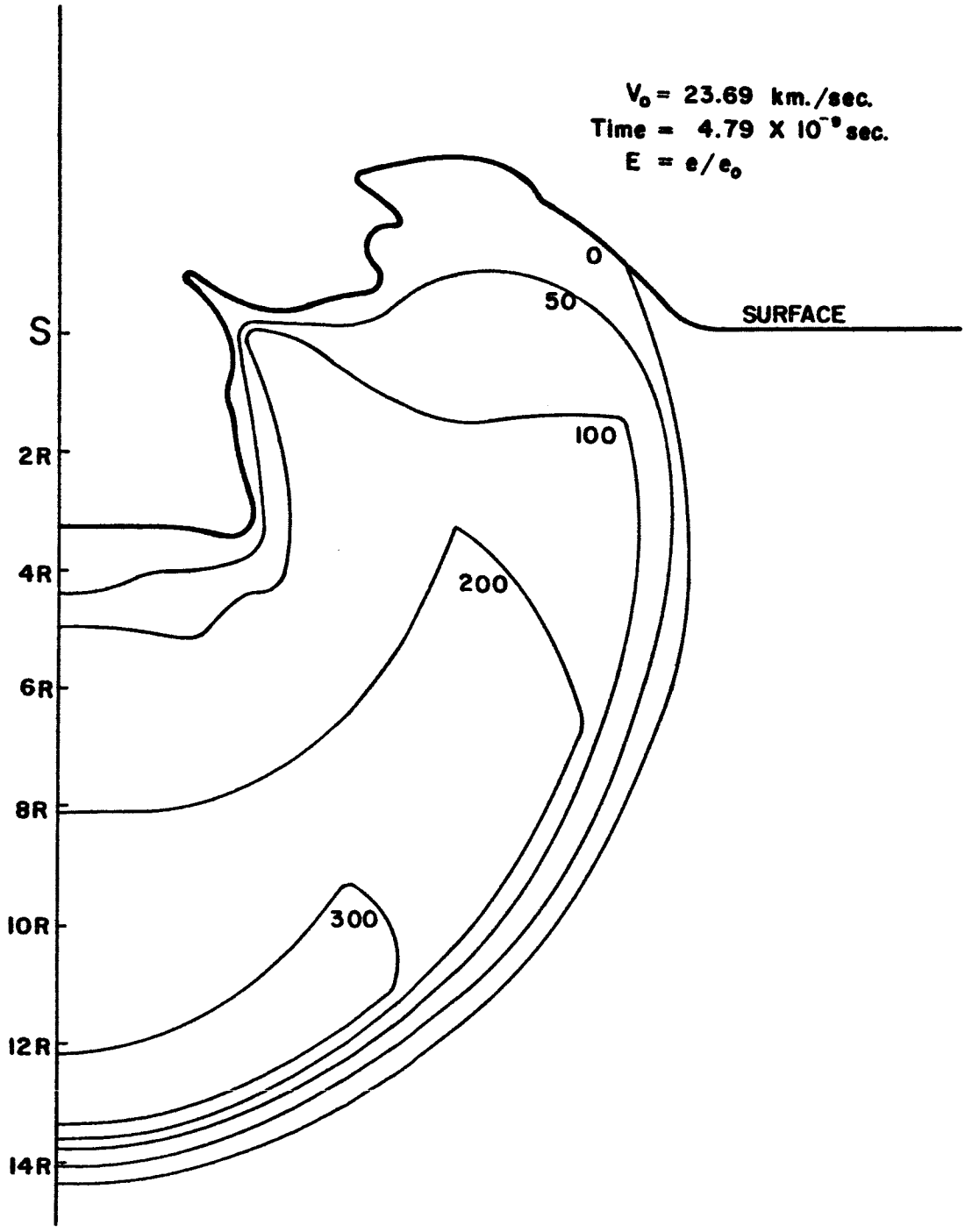

Figure 149. Energy Map (t = 4.79 x 10^{-9} sec) III

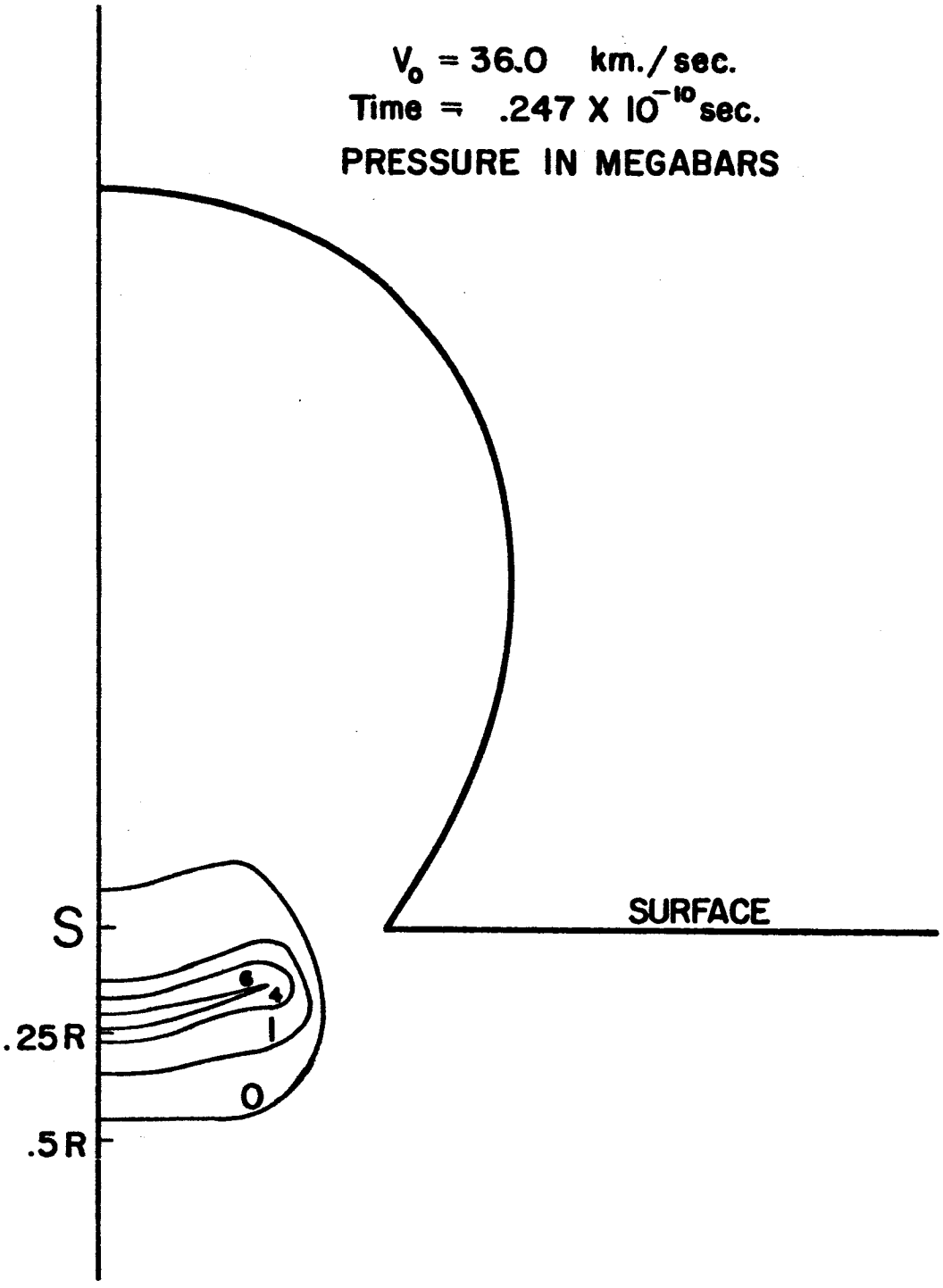

Figure 150. Pressure Map (t = .247 x 10^{-10} sec) IV

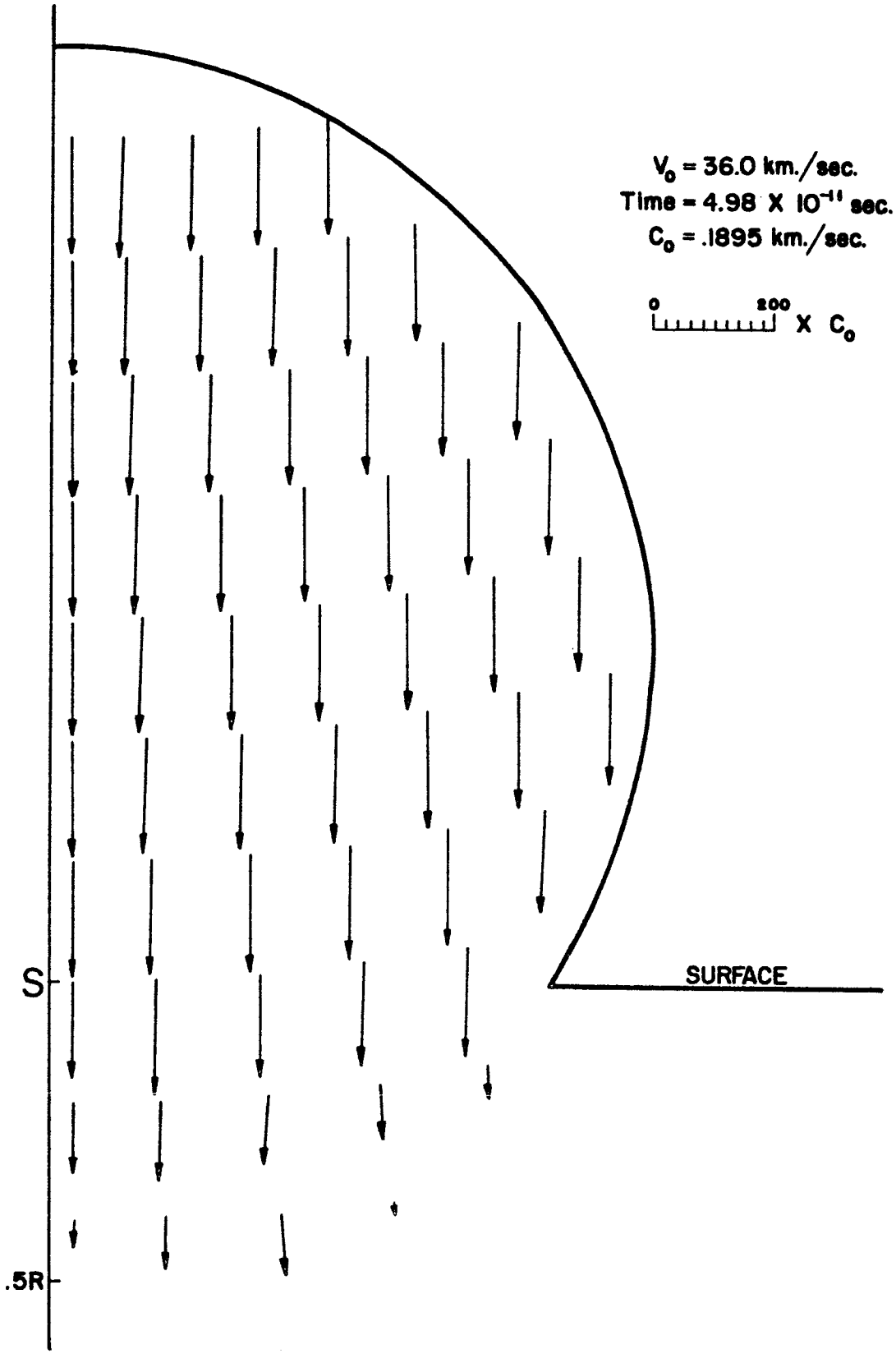

Figure 151. Velocity Map (t = 4.98 x 10^{-11} sec) IV

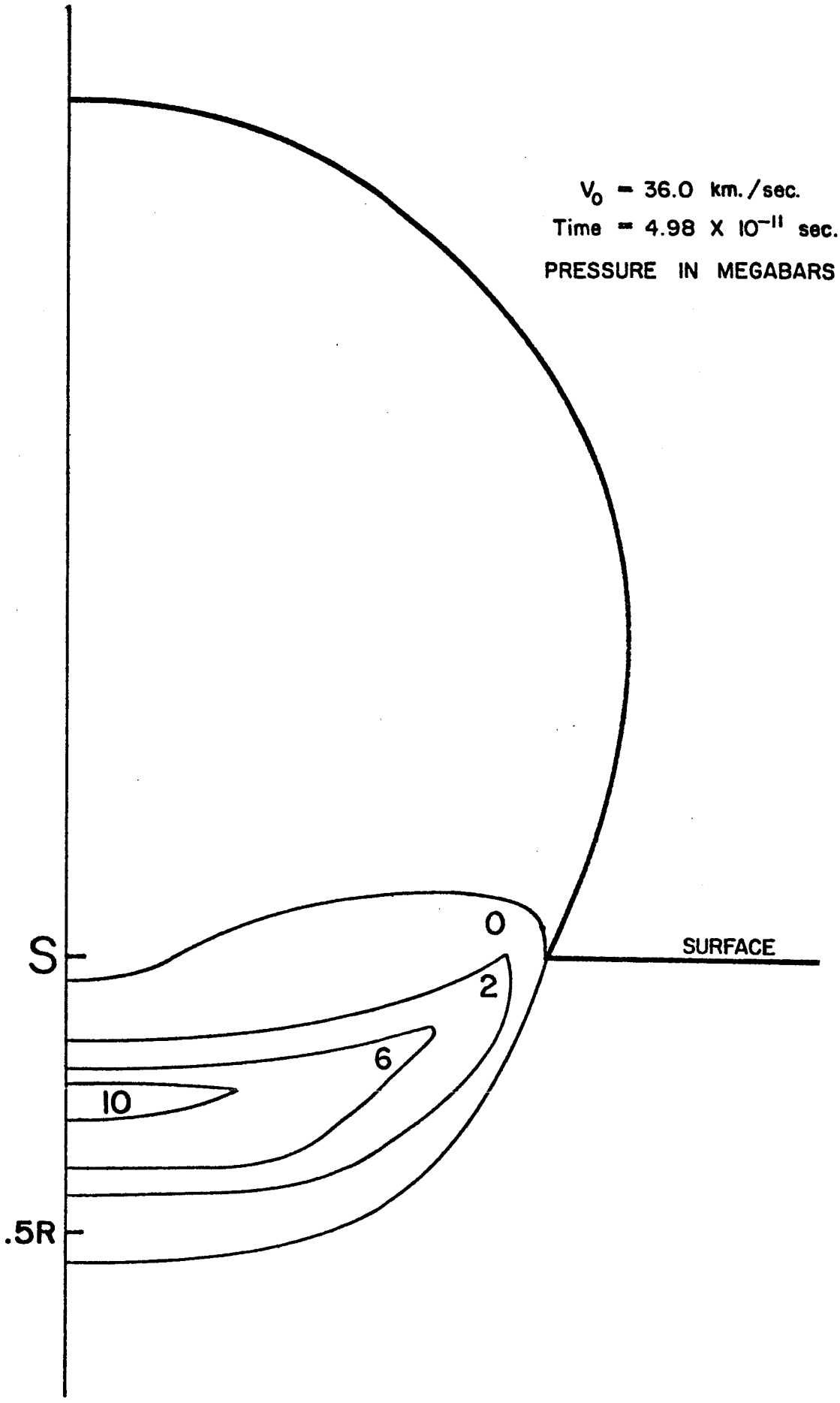

Figure 152. Pressure Map (t = 4.98 x 10^{-11} sec) IV

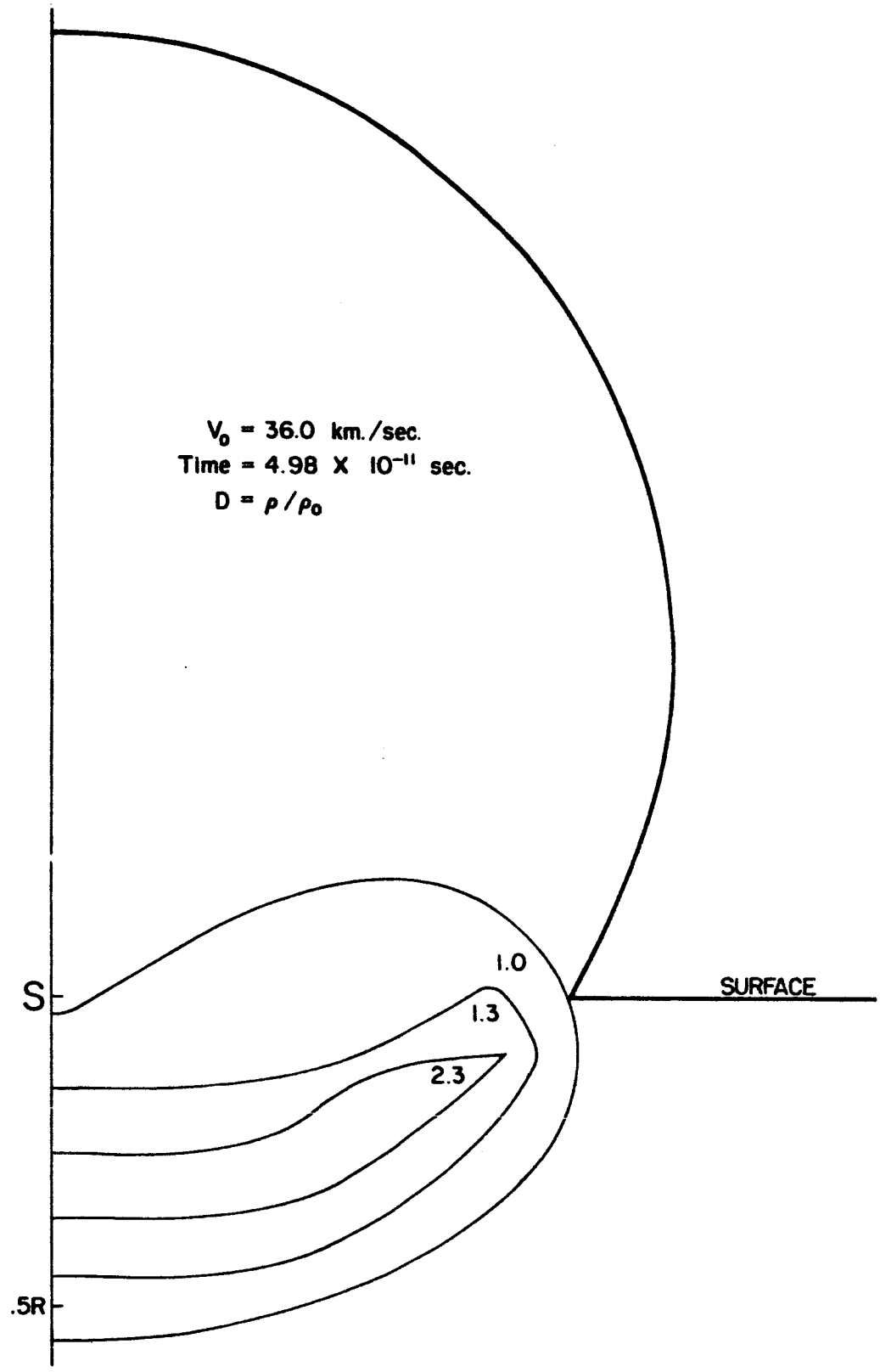

Figure 153. Density Map (t = 4.98 x 10^{-11} sec) IV

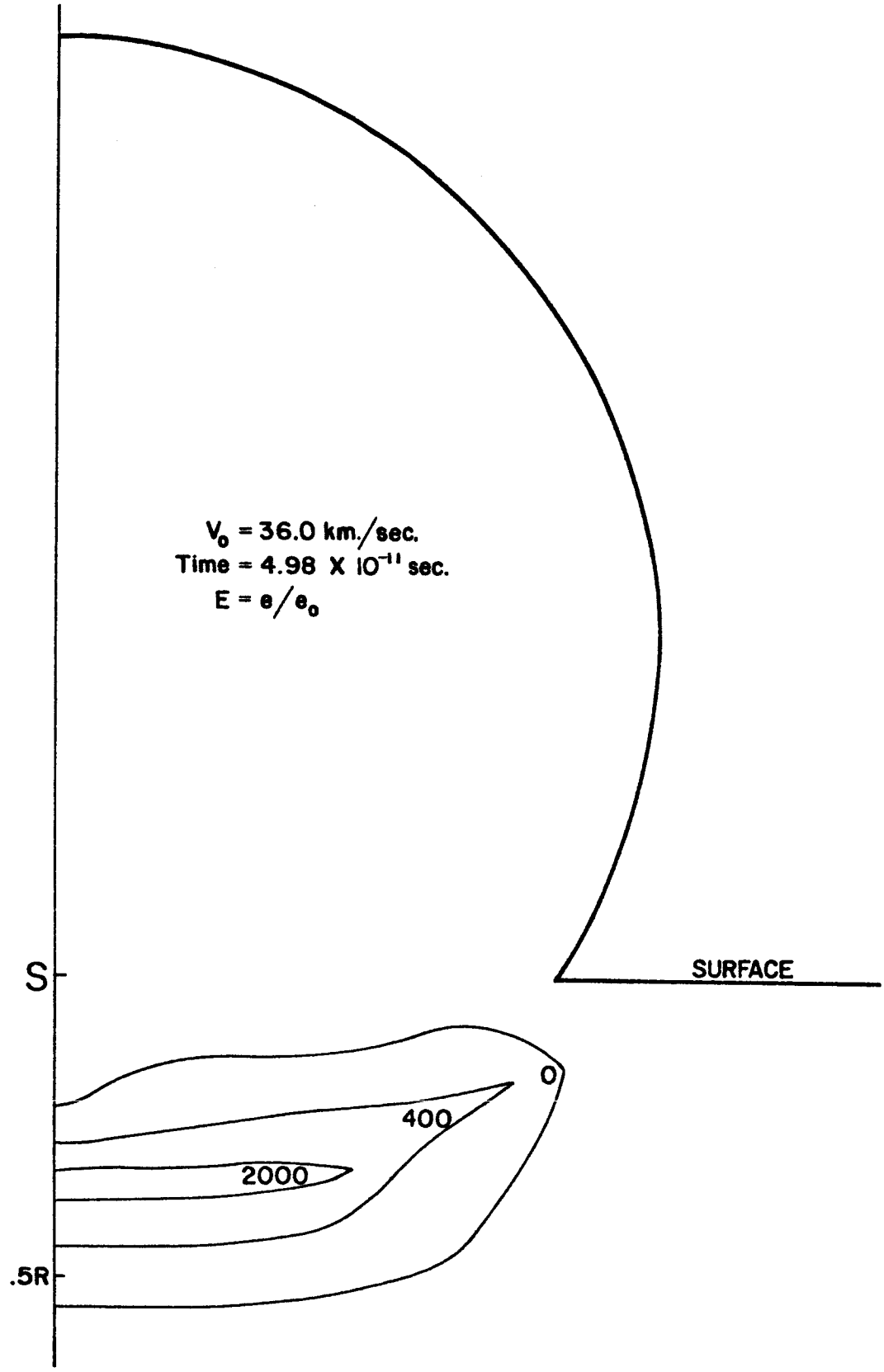

Figure 154. Energy Map (t = 4.98 x 10^{-11} sec) IV

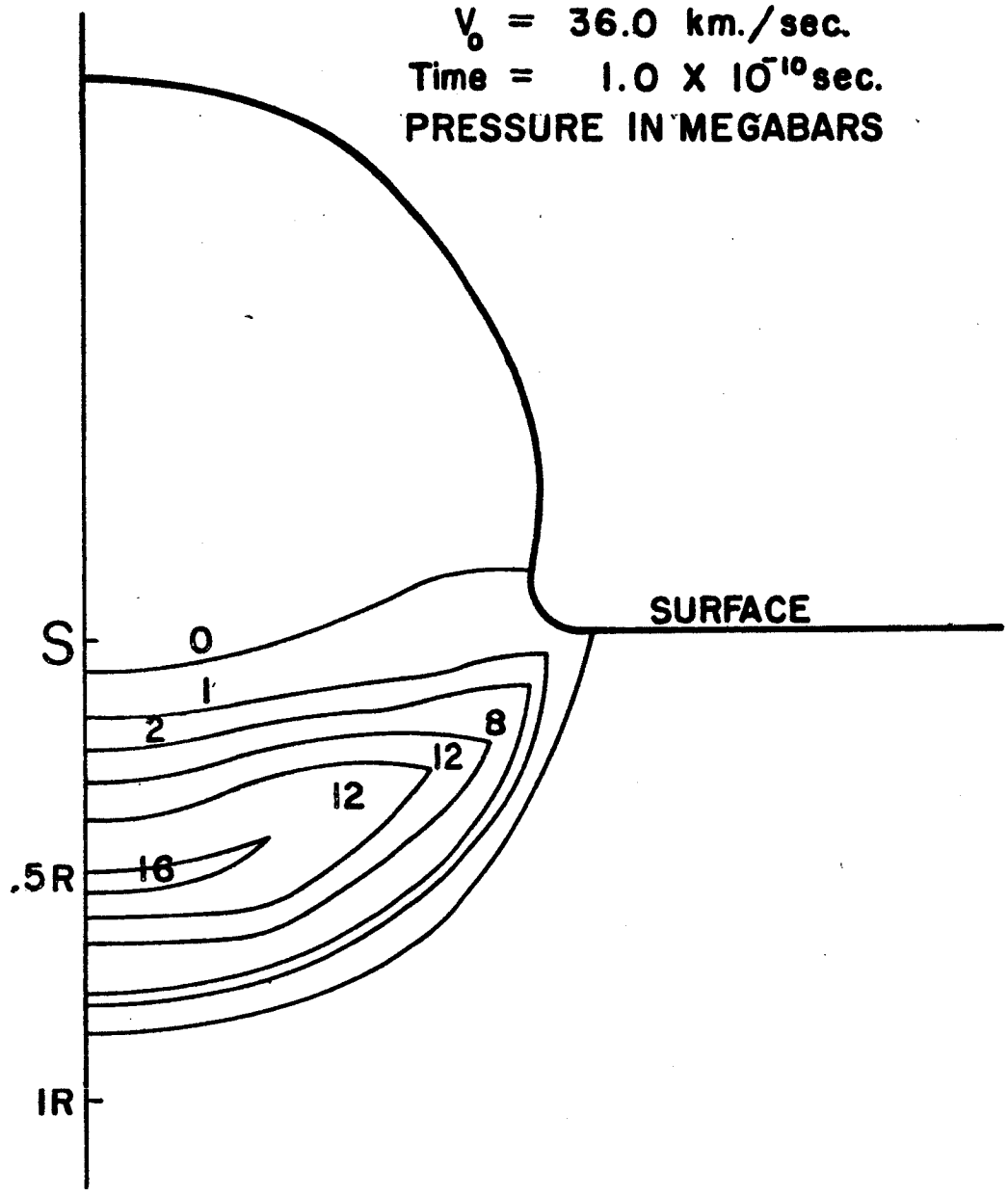

Figure 155. Pressure Map (t = 1.0 x 10^{-10} sec) IV

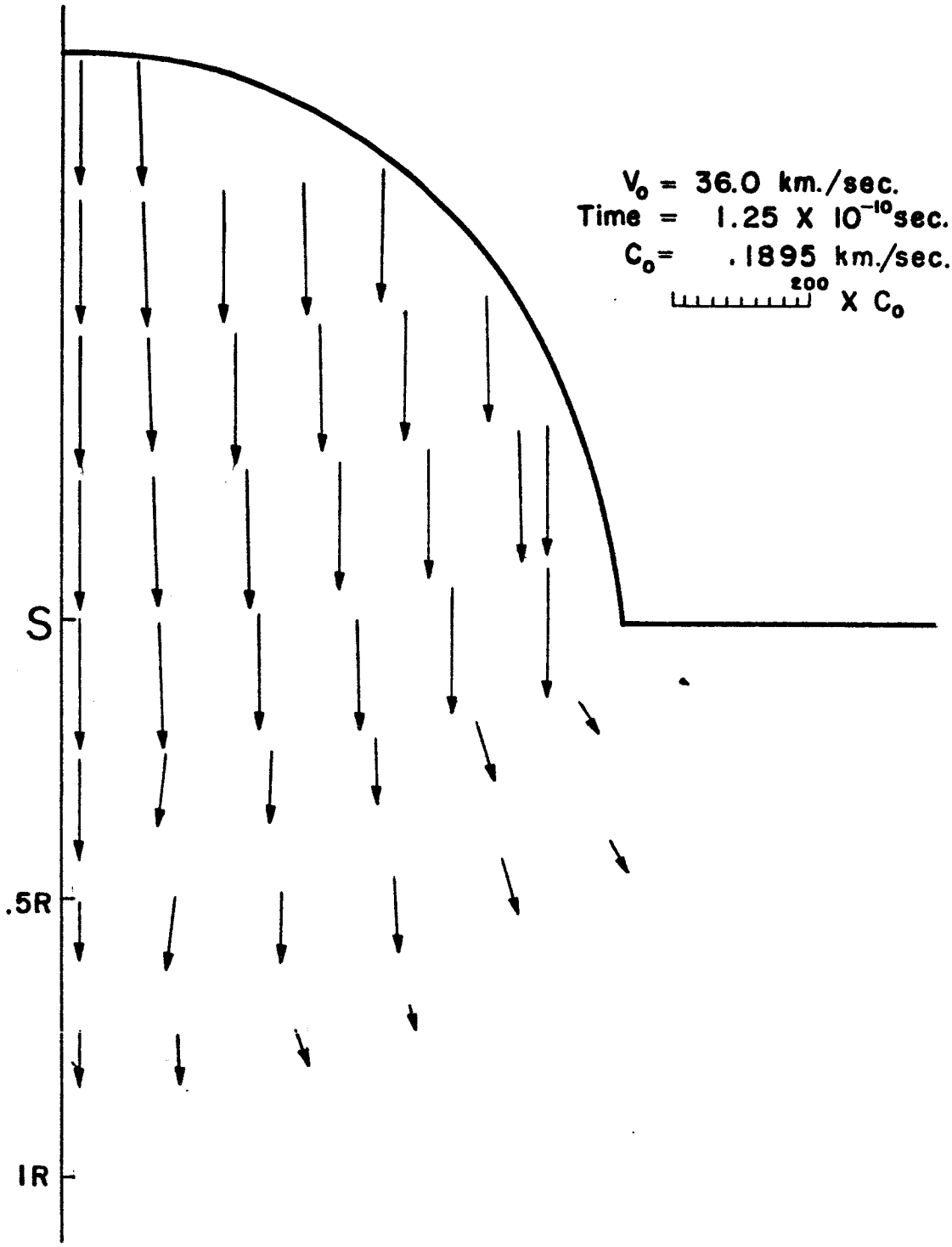

Figure 156. Velocity Map (t = 1.25 x 10^{-10} sec) IV

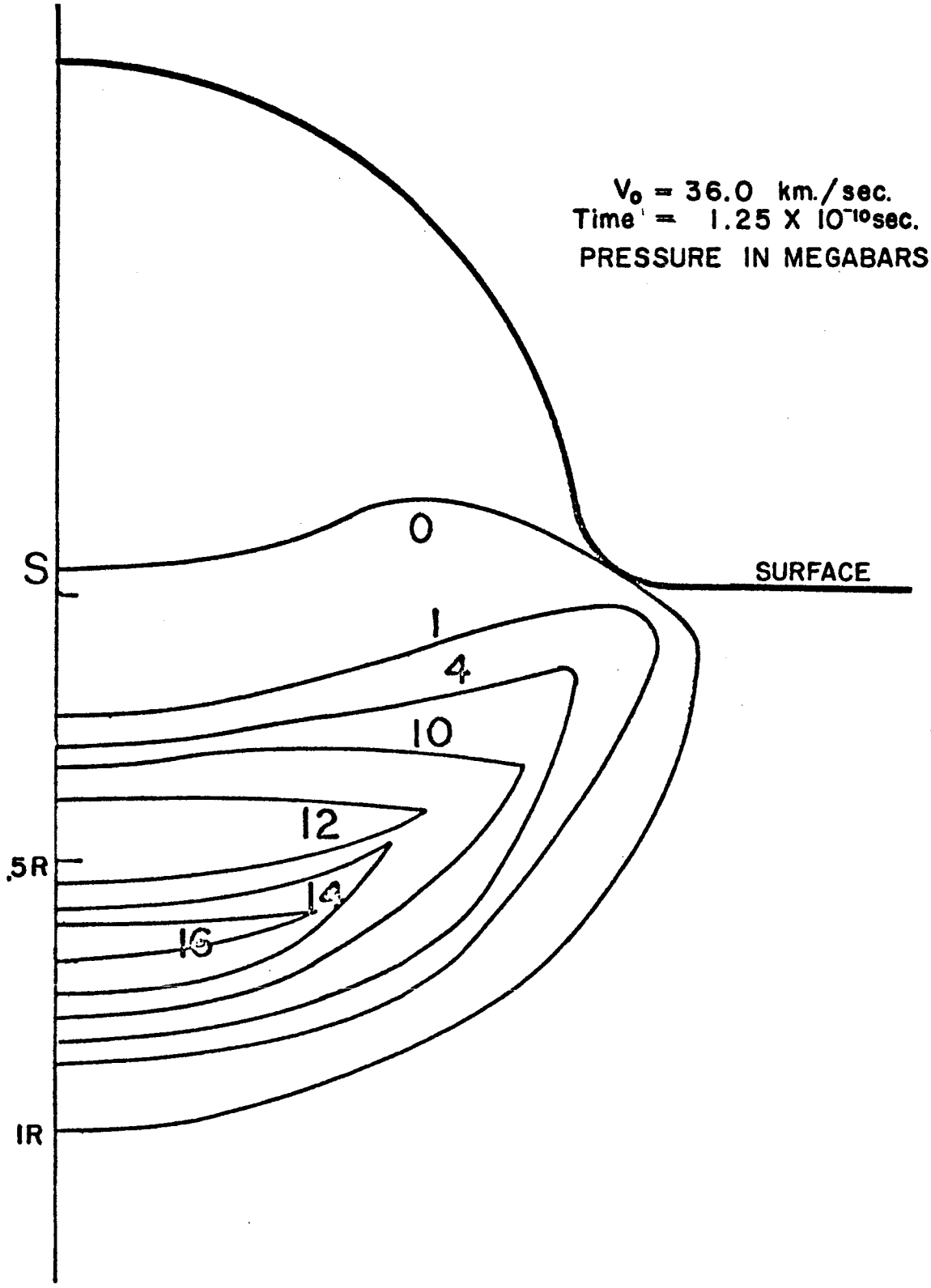

Figure 157. Pressure Map (t = 1.25 x 10^{-10} sec) IV

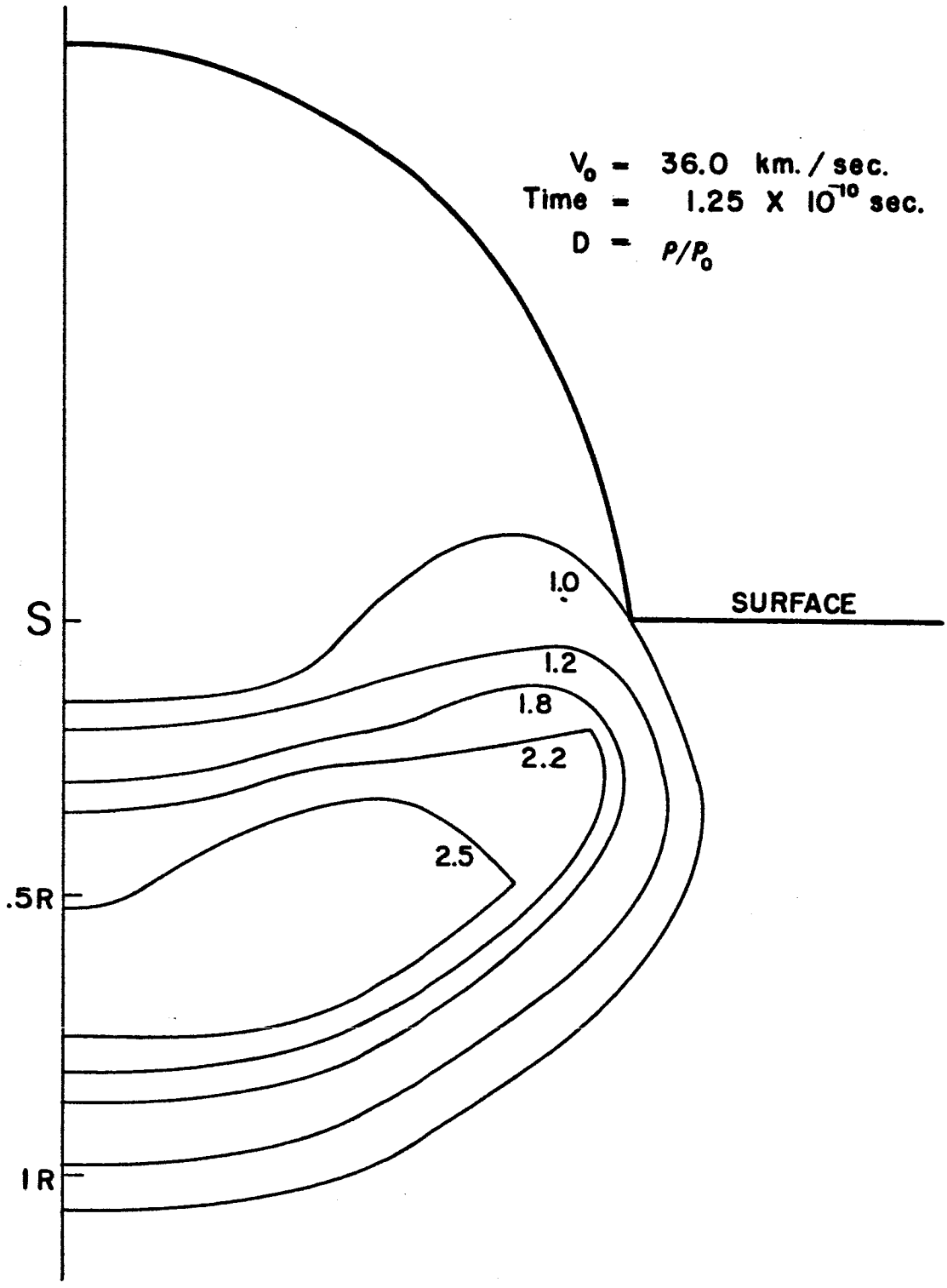

Figure 158. Density Map (t = 1.25 x 10^{-10} sec) IV

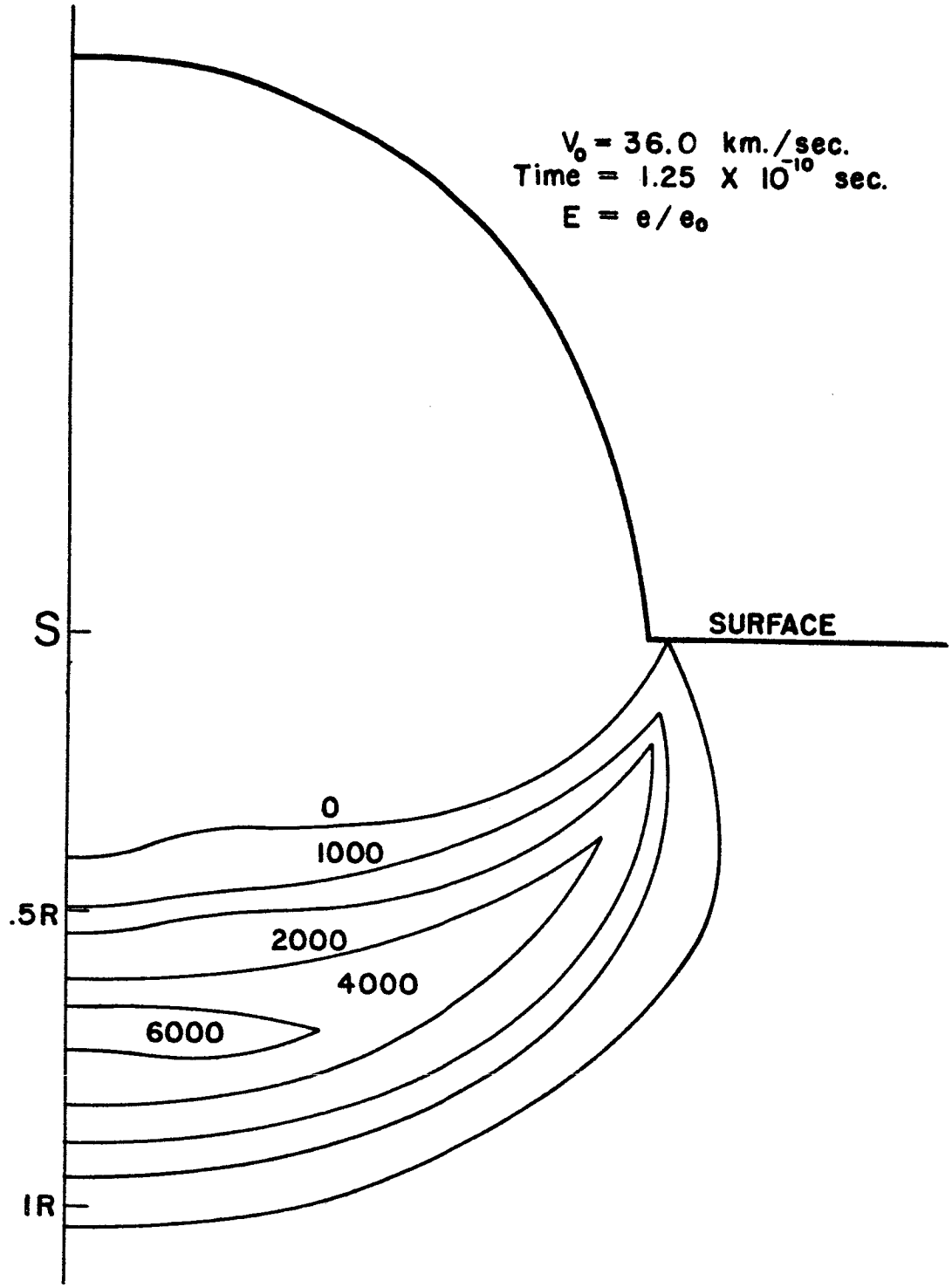

Figure 159. Energy Map (t = 1.25 x 10^{-10} sec) IV

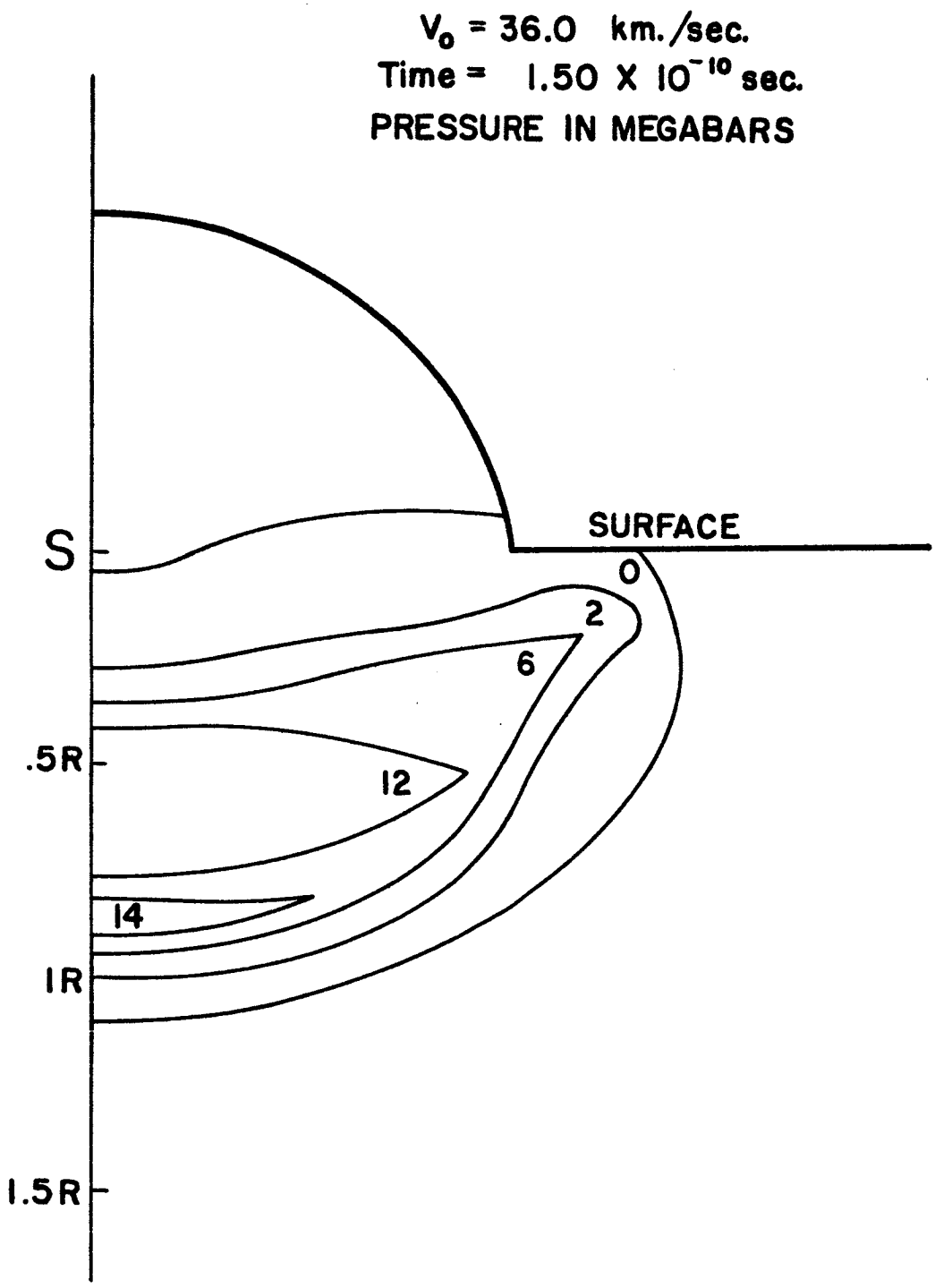

Figure 160. Pressure Map (t = 1.50 x 10^{-10} sec) IV

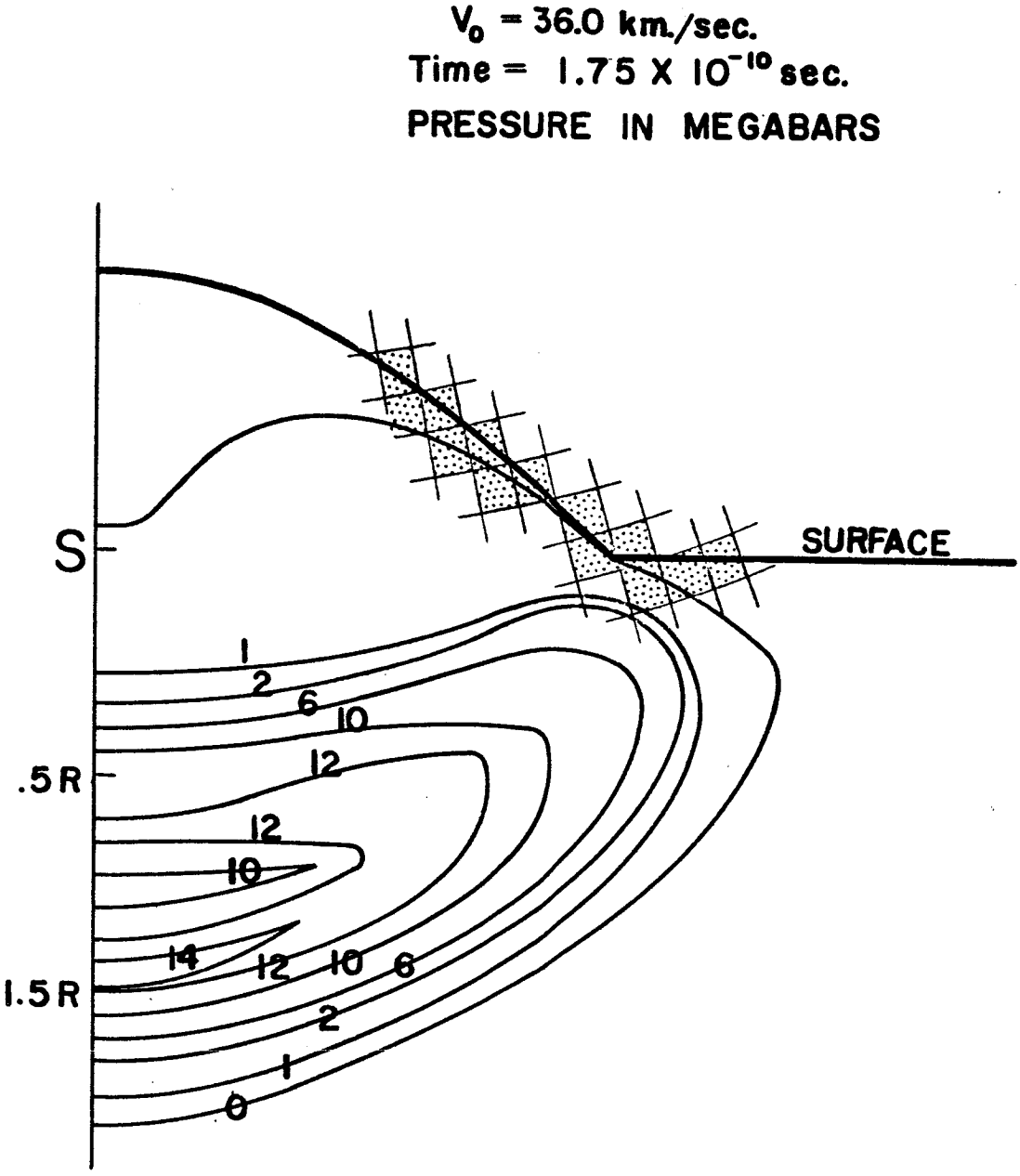

Figure 161. Pressure Map (t = 1.75 x 10^{-10} sec) IV

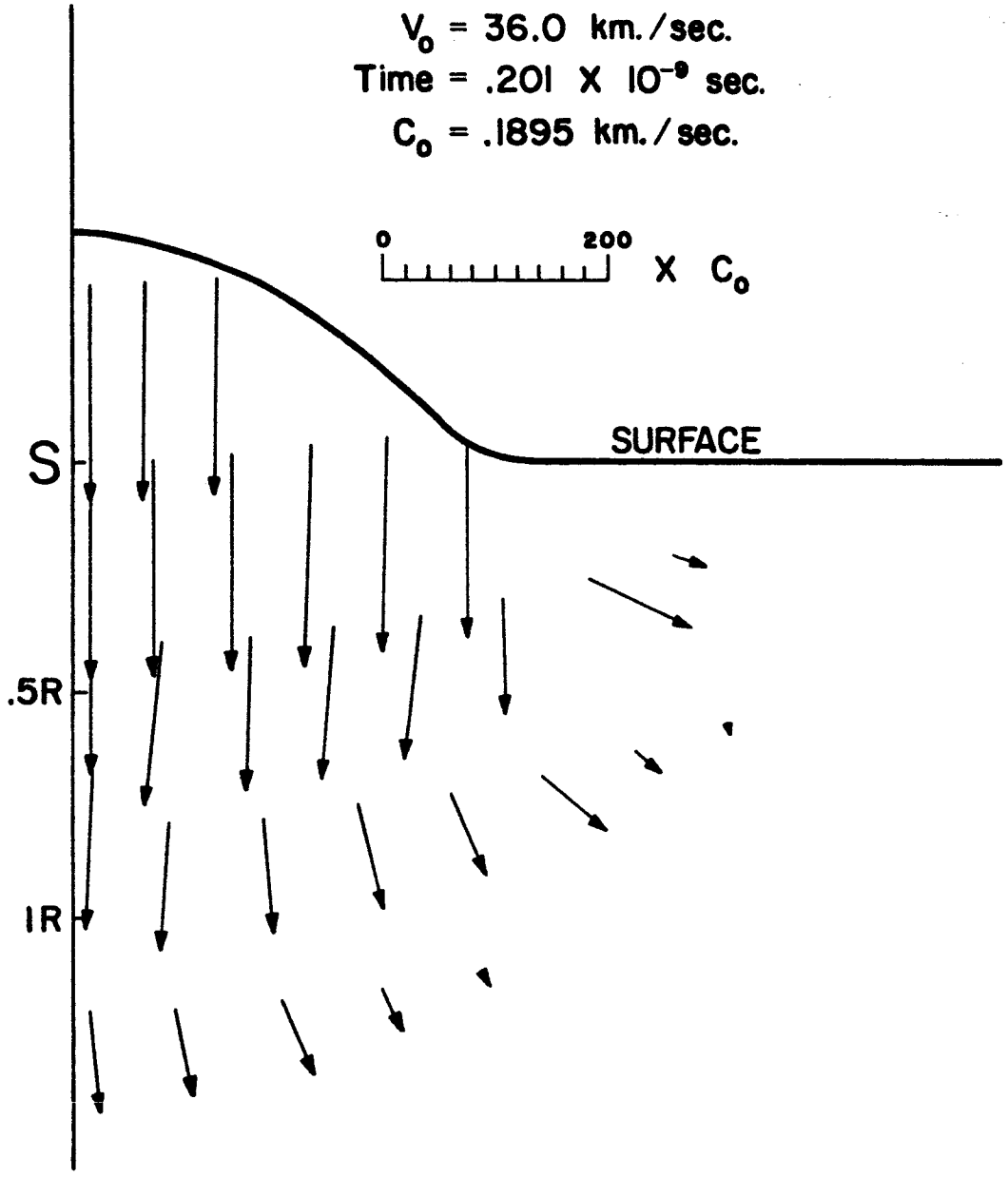

Figure 162. Velocity Map (t = .201 x 10^{-9} sec) IV

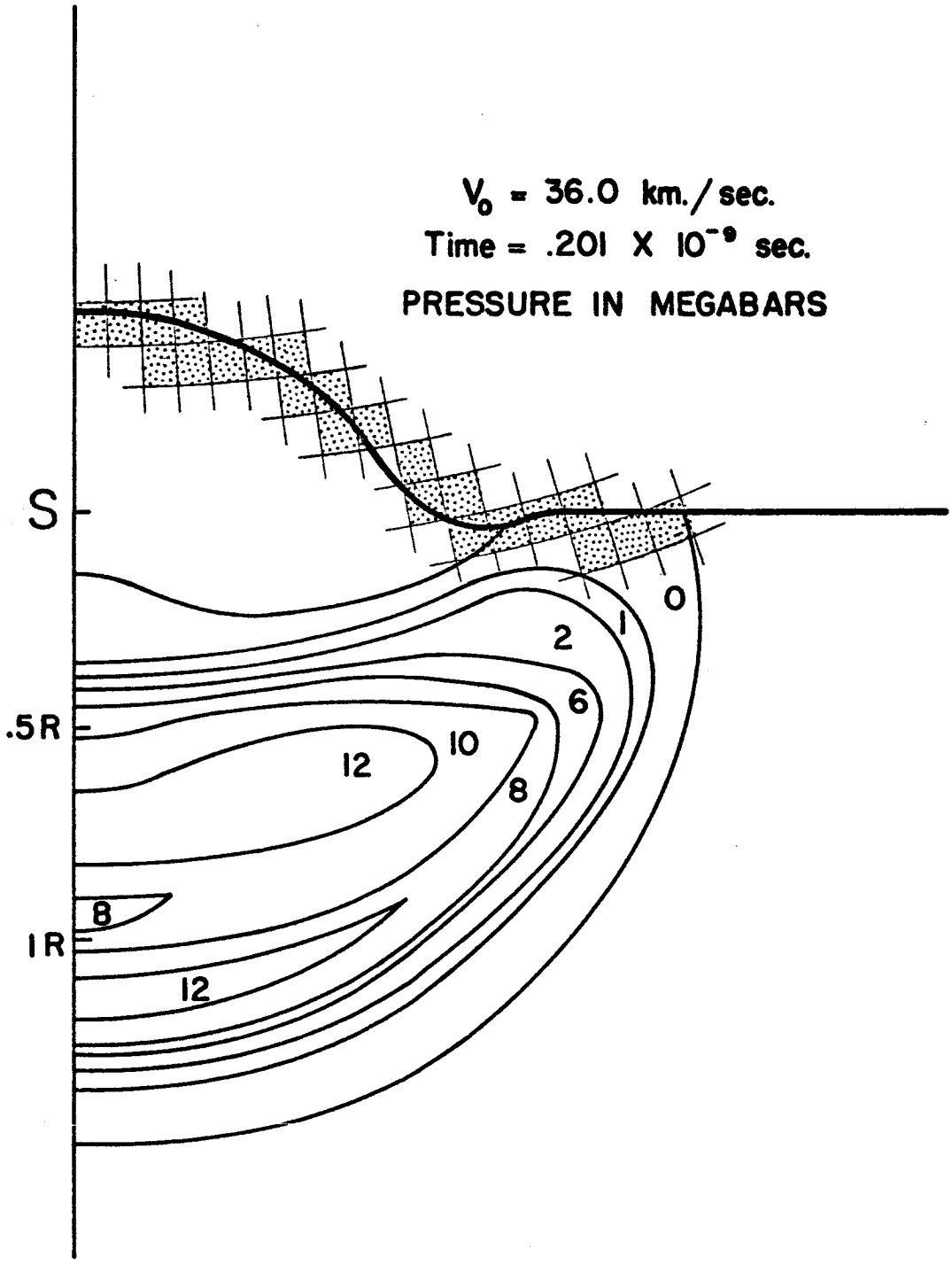

Figure 163. Pressure Map (t = .201 x 10^{-9} sec) IV

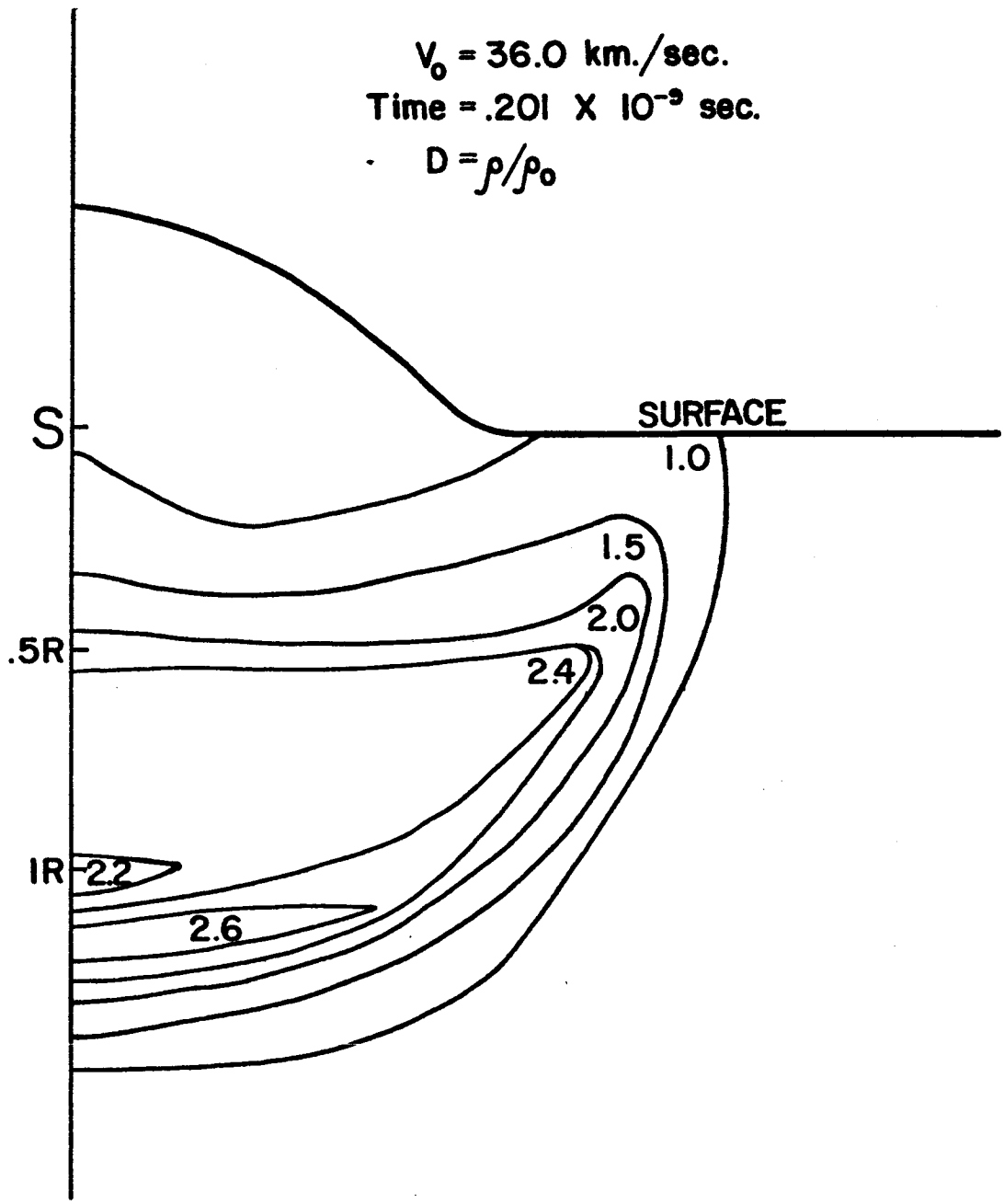

Figure 164. Density Map (t = .201 x 10^{-9} sec) IV

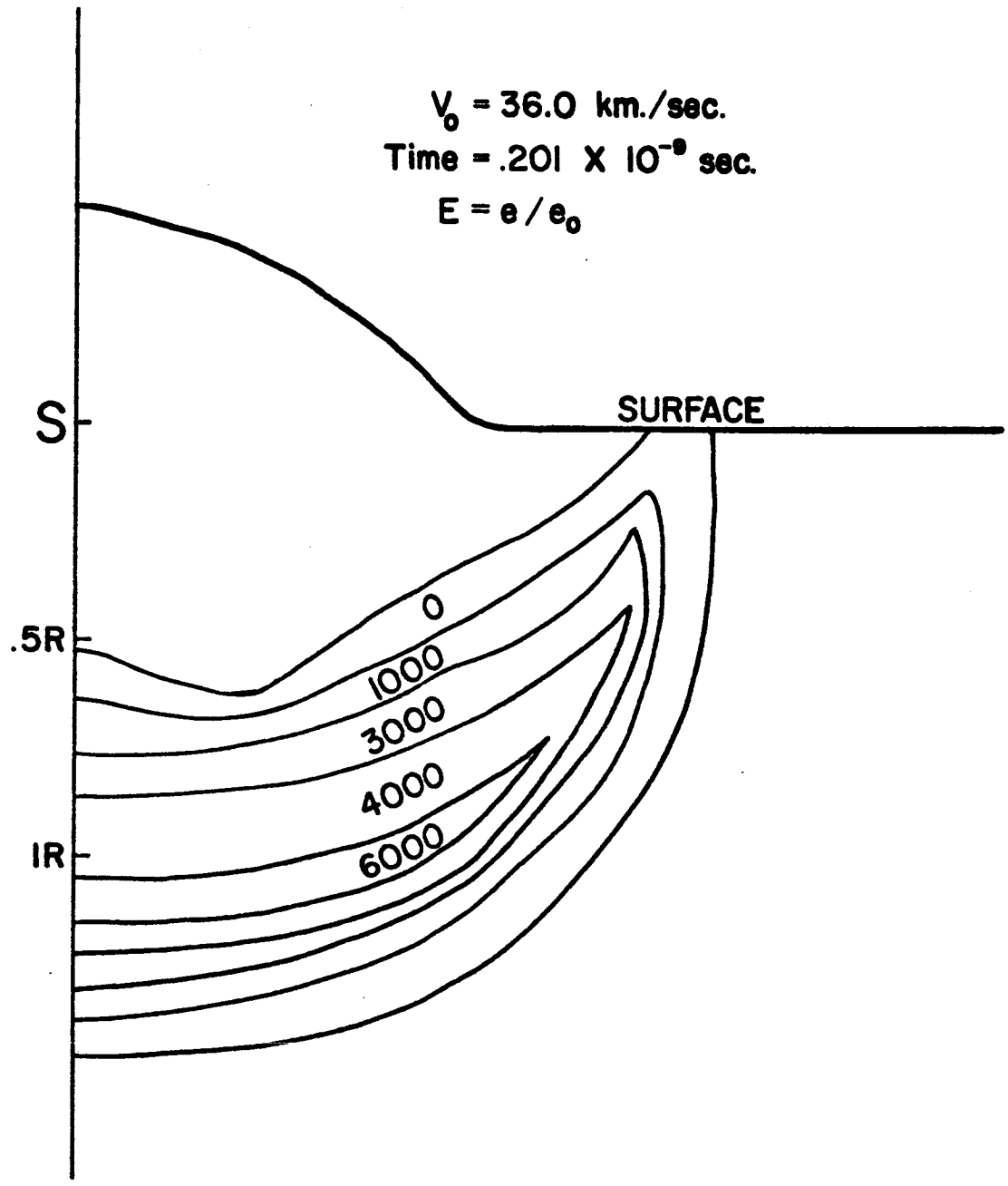

Figure 165. Energy Map (t = .201 x 10^{-9} sec) IV

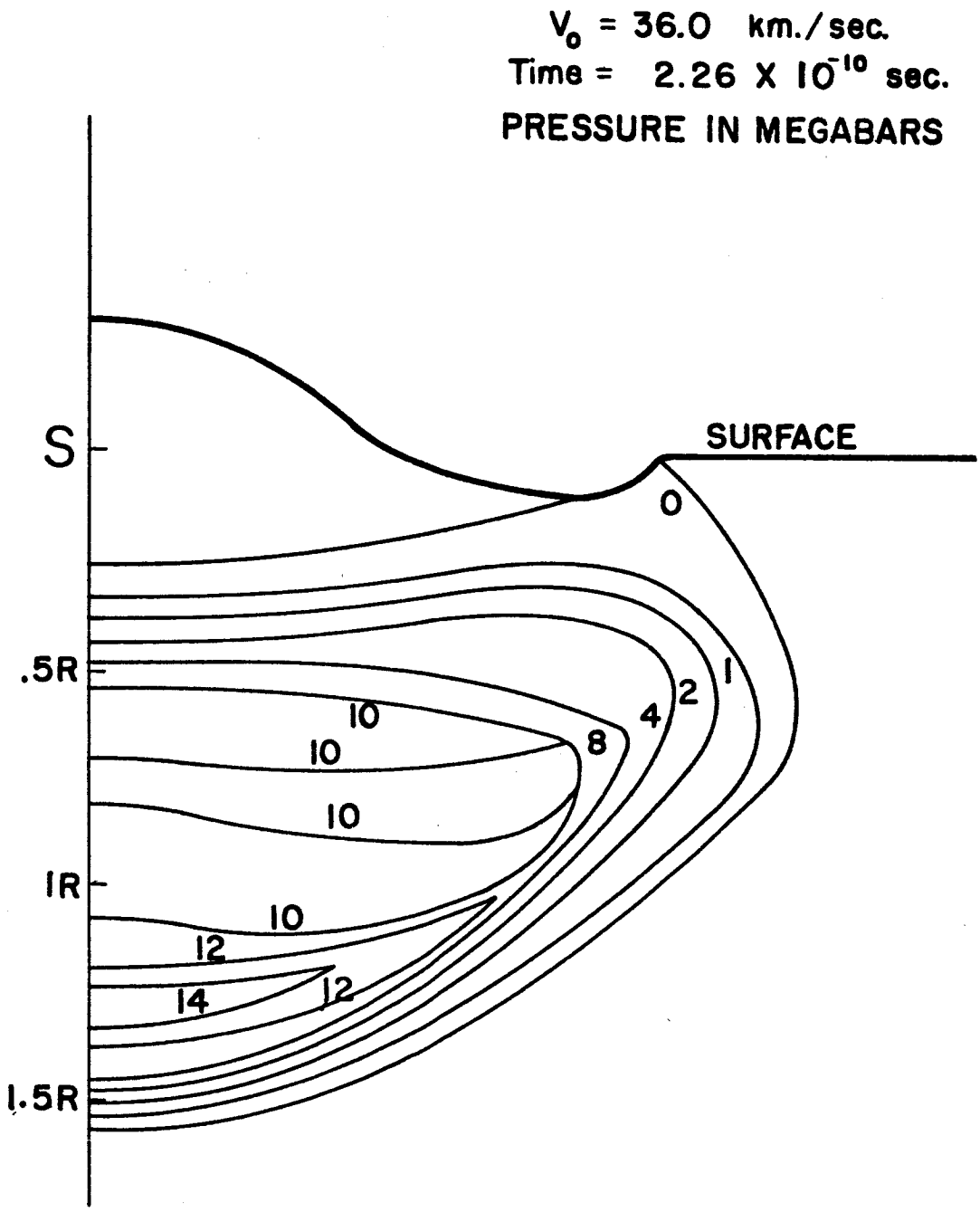

Figure 166. Pressure Map (t = 2.26 x 10^{-10} sec) IV

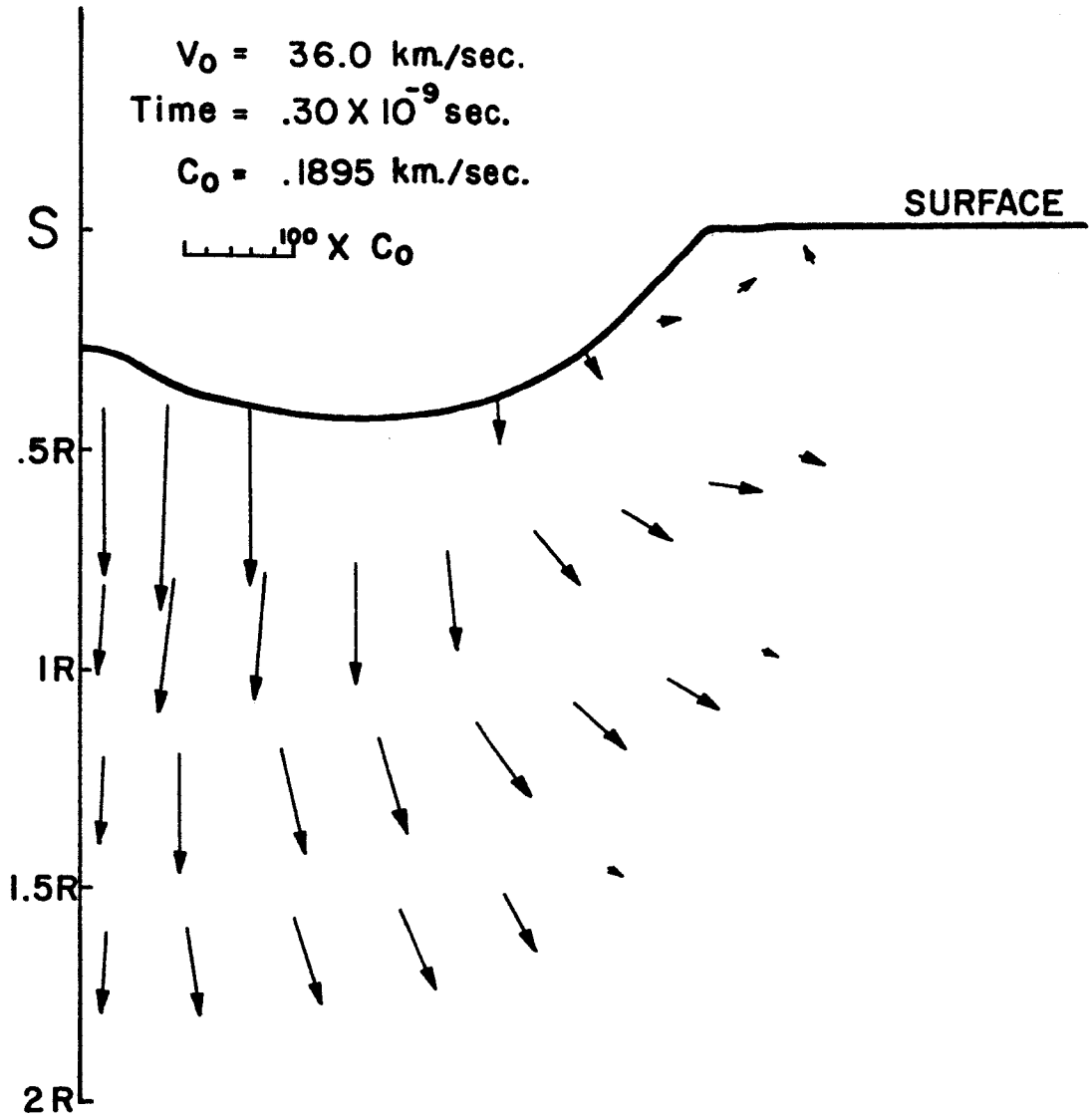

Figure 167. Velocity Map (t = .30 x 10^{-9} sec) IV

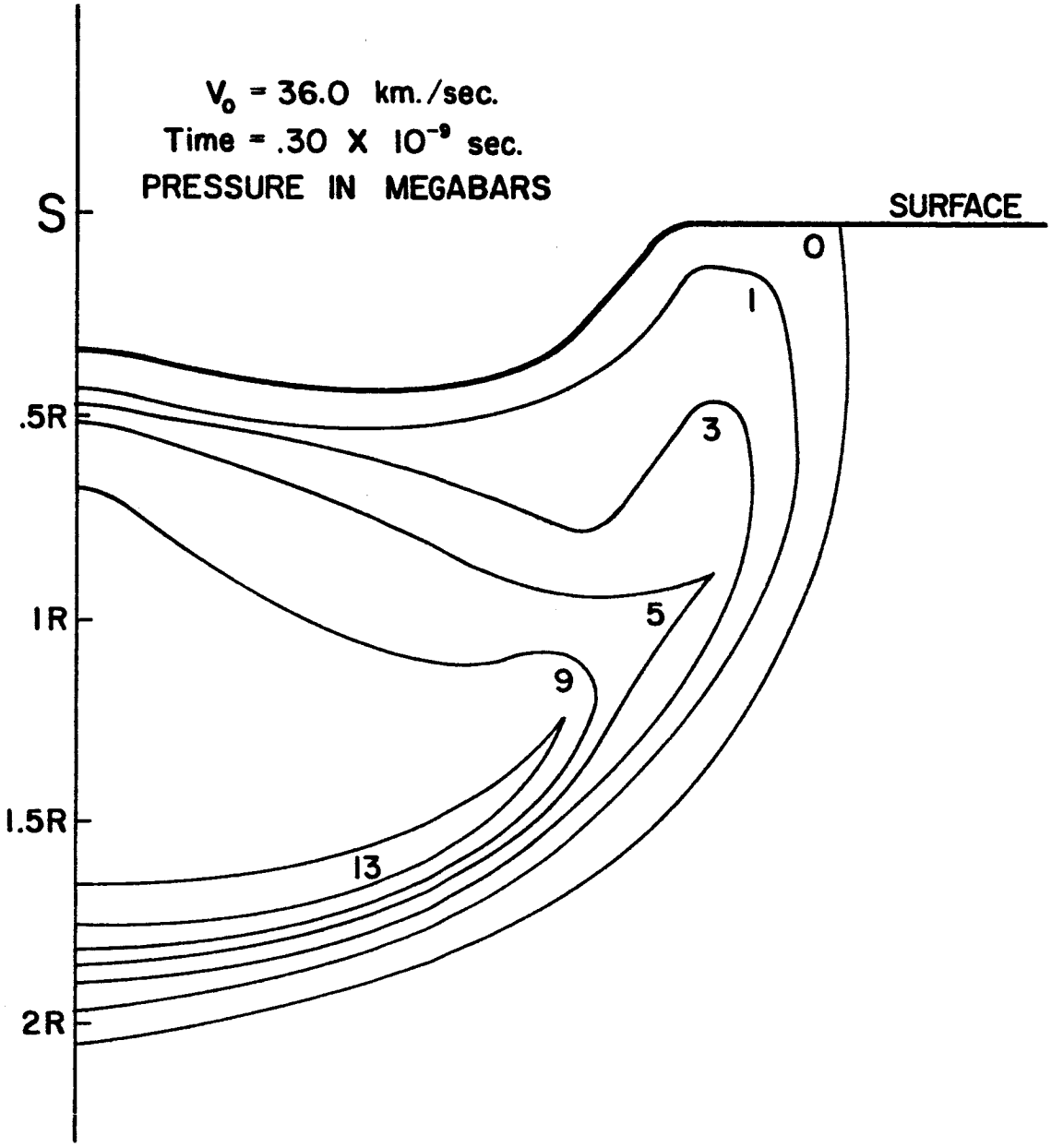

Figure 168. Pressure Map (t = .30 x 10^{-9} sec) IV

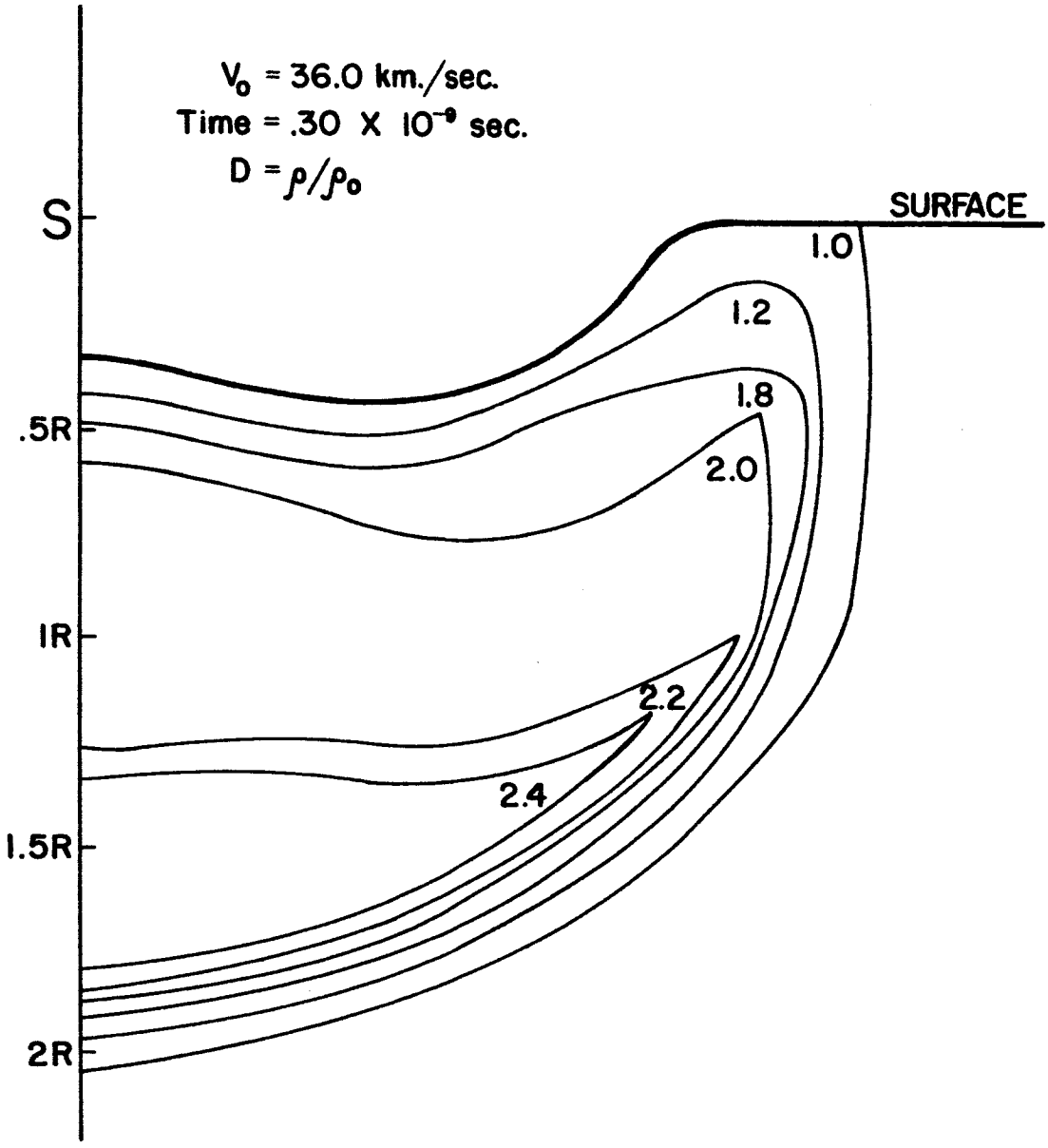

Figure 169. Density Map (t = .30 x 10^{-9} sec) IV

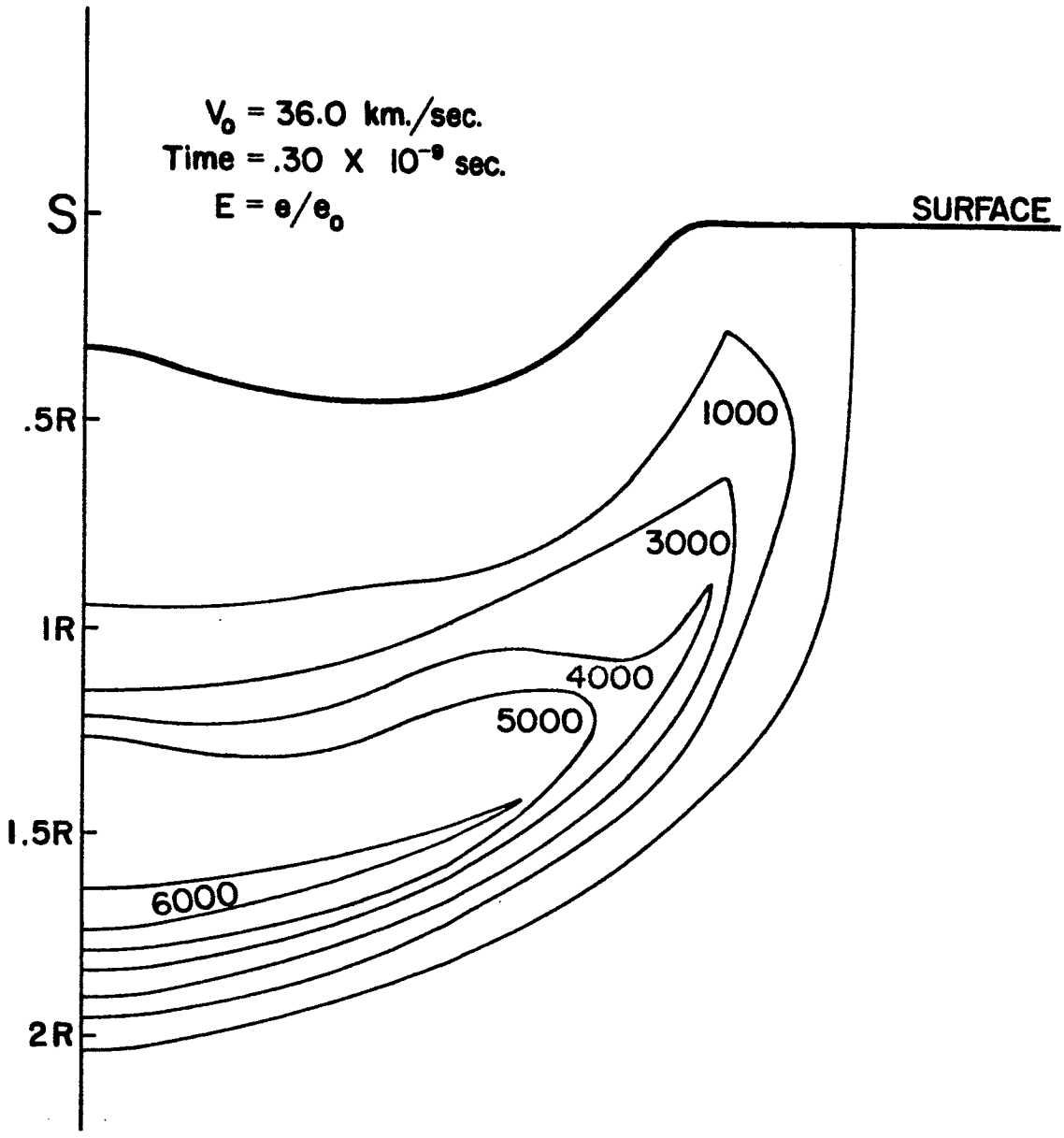

Figure 170. Energy Map (t = .30 x 10^{-9} sec) IV

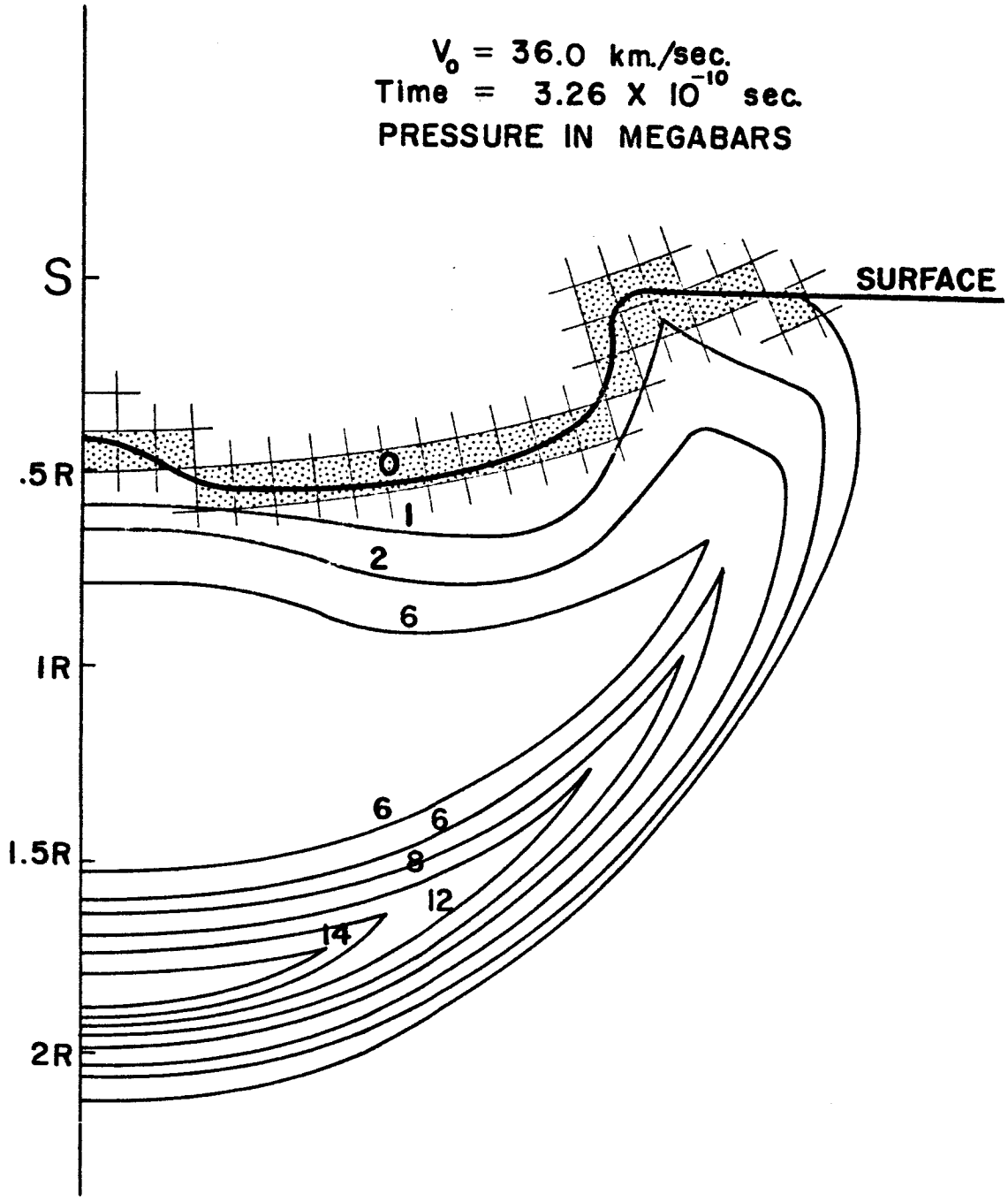

Figure 171. Pressure Map (t = 3.26 x 10^{-10} sec) IV

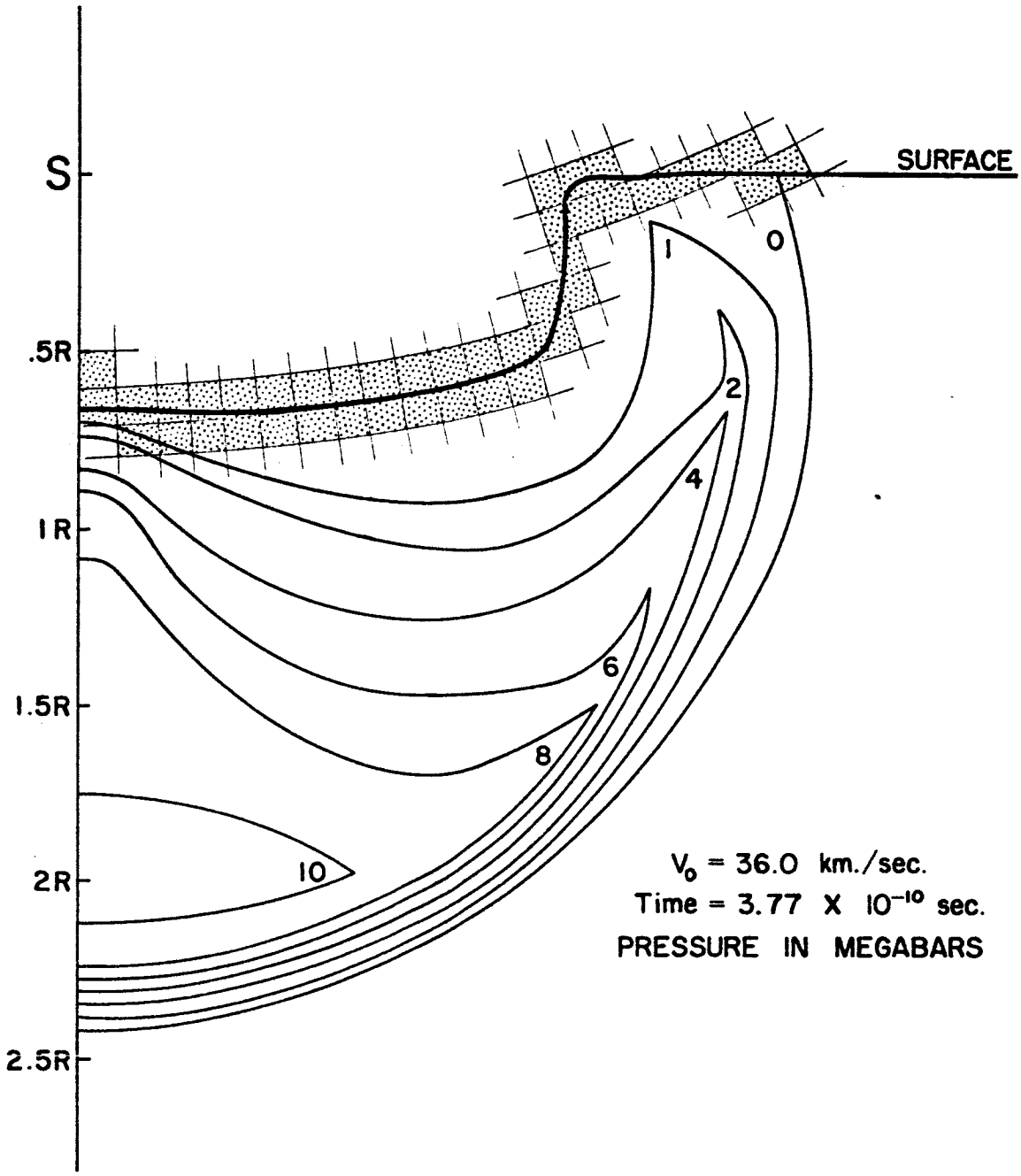

Figure 172. Pressure Map (t = 3.77 x 10^{-10} sec) IV

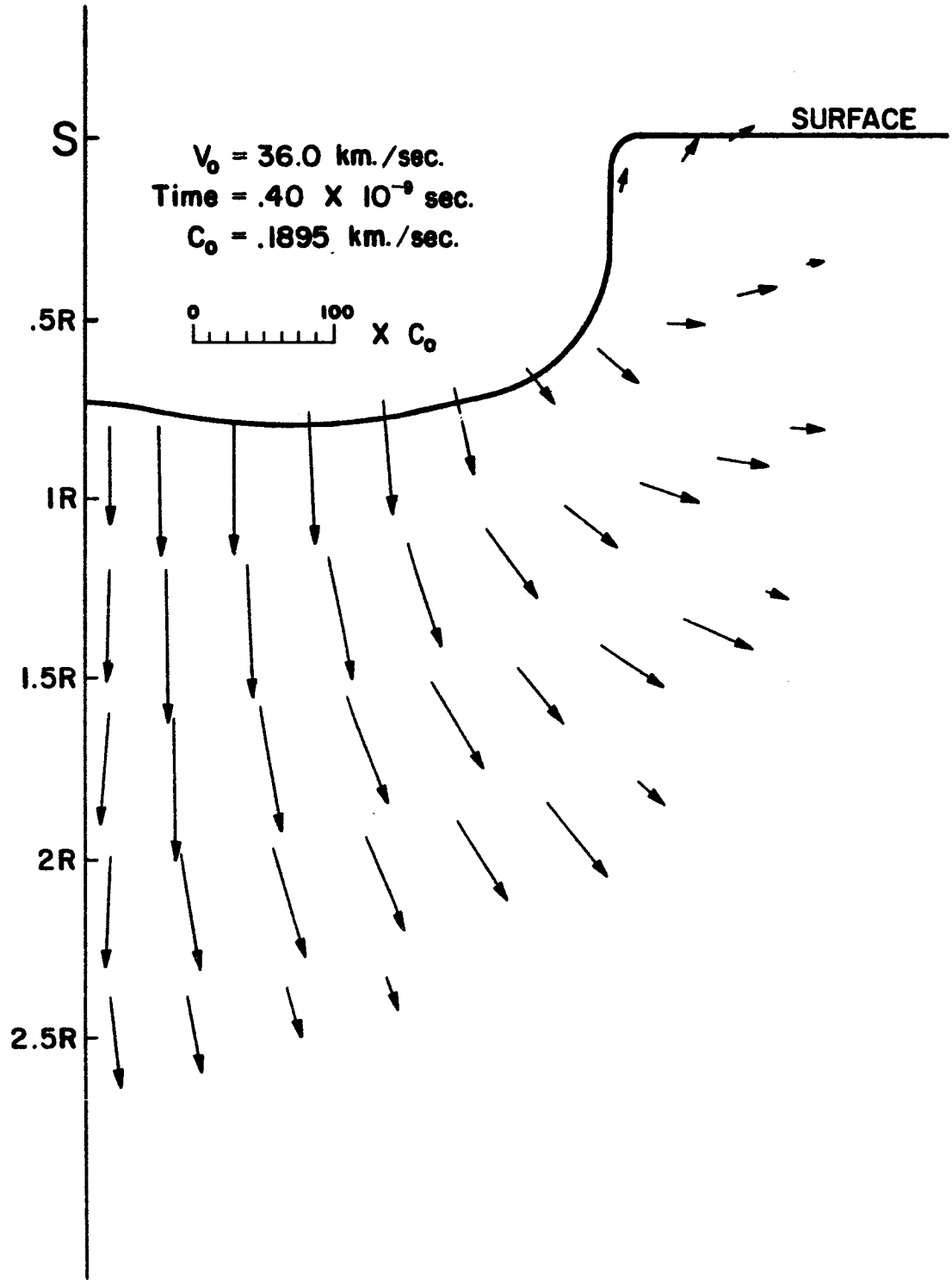

Figure 173. Velocity Map (t = .40 x 10^{-9} sec) IV

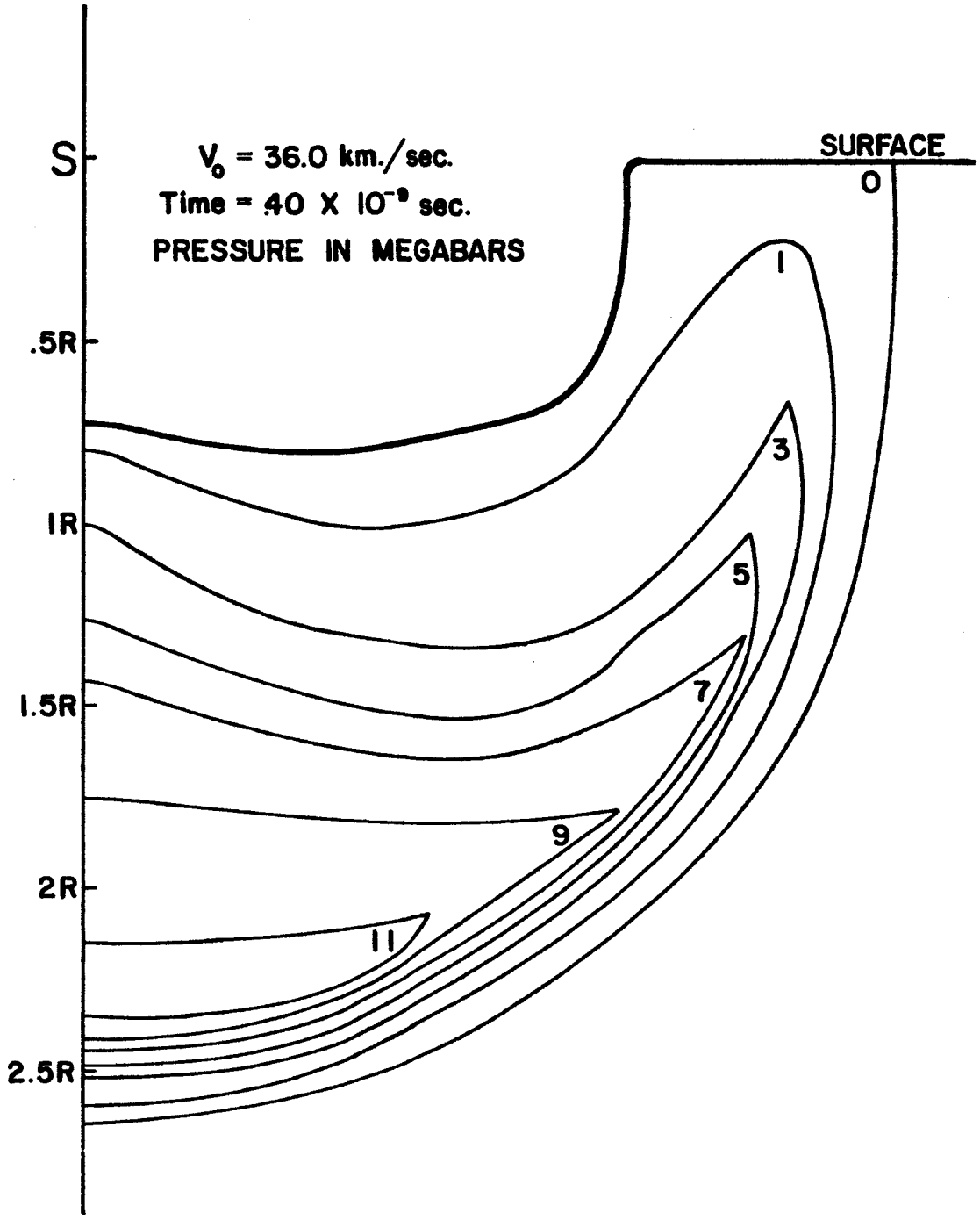

Figure 174. Pressure Map (t = .40 x 10^{-9} sec) IV

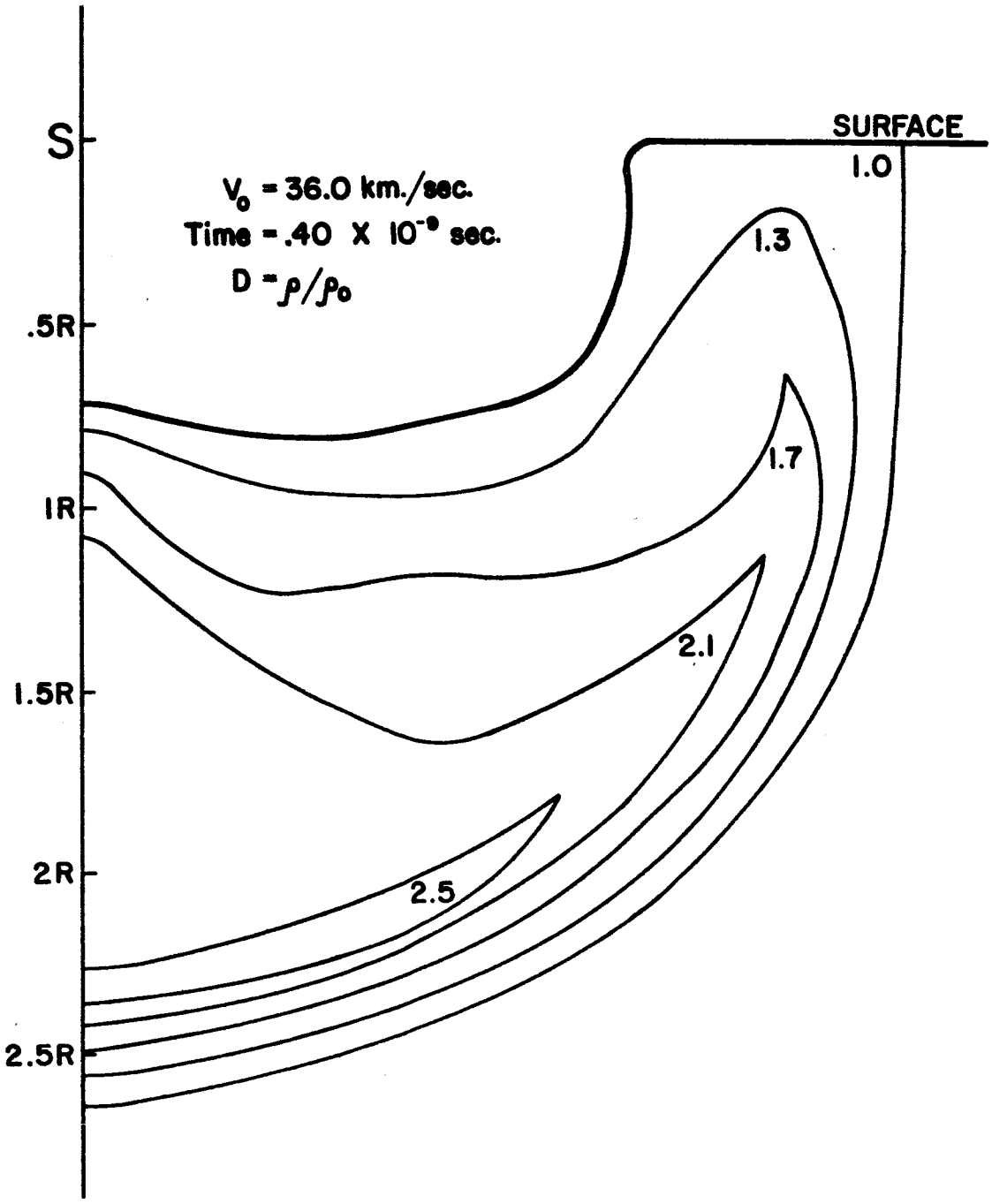

Figure 175. Density Map (t = .40 x 10^{-9} sec) IV

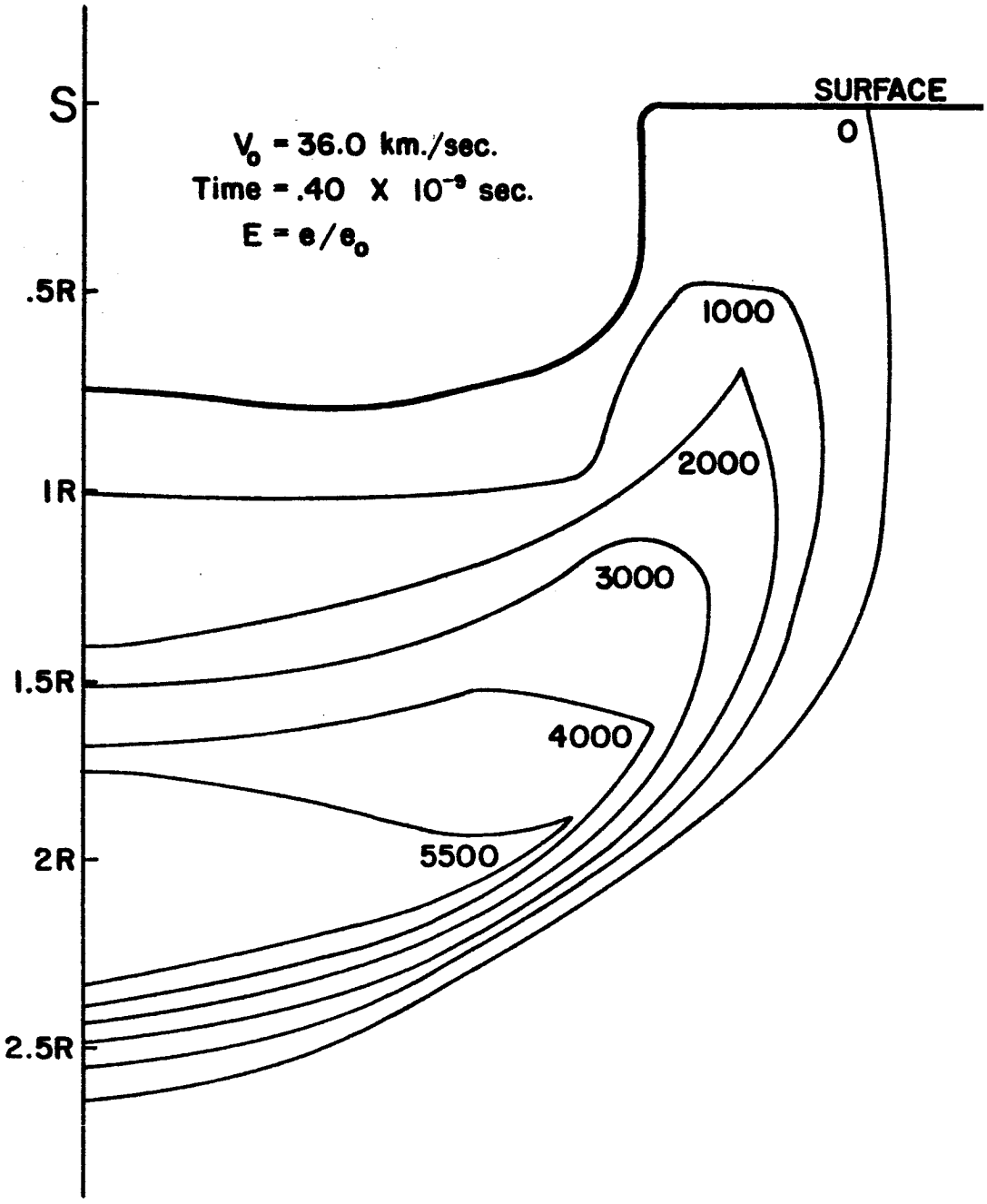

Figure 176. Energy Map (t = .40 x 10^{-9} sec) IV

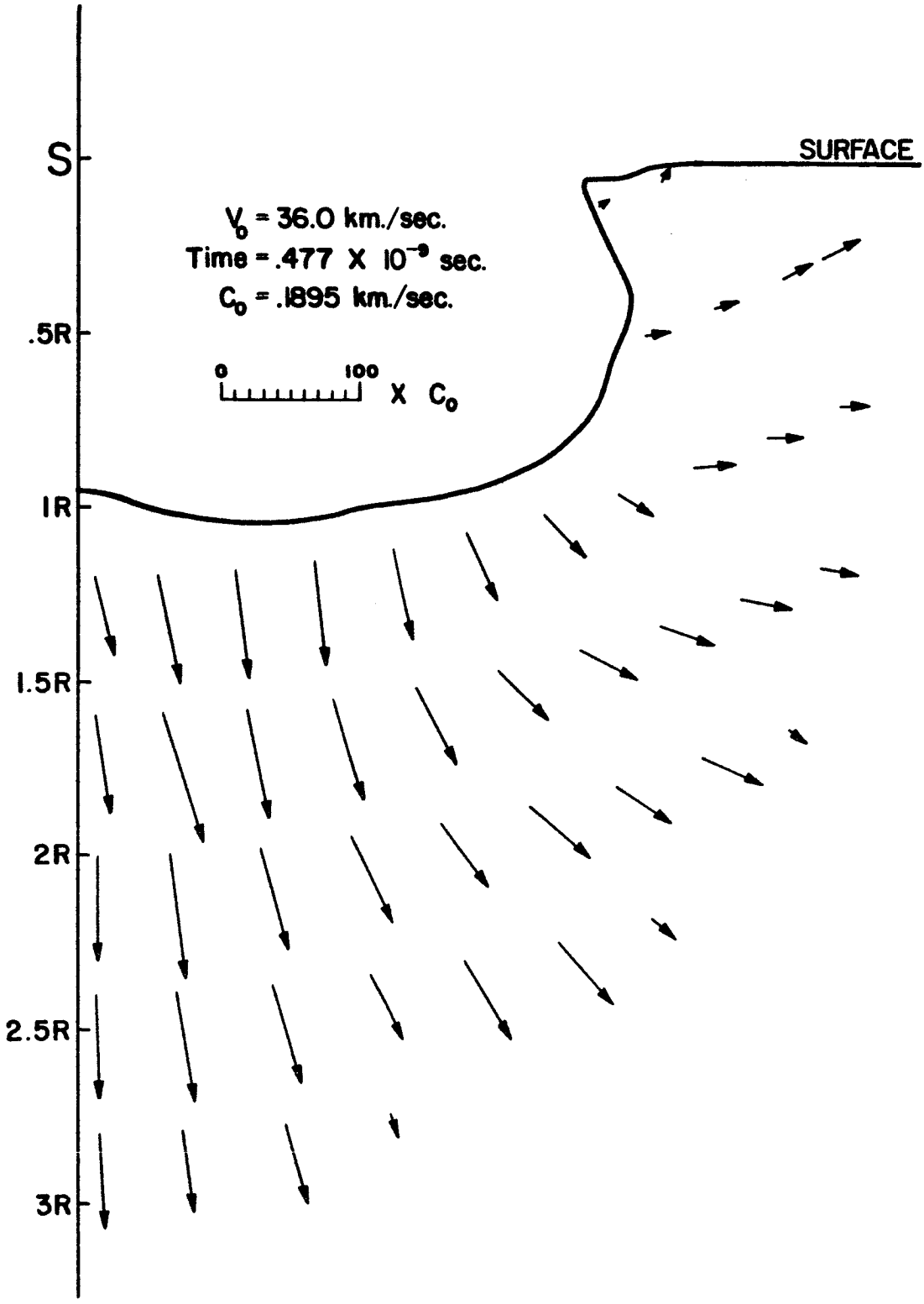

Figure 177. Velocity Map (t = .477 x 10^{-9} sec) IV

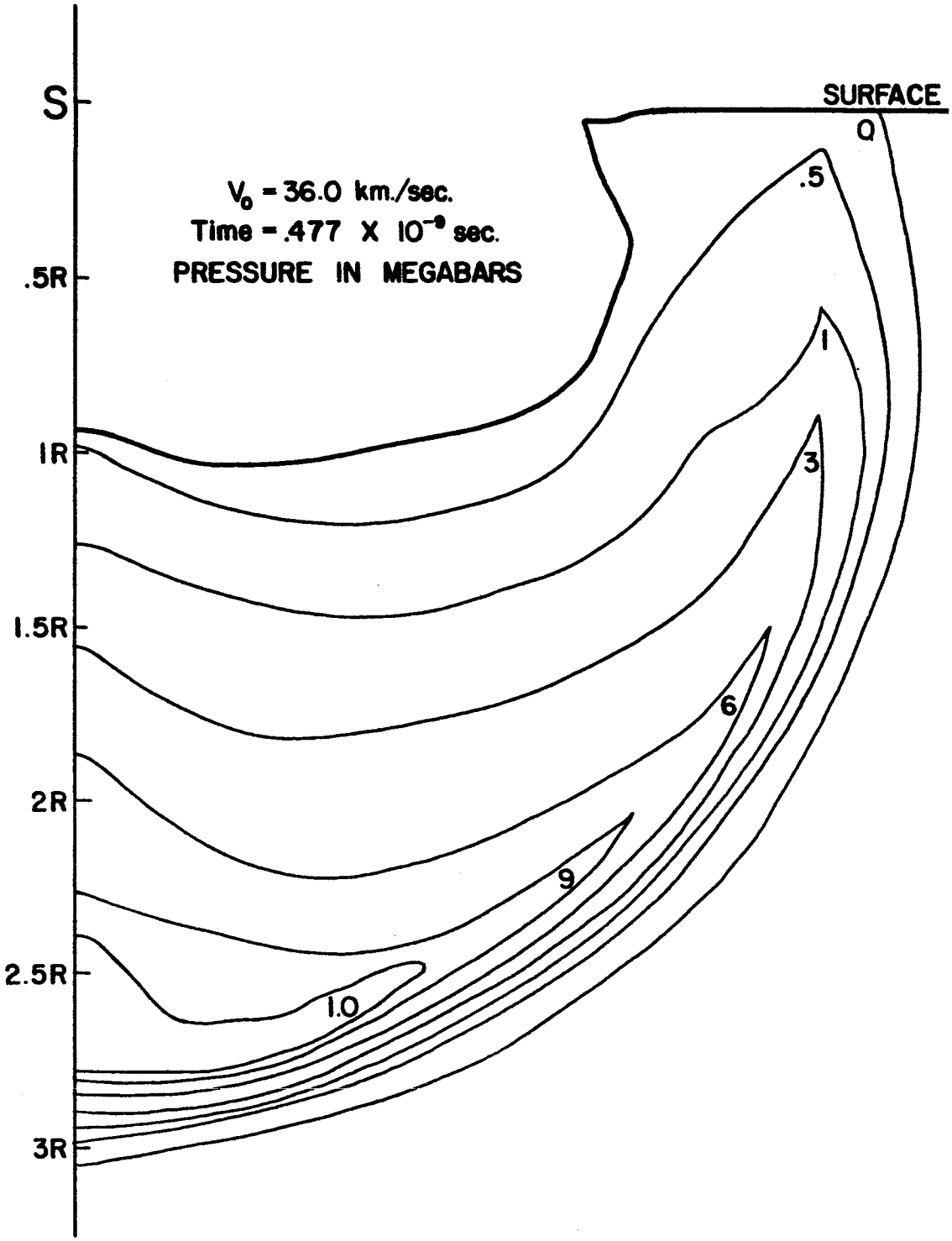

Figure 178. Pressure Map (t = .477 x 10^{-9} sec) IV

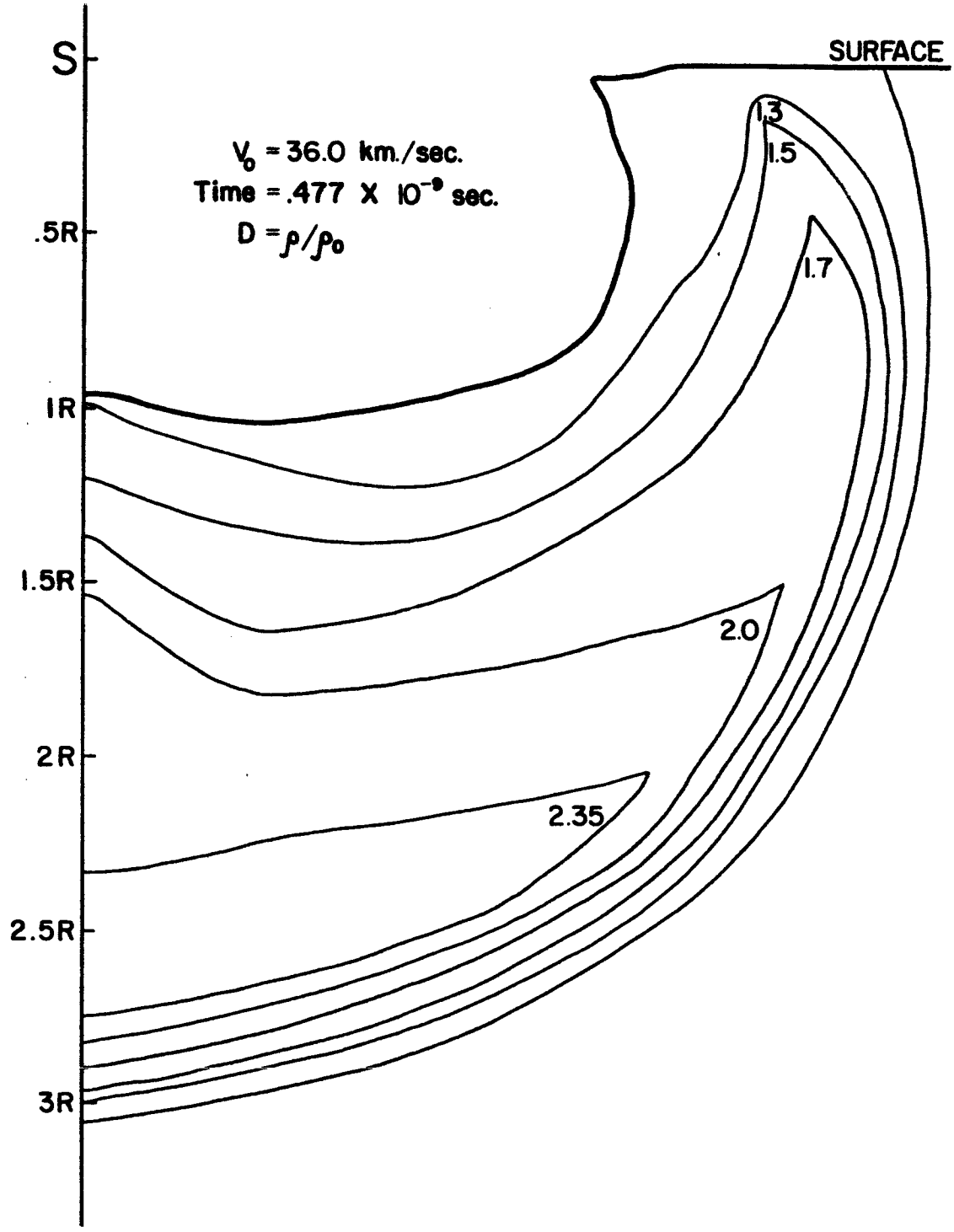

Figure 179. Density Map (t = .477 x 10^{-9} sec) IV

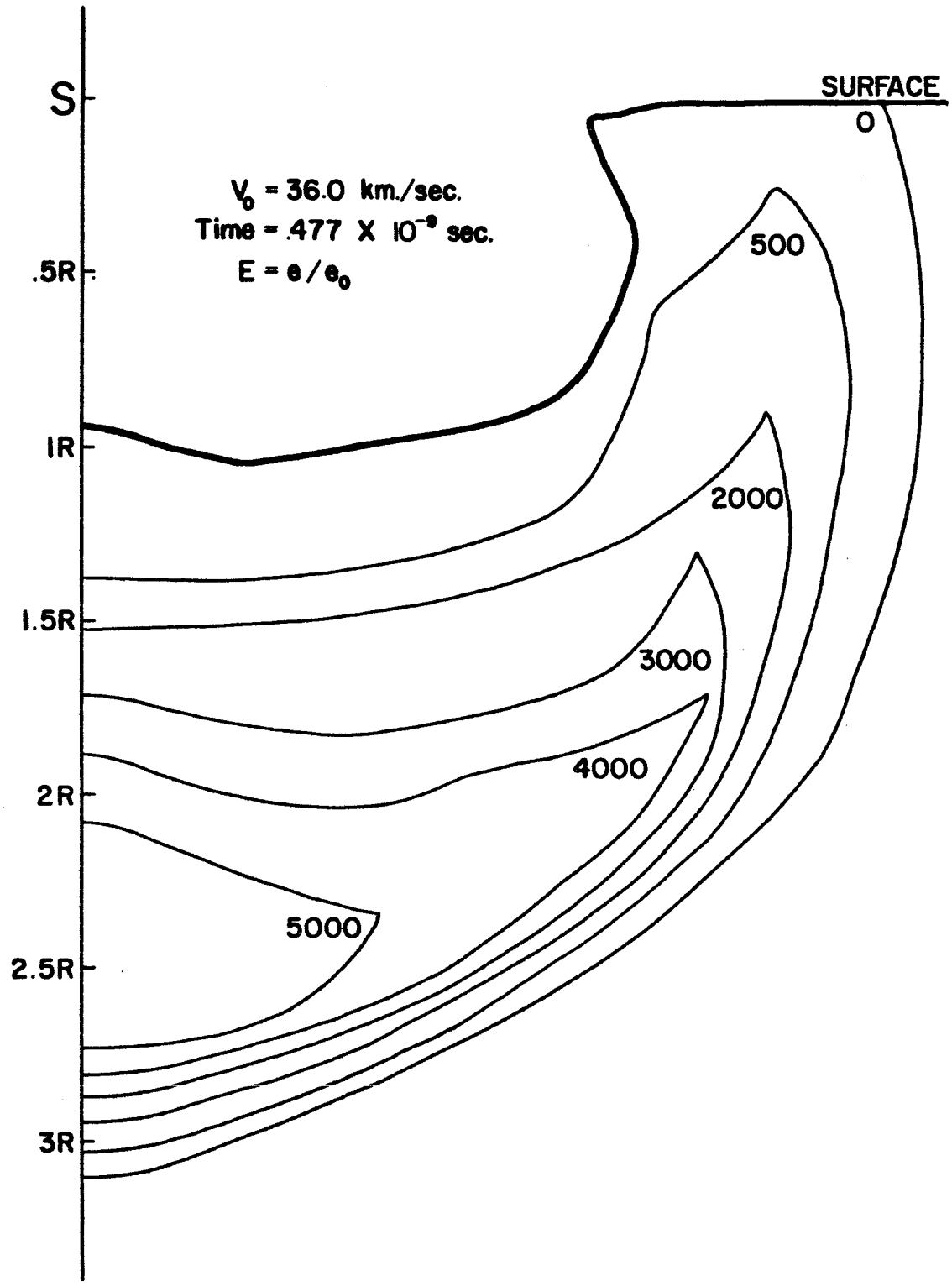

Figure 180. Energy Map (t = .477 x 10^{-9} sec) IV

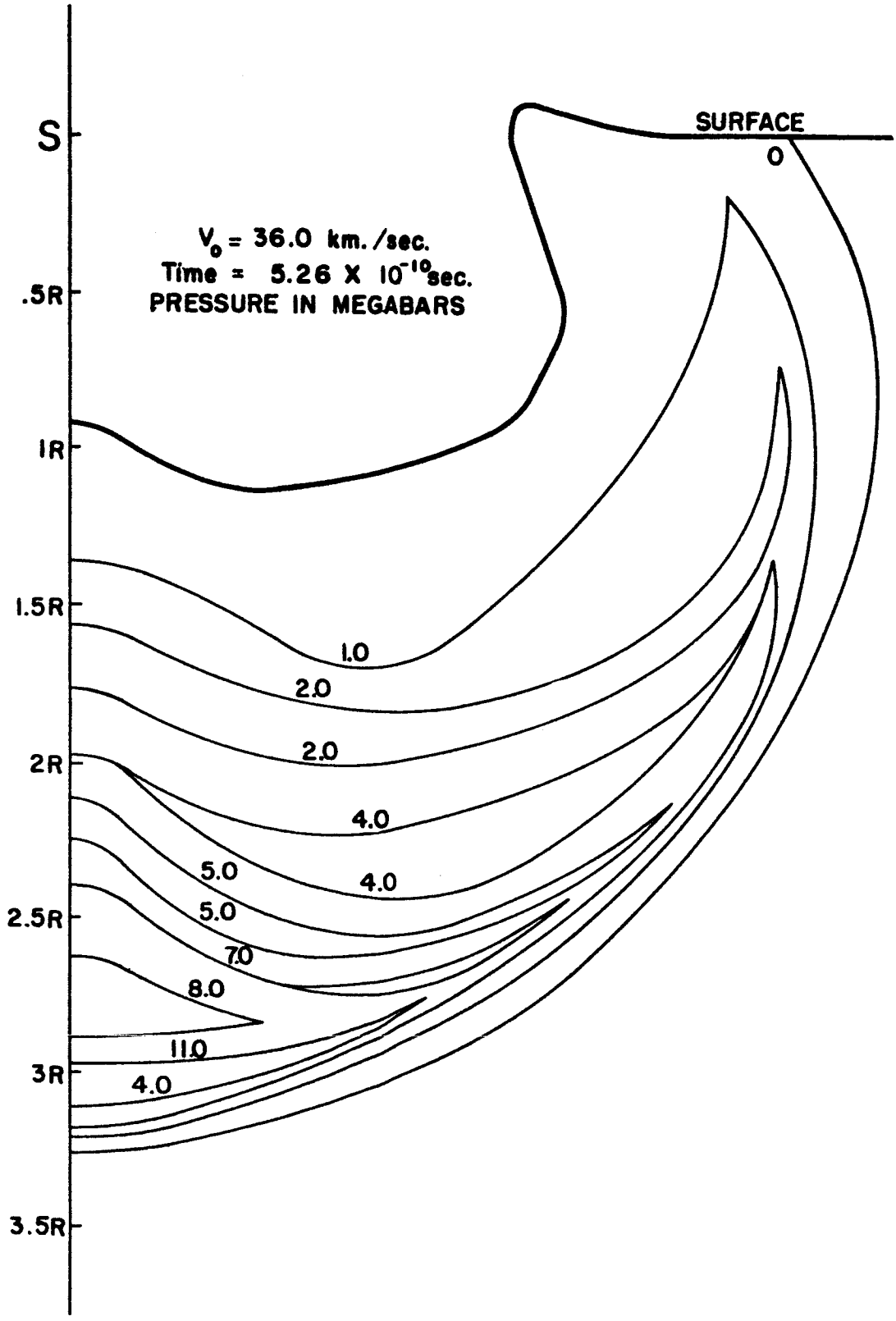

Figure 181. Pressure Map (t = 5.26 x 10^{-10} sec) IV

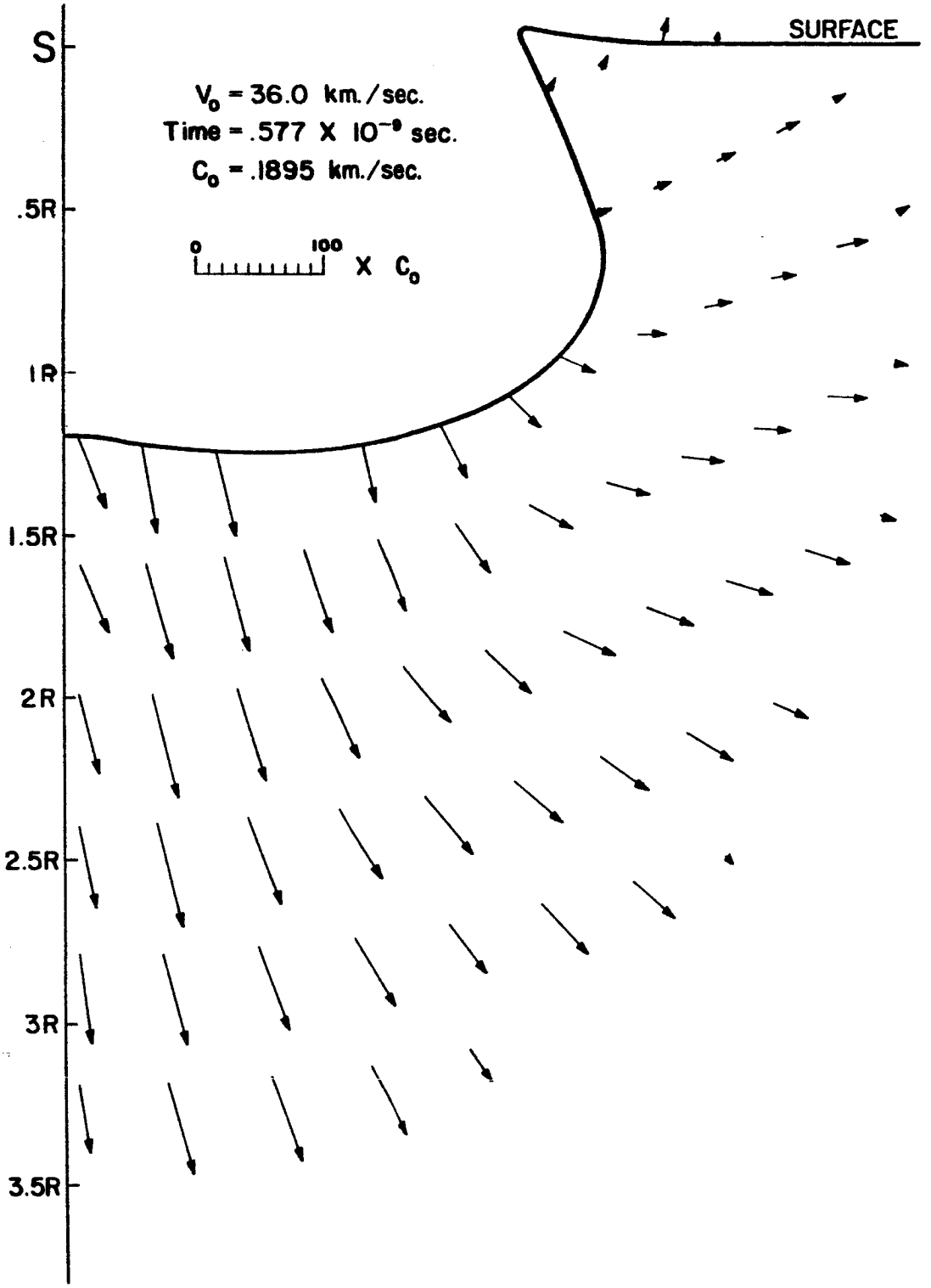

Figure 182. Velocity Map (t = .577 x 10^{-10} sec) IV

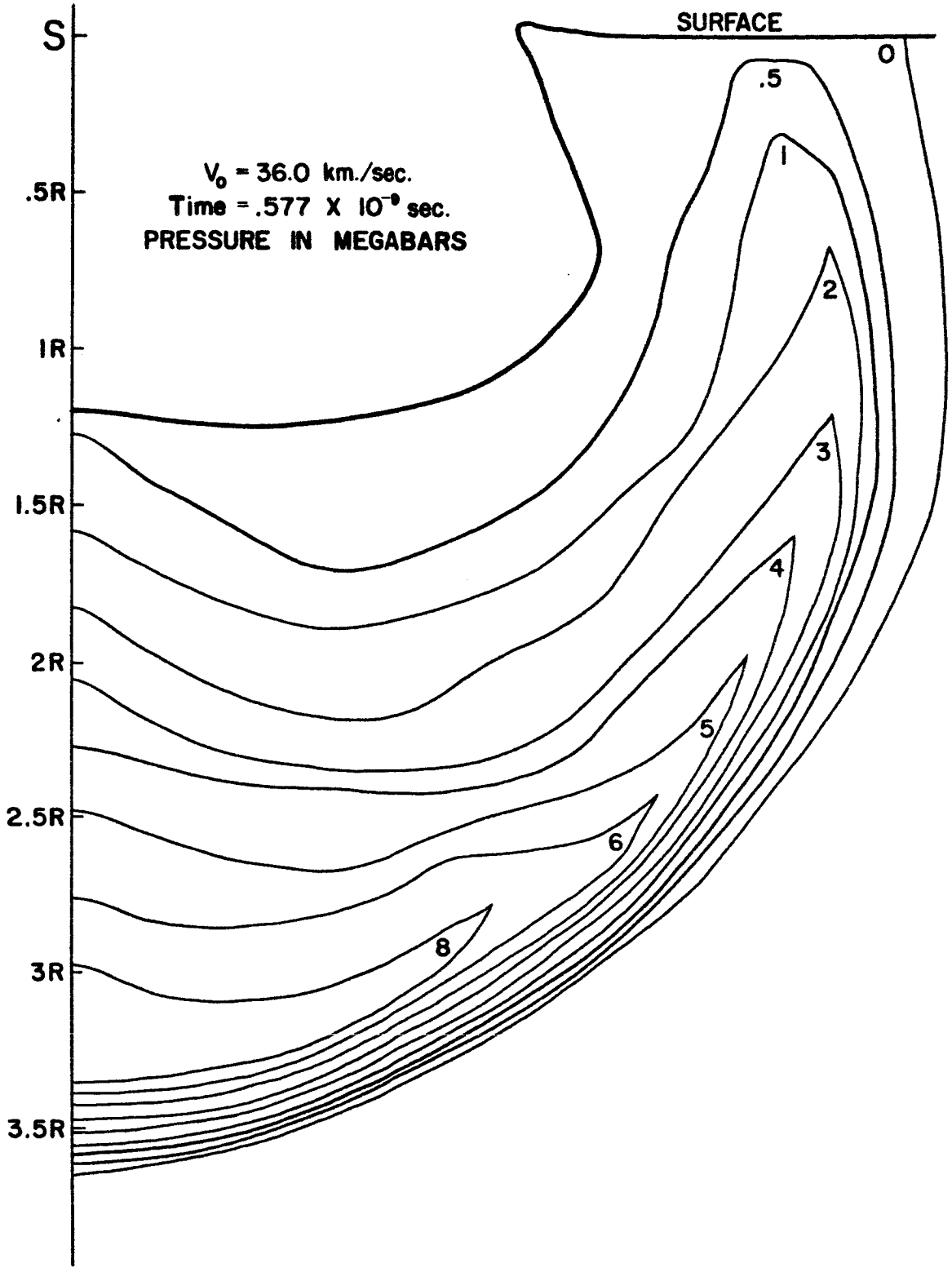

Figure 183. Pressure Map ($t = .577 \times 10^{-10}$ sec) IV

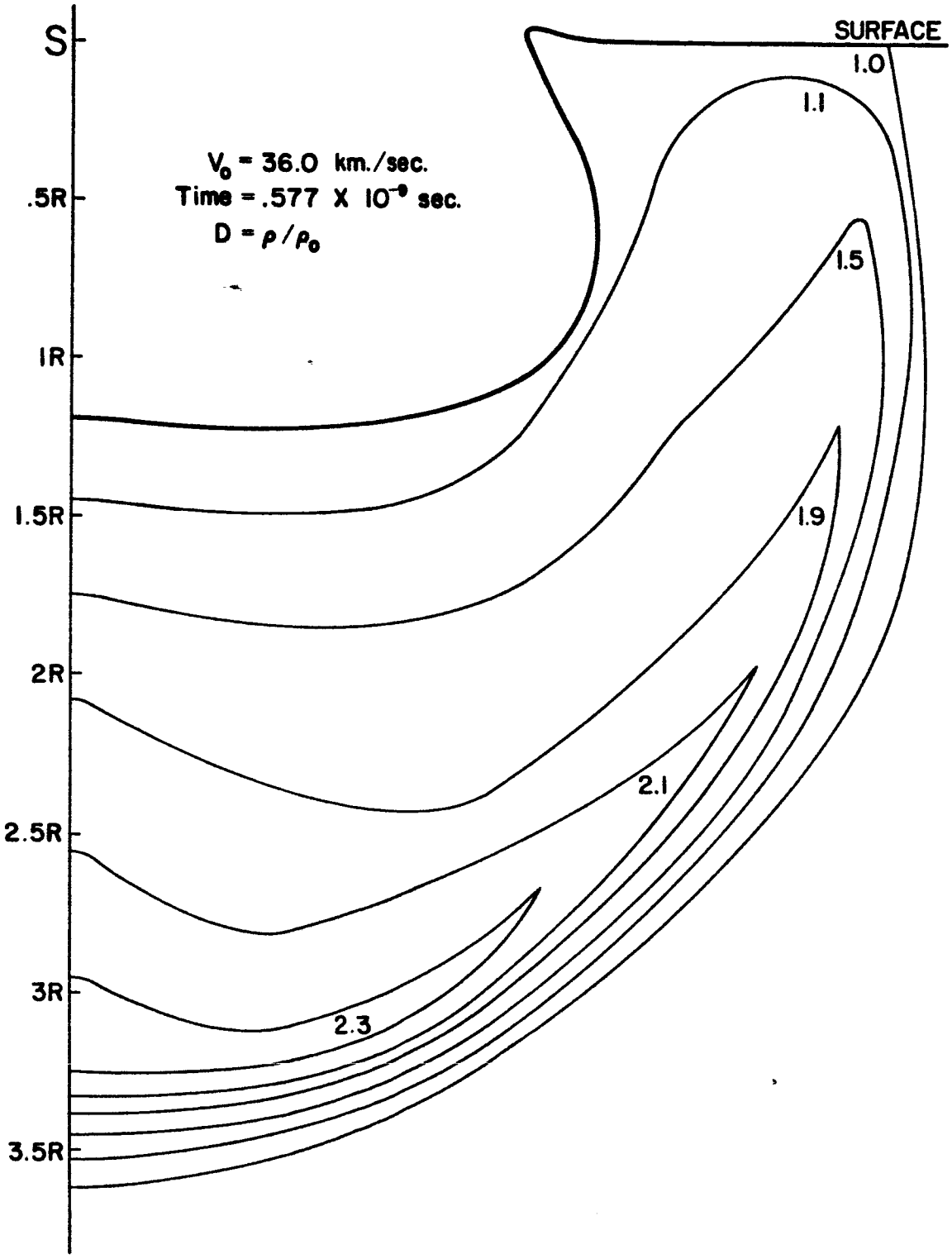

Figure 184. Density Map (t = .577 x 10^{-10} sec) IV

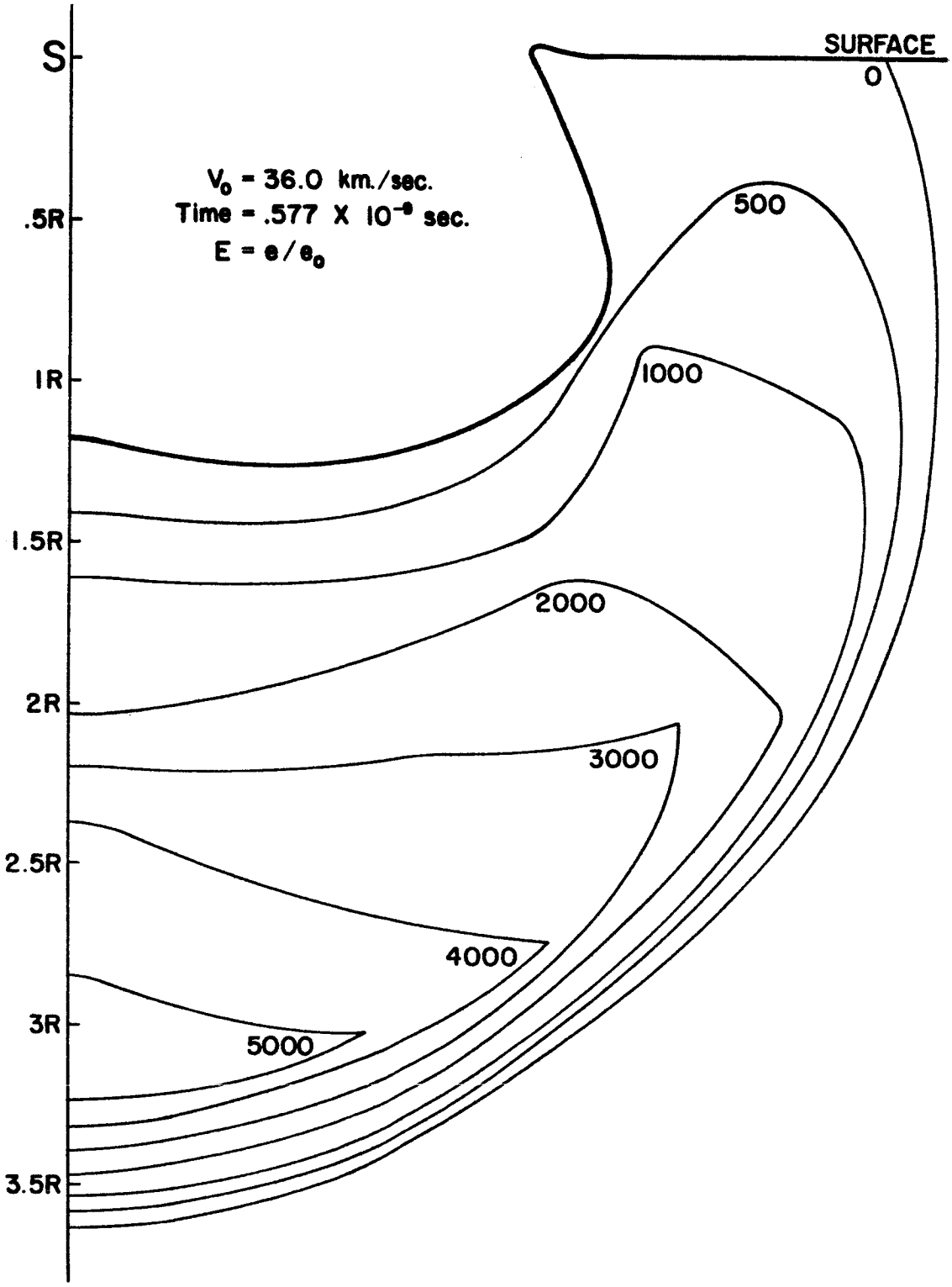

Figure 185. Energy Map (t = .577 x 10^{-10} sec) IV

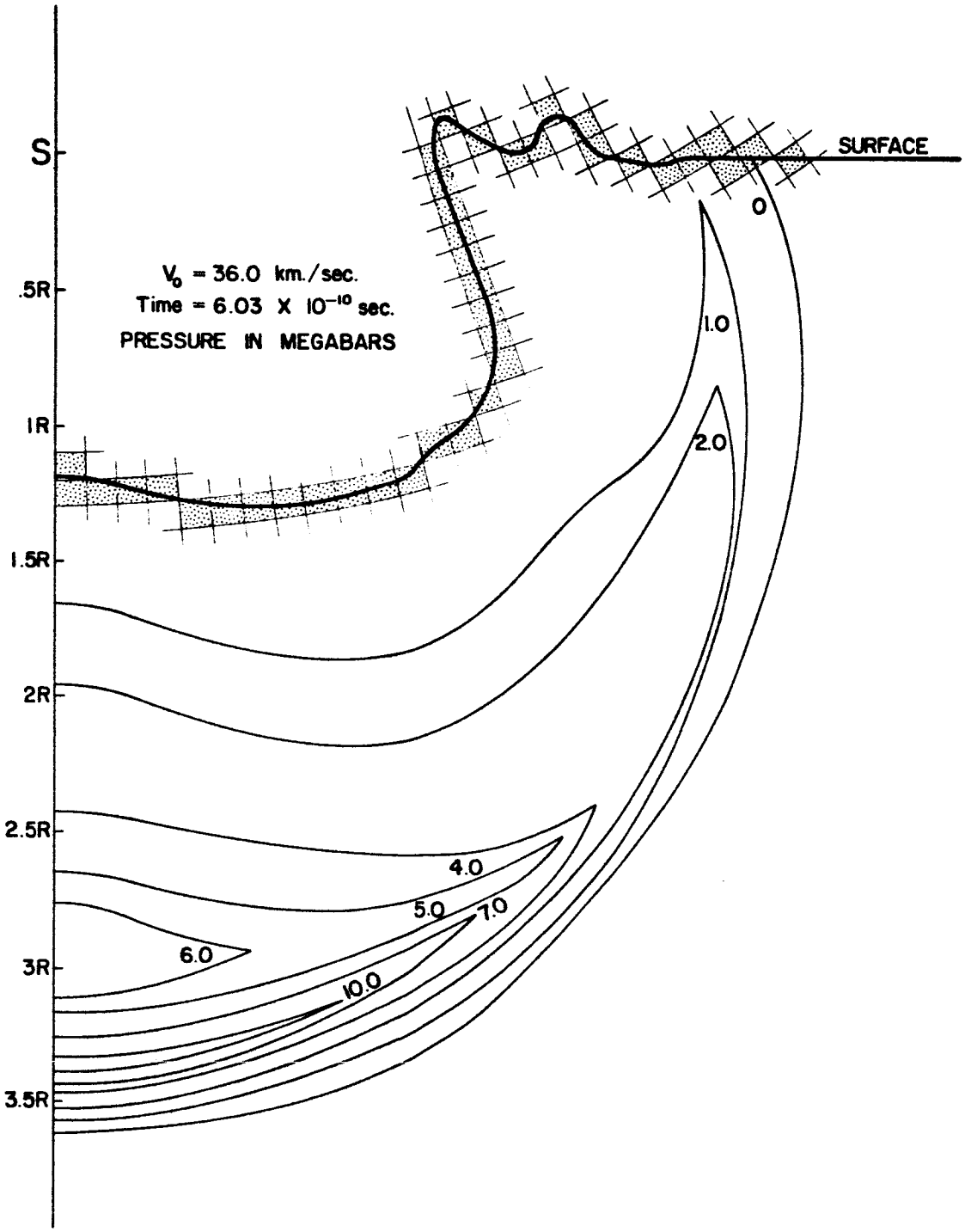

Figure 186. Pressure Map (t = 6.03 x 10^{-10} sec) IV

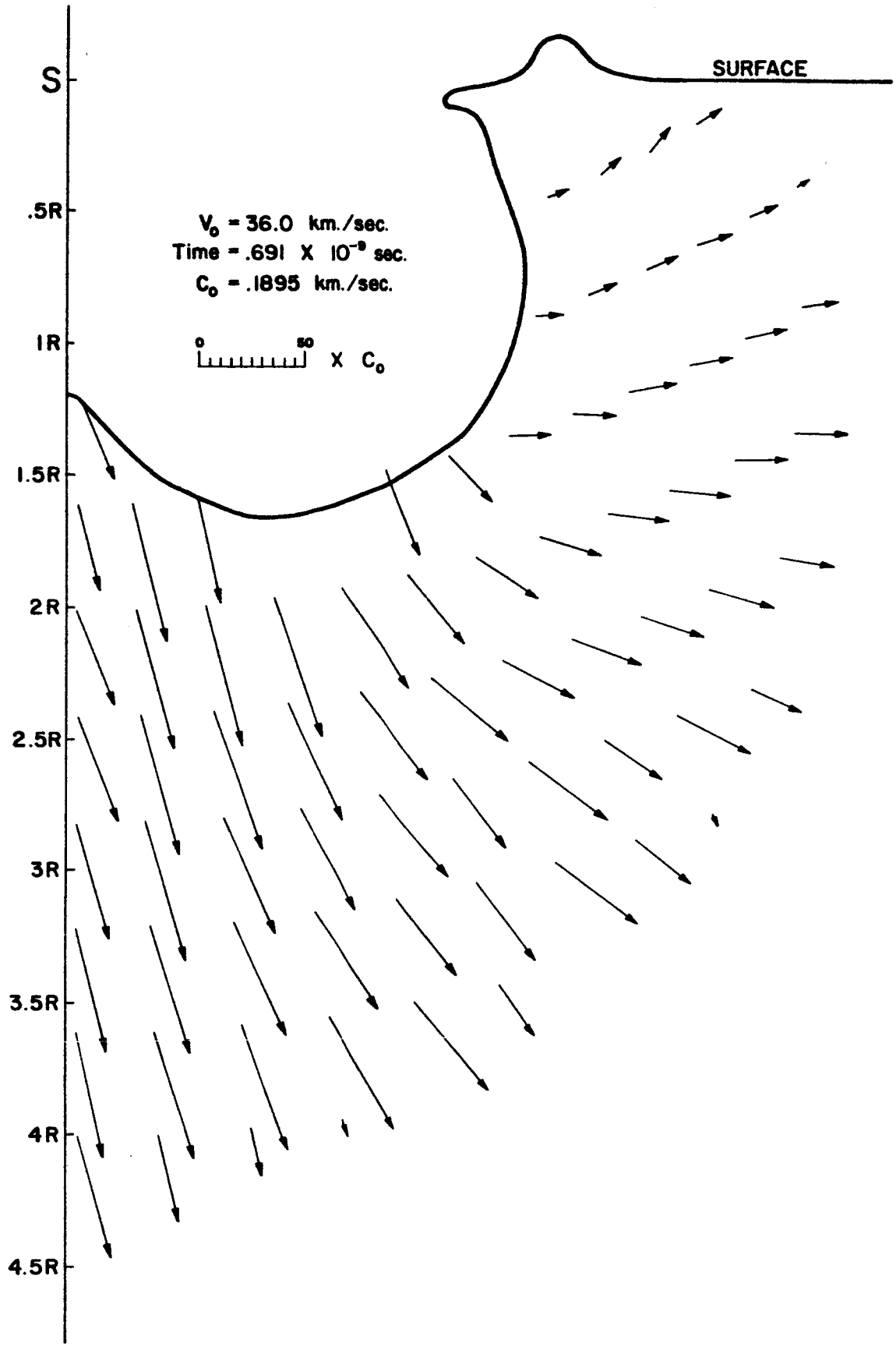

Figure 187. Velocity Map (t = .691 x 10^{-9} sec) IV

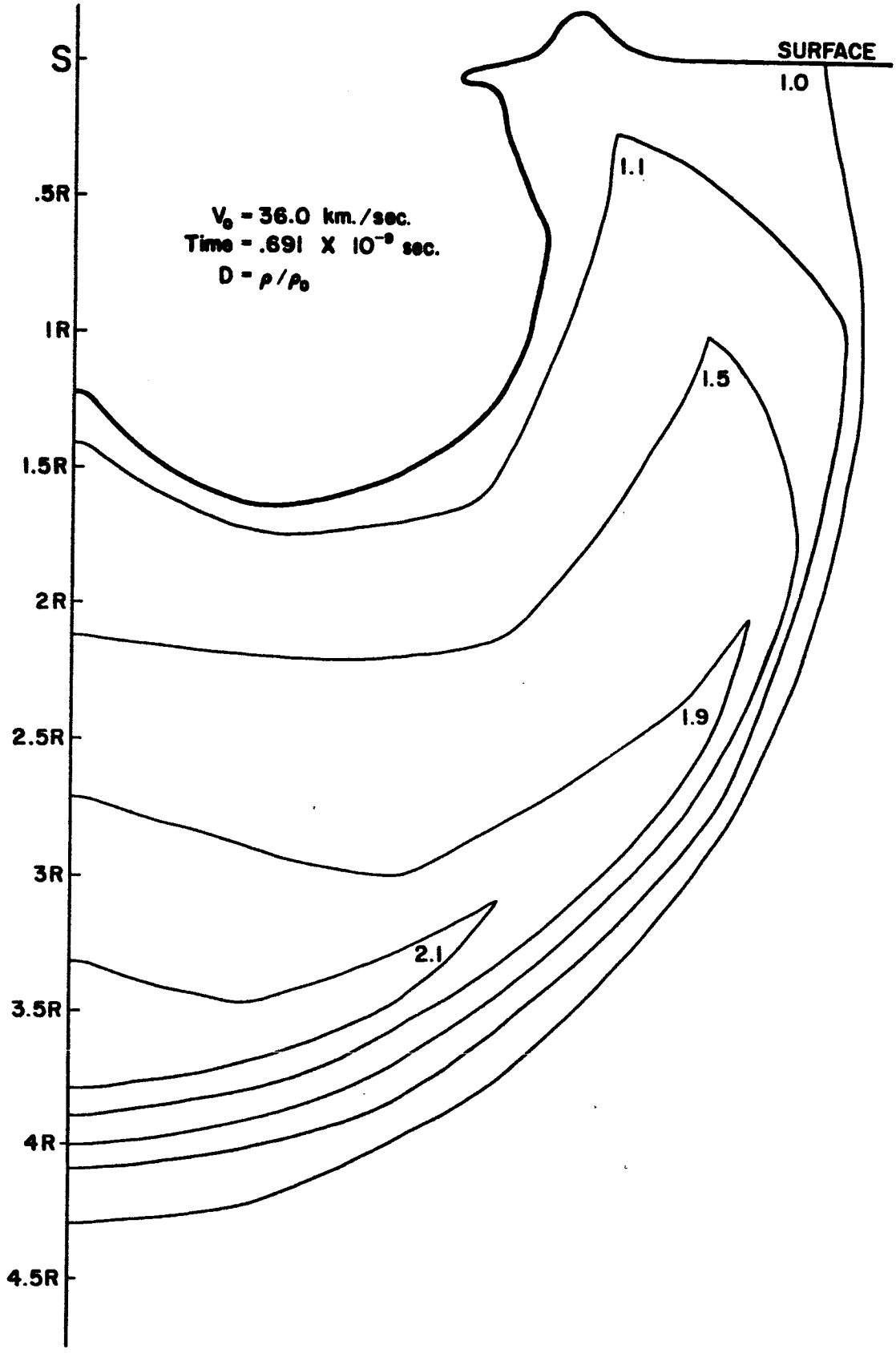

Figure 188. Density Map (t = .691 x 10^{-9} sec) IV

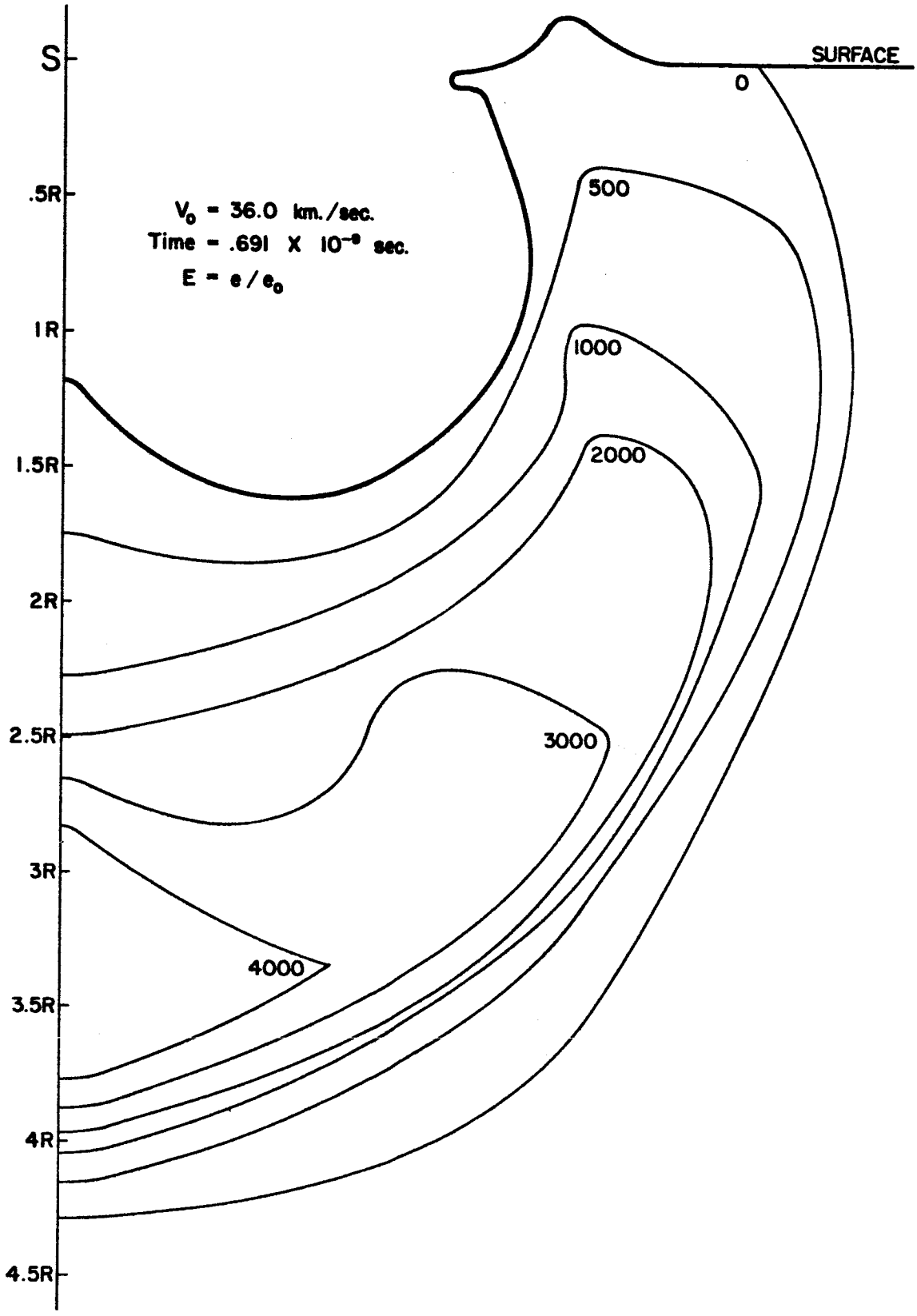

Figure 189. Energy Map (t = .691 x 10^{-9} sec) IV

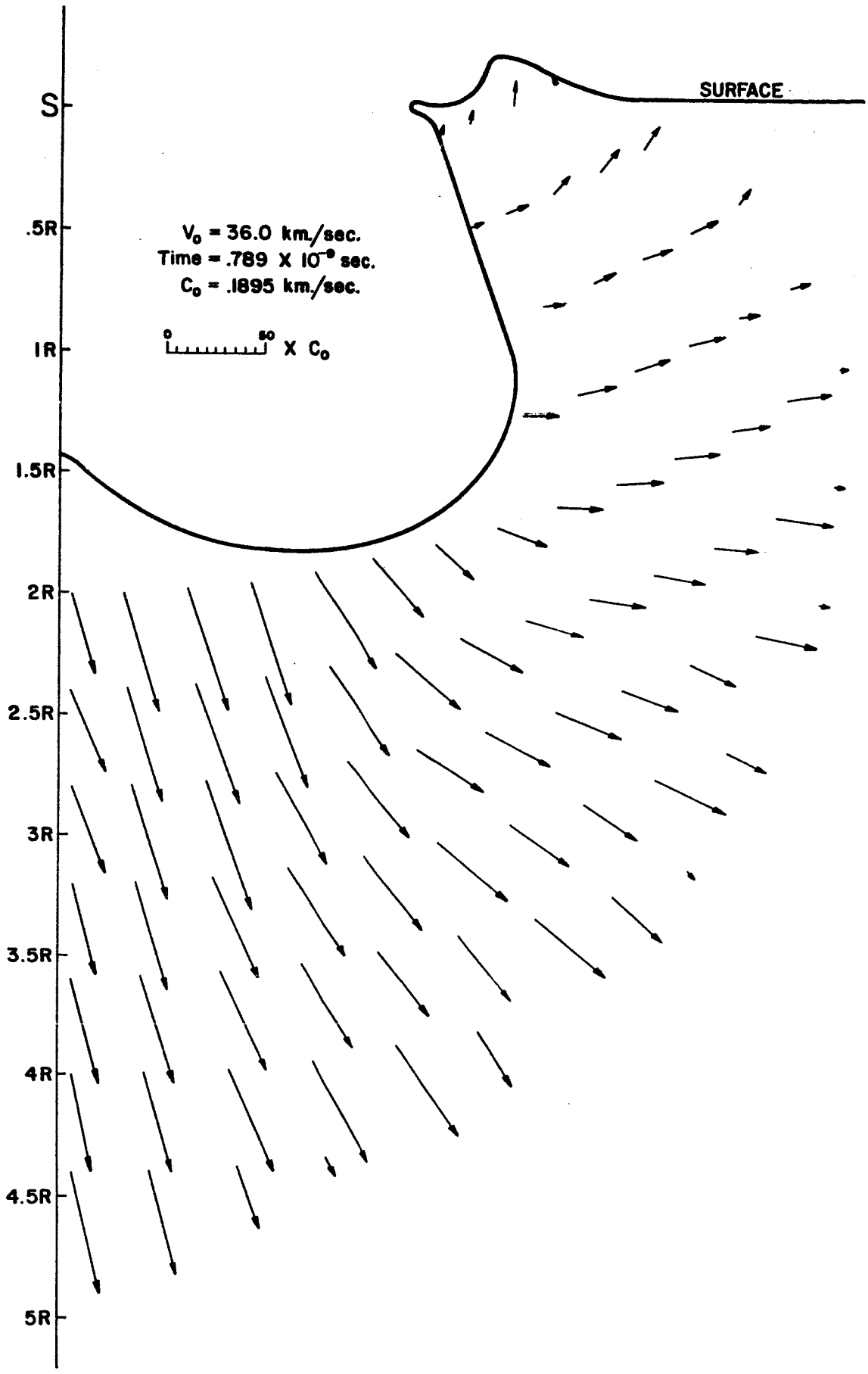

Figure 190. Velocity Map (t = .789 x 10^{-9} sec) IV

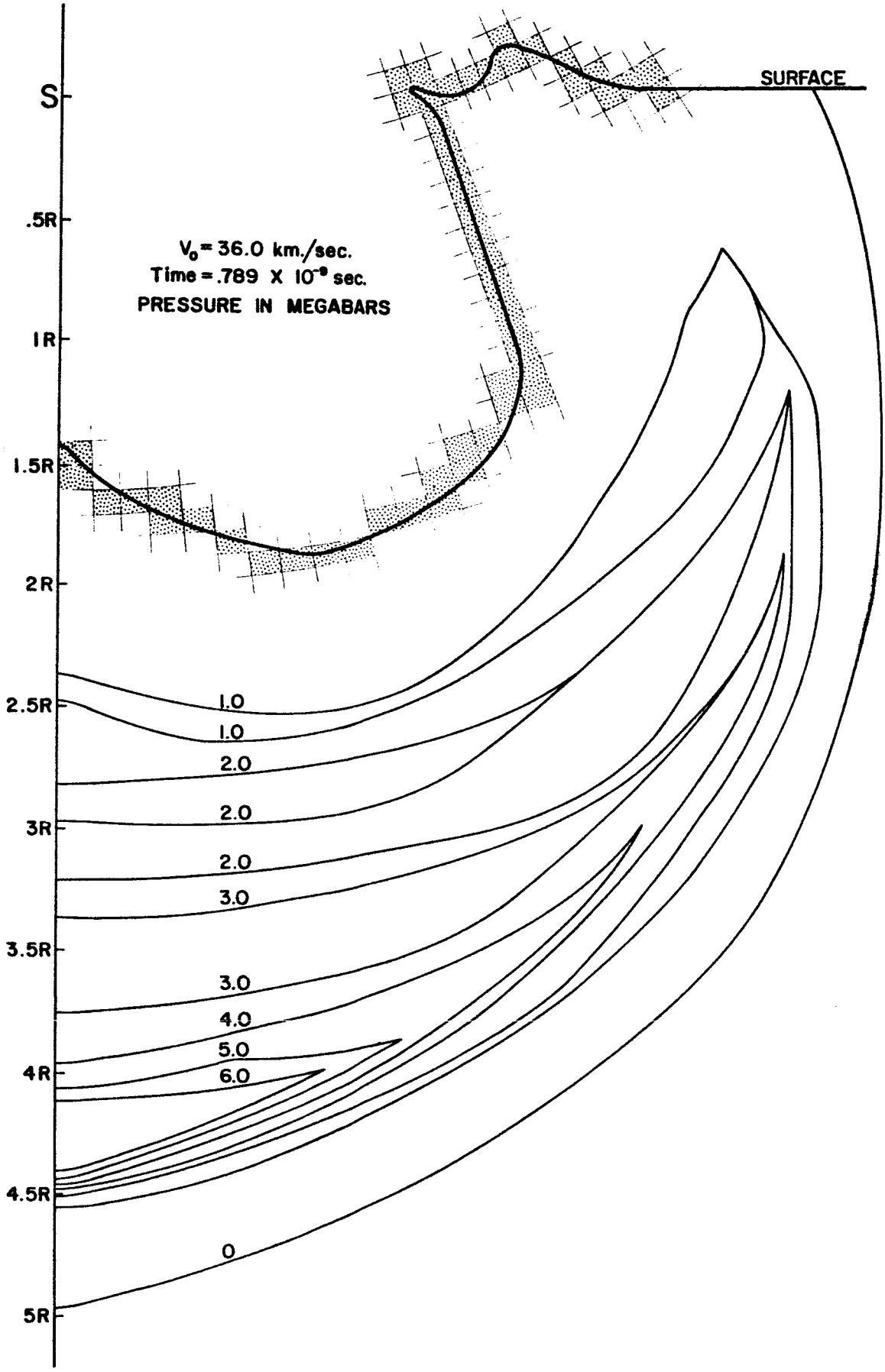

Figure 191. Pressure Map (t = .789 x 10^{-9} sec) IV

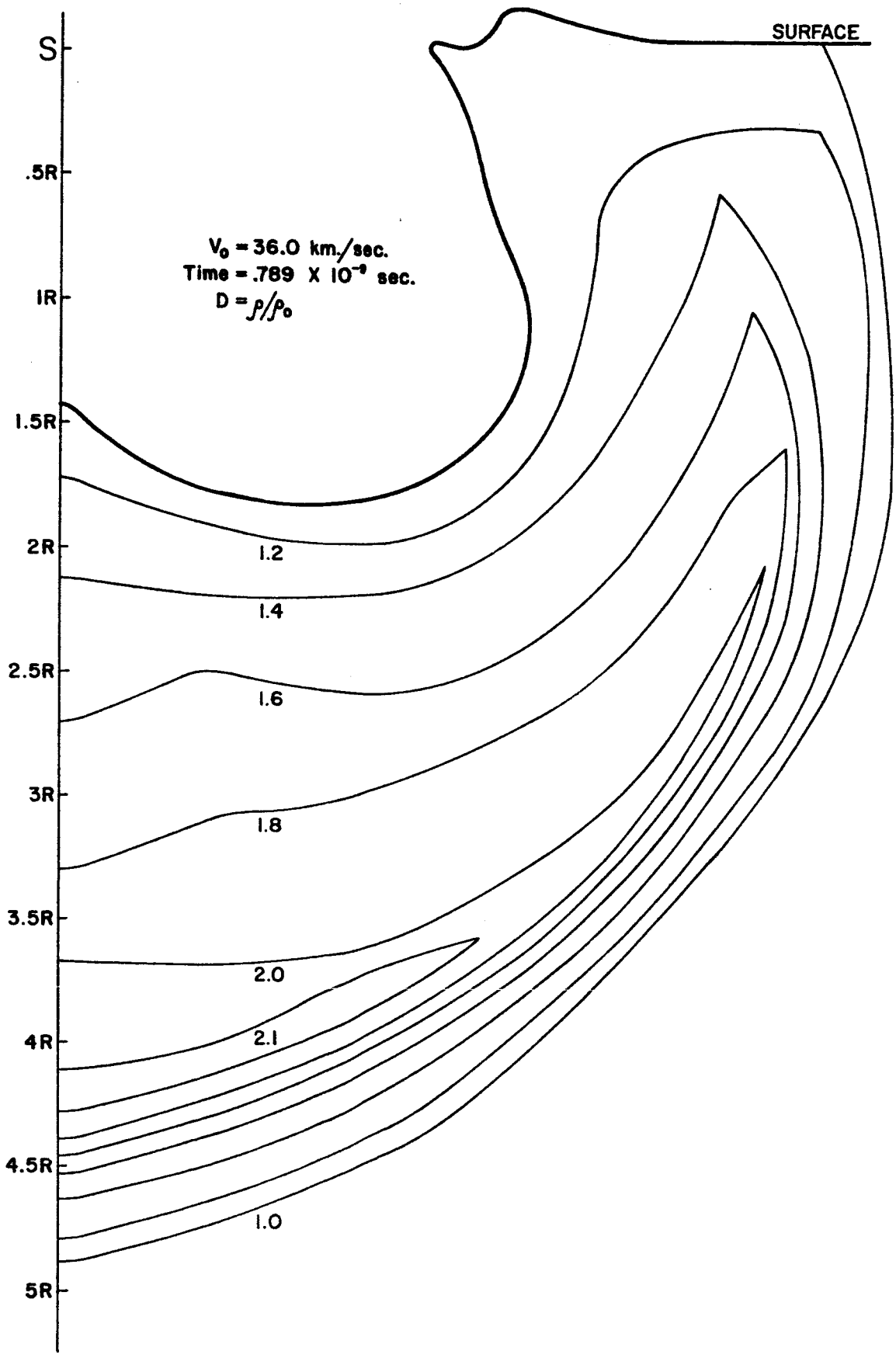

Figure 192. Density Map (t = .789 x 10^{-9} sec) IV

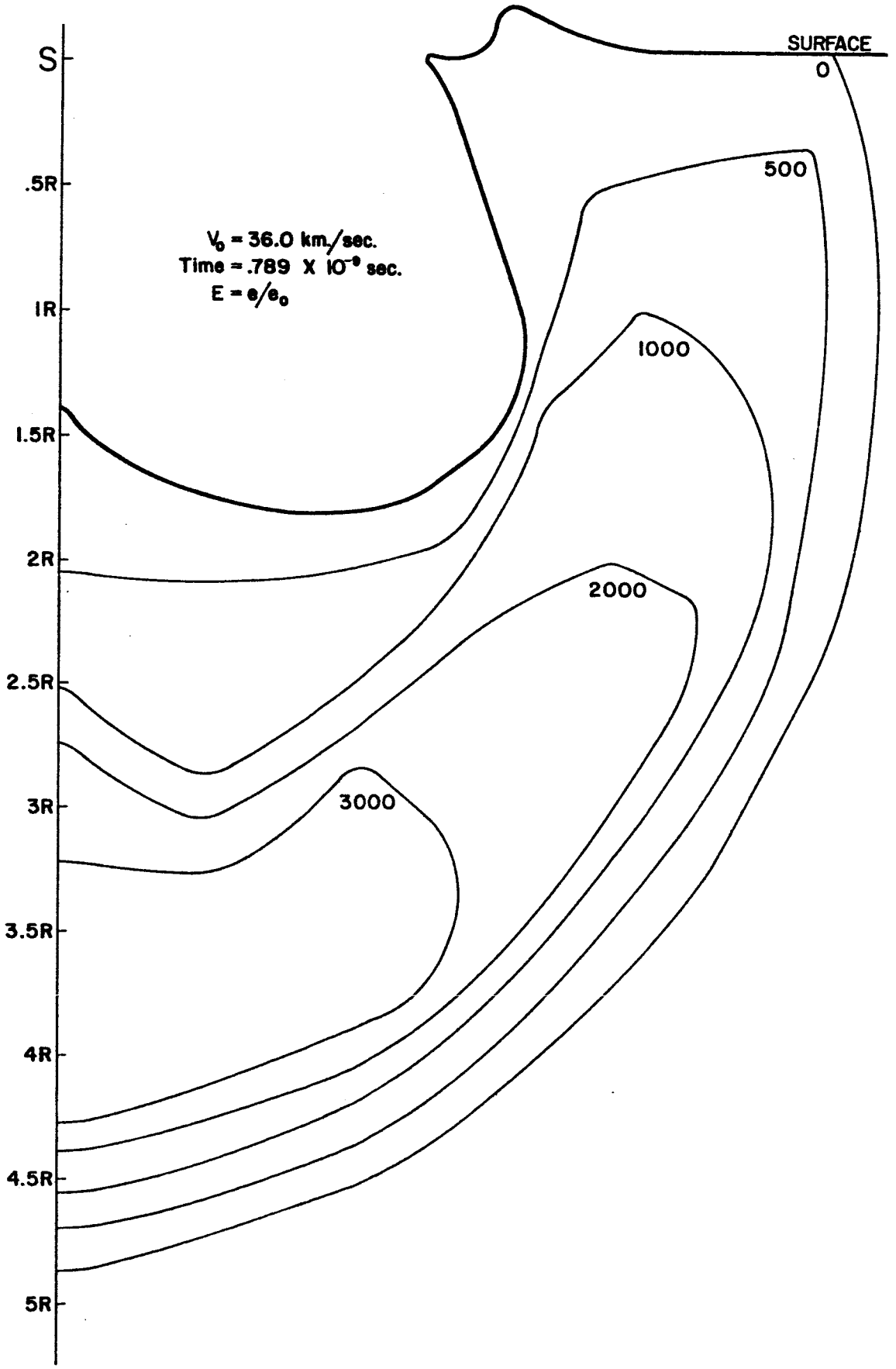

Figure 193. Energy Map (t = .789 x 10^{-9} sec) IV

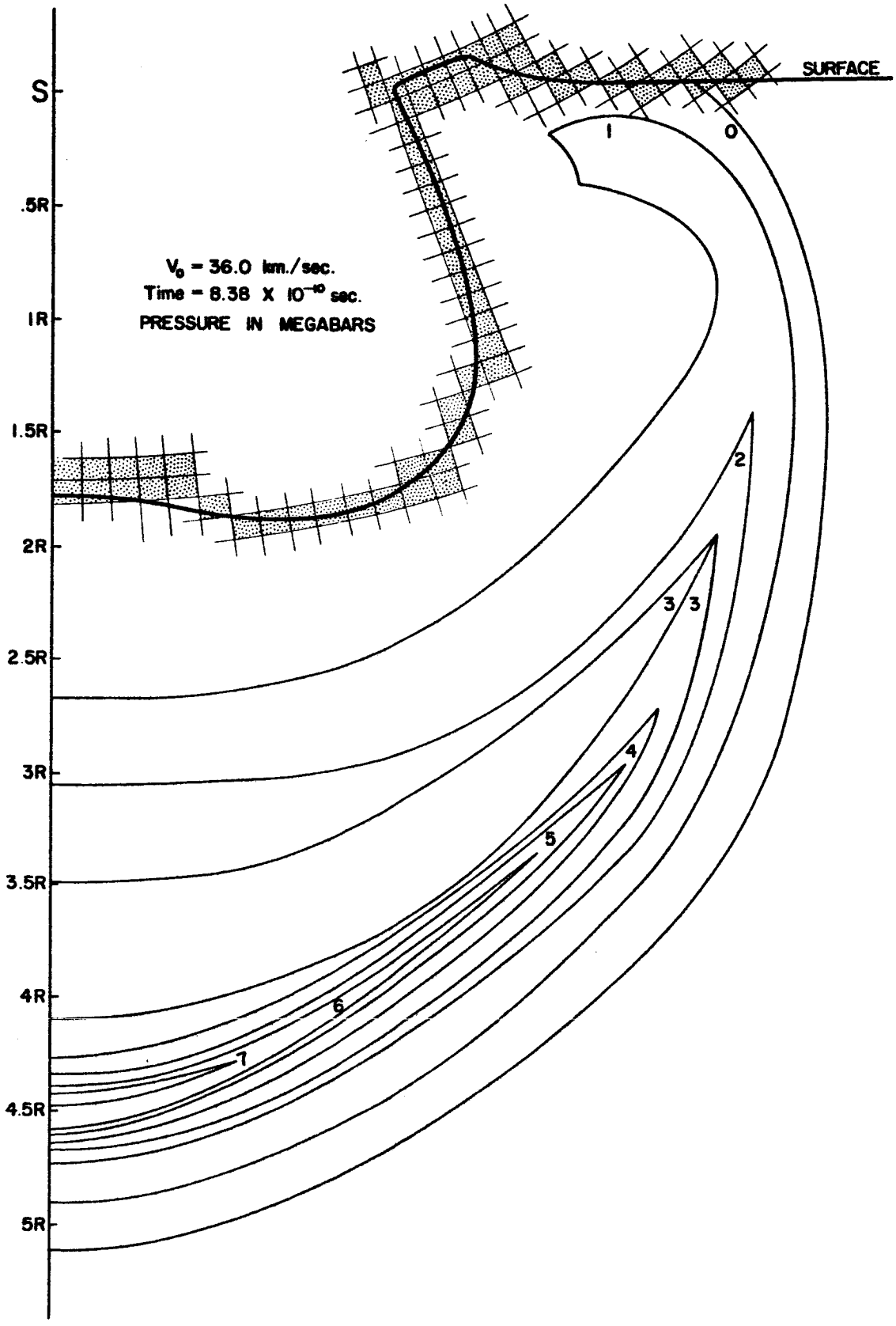

Figure 194. Pressure Map (t = 8.38 x 10^{-10} sec) IV

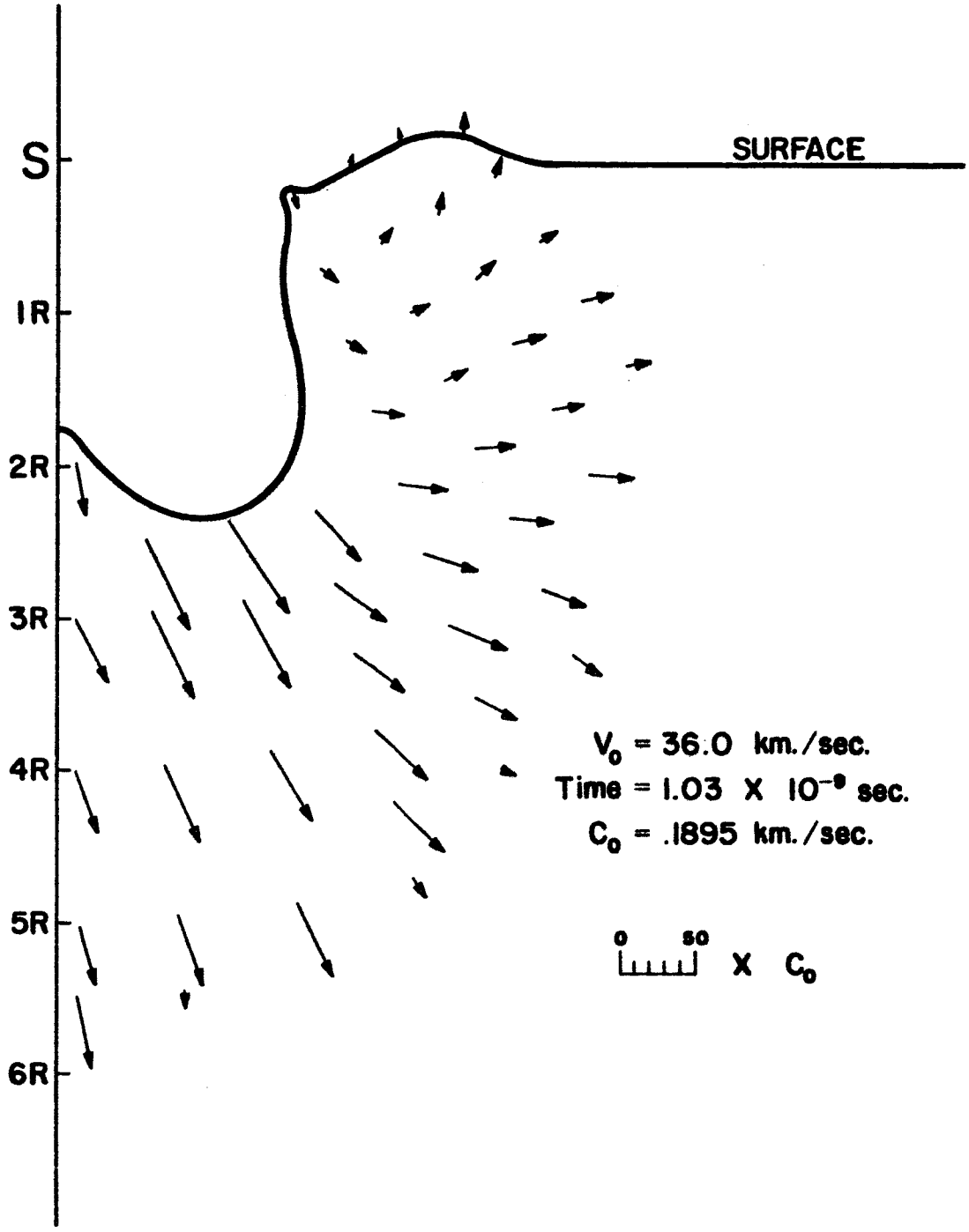

Figure 195. Velocity Map (t = 1.03 x 10^{-9} sec) IV

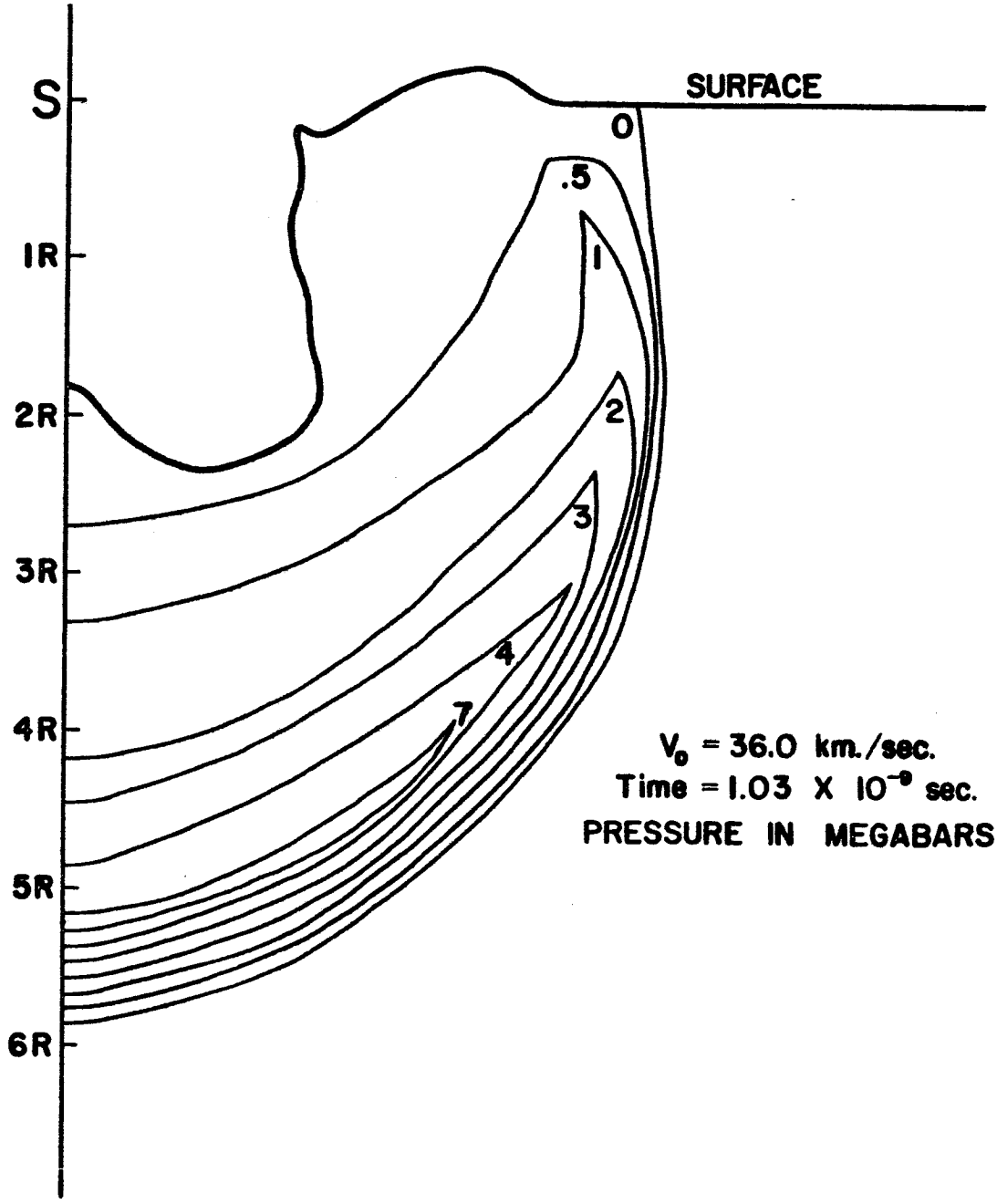

Figure 196. Pressure Map (t = 1.03 x 10^{-9} sec) IV

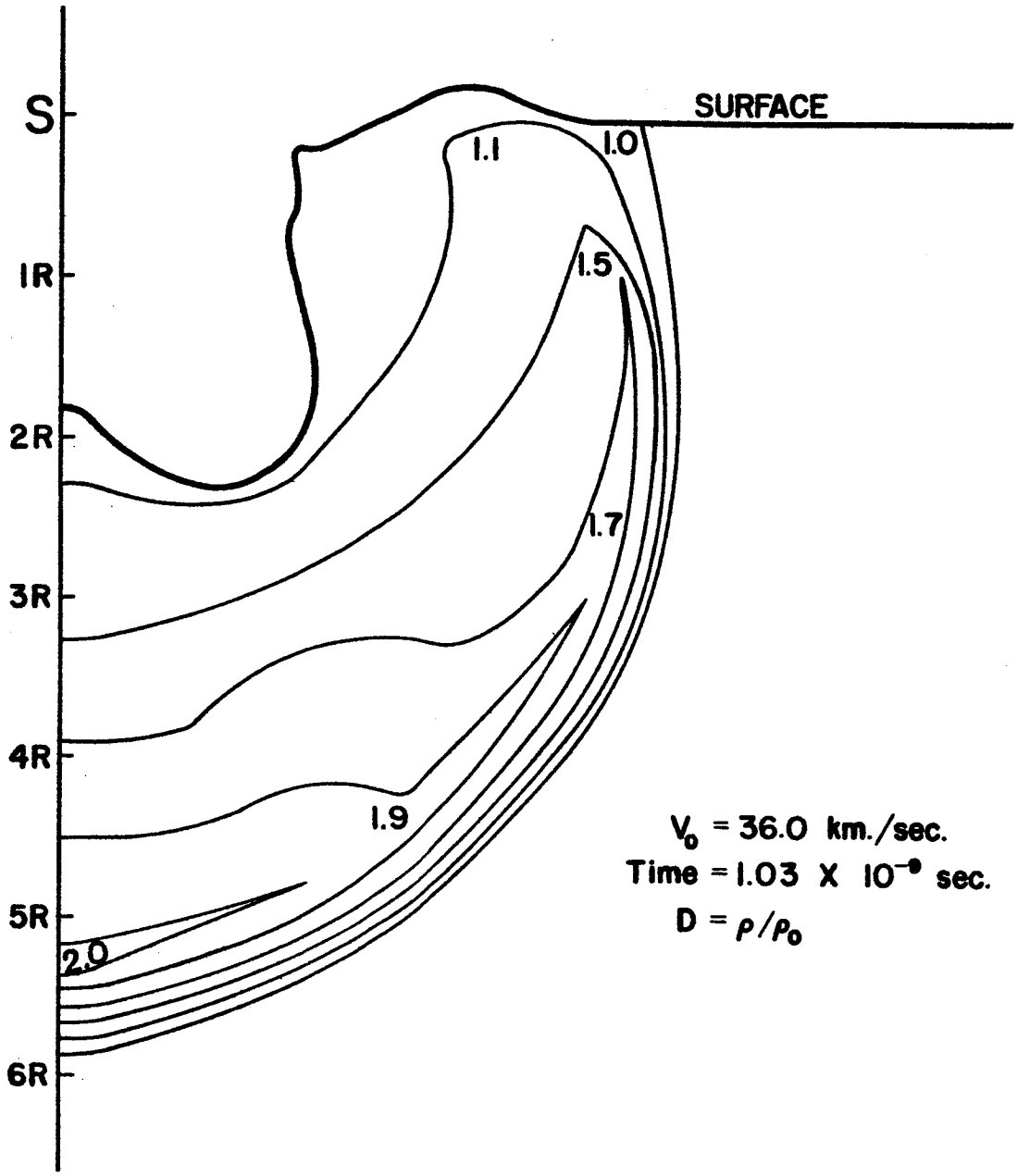

Figure 197. Density Map (t = 1.03 x 10^{-9} sec) IV

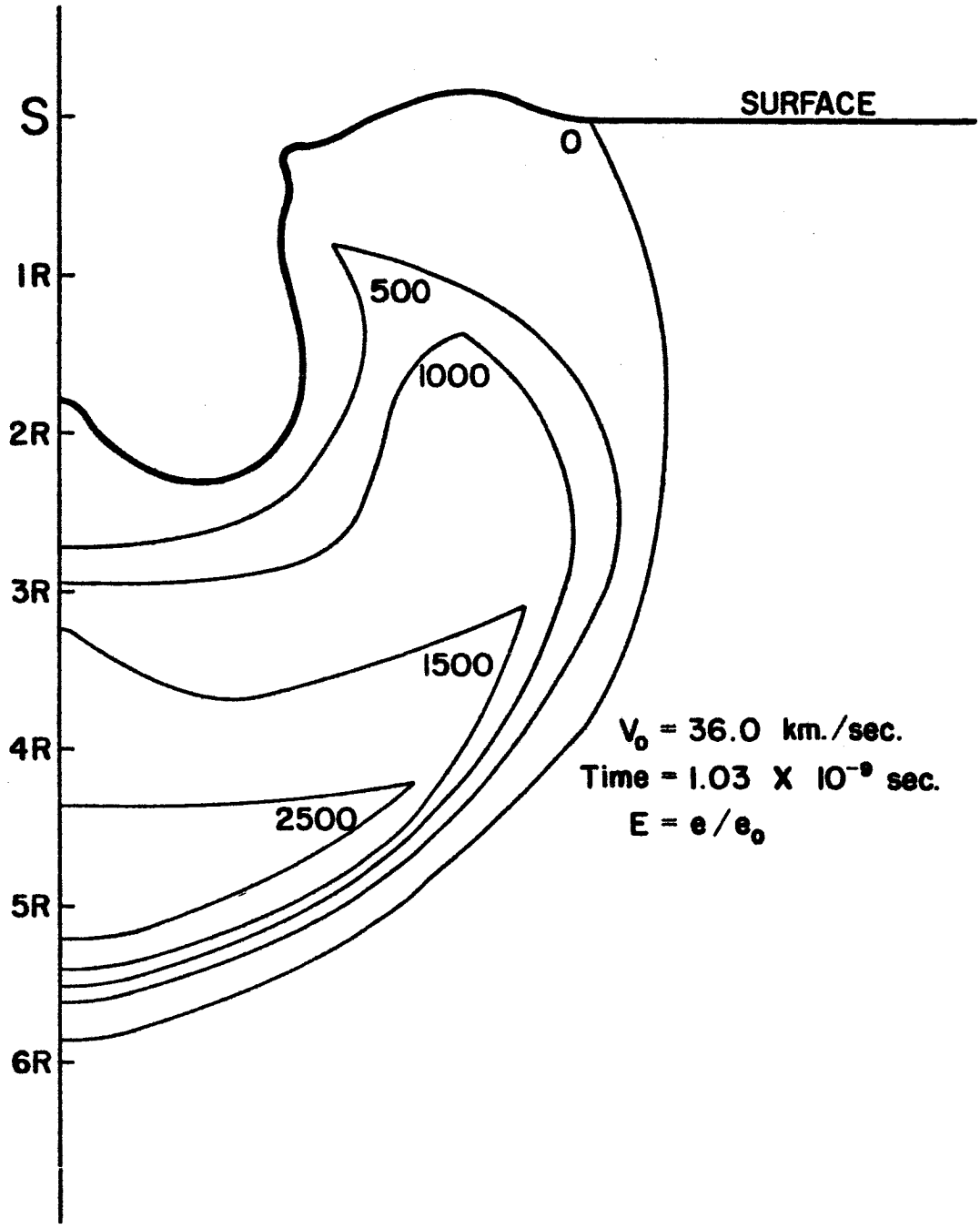

Figure 198. Energy Map (t = 1.03 x 10^{-9} sec) IV

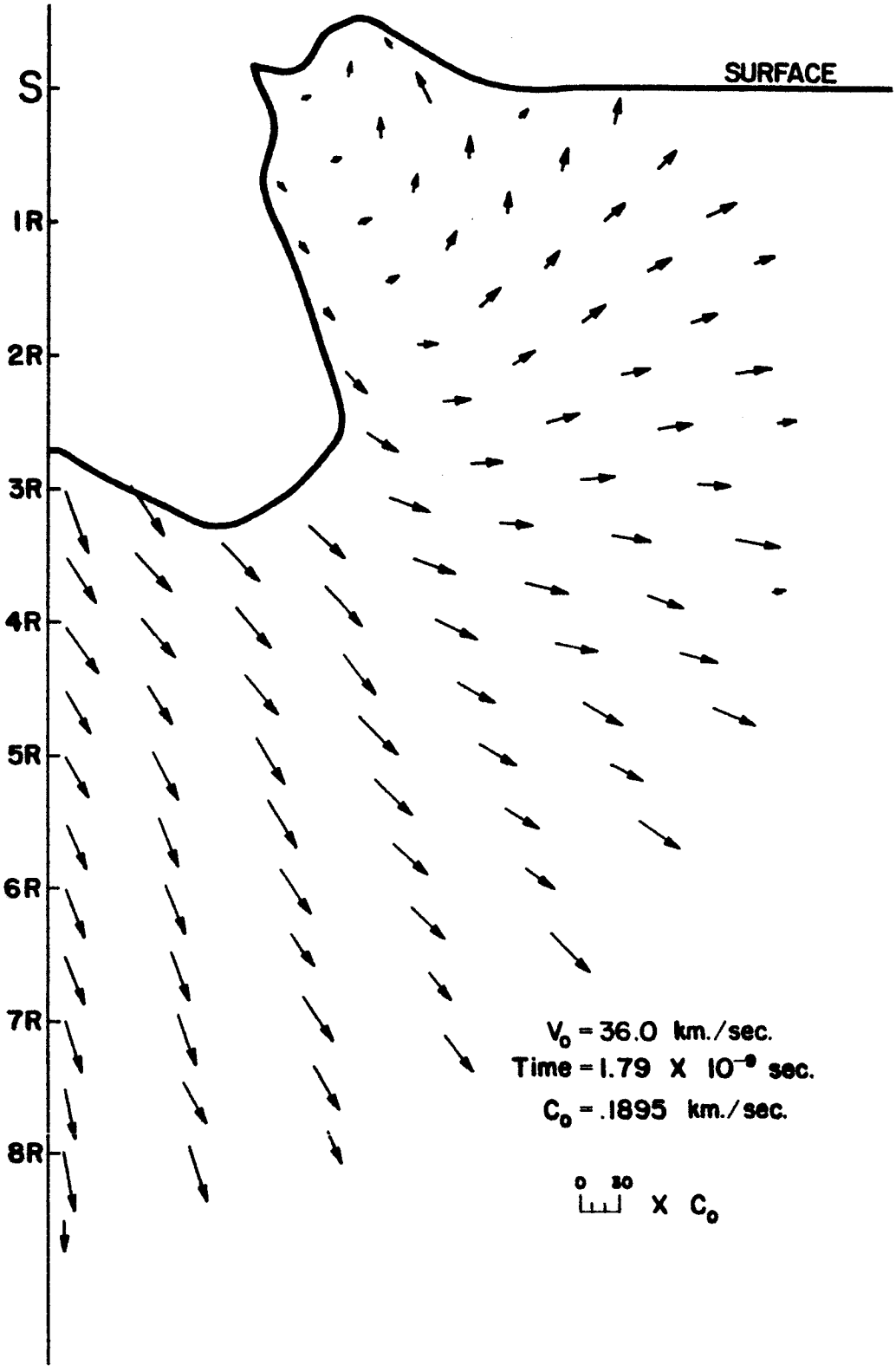

Figure 199. Velocity Map (t = 1.79 x 10^{-9} sec) IV

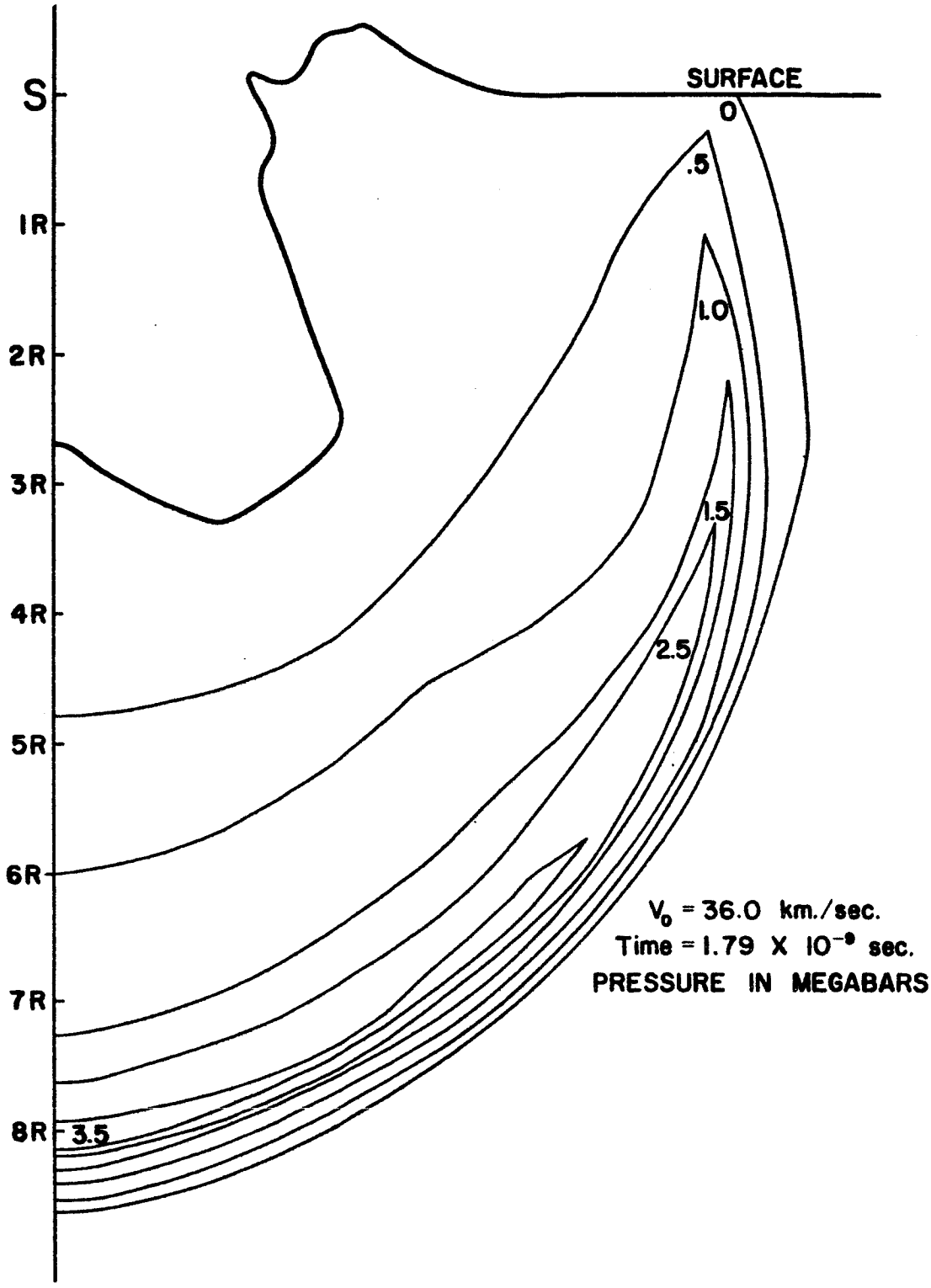

Figure 200. Pressure Map (t = 1.79 x 10^{-9} sec) IV

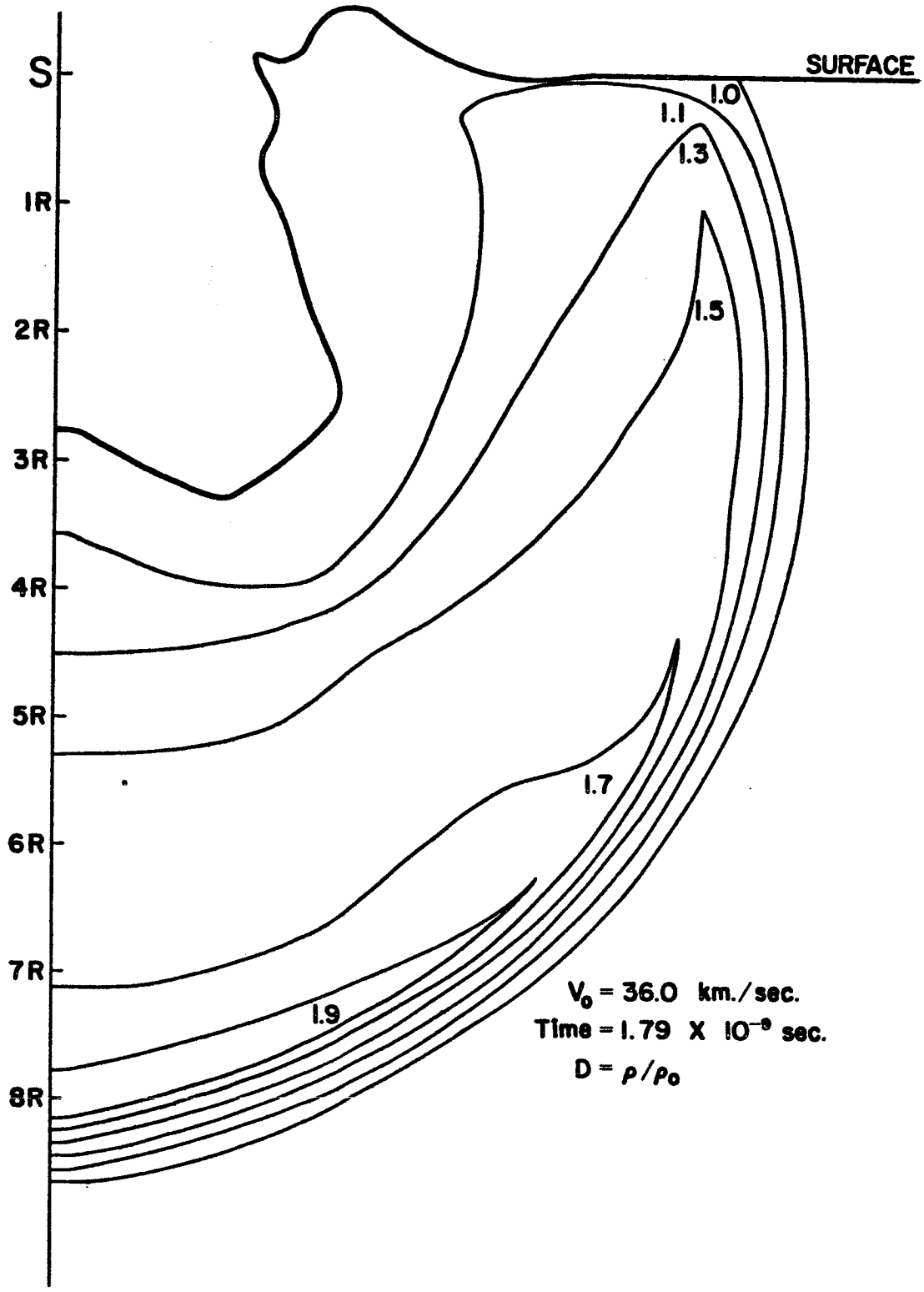

Figure 201. Density Map (t = 1.79 x 10^{-9} sec) IV

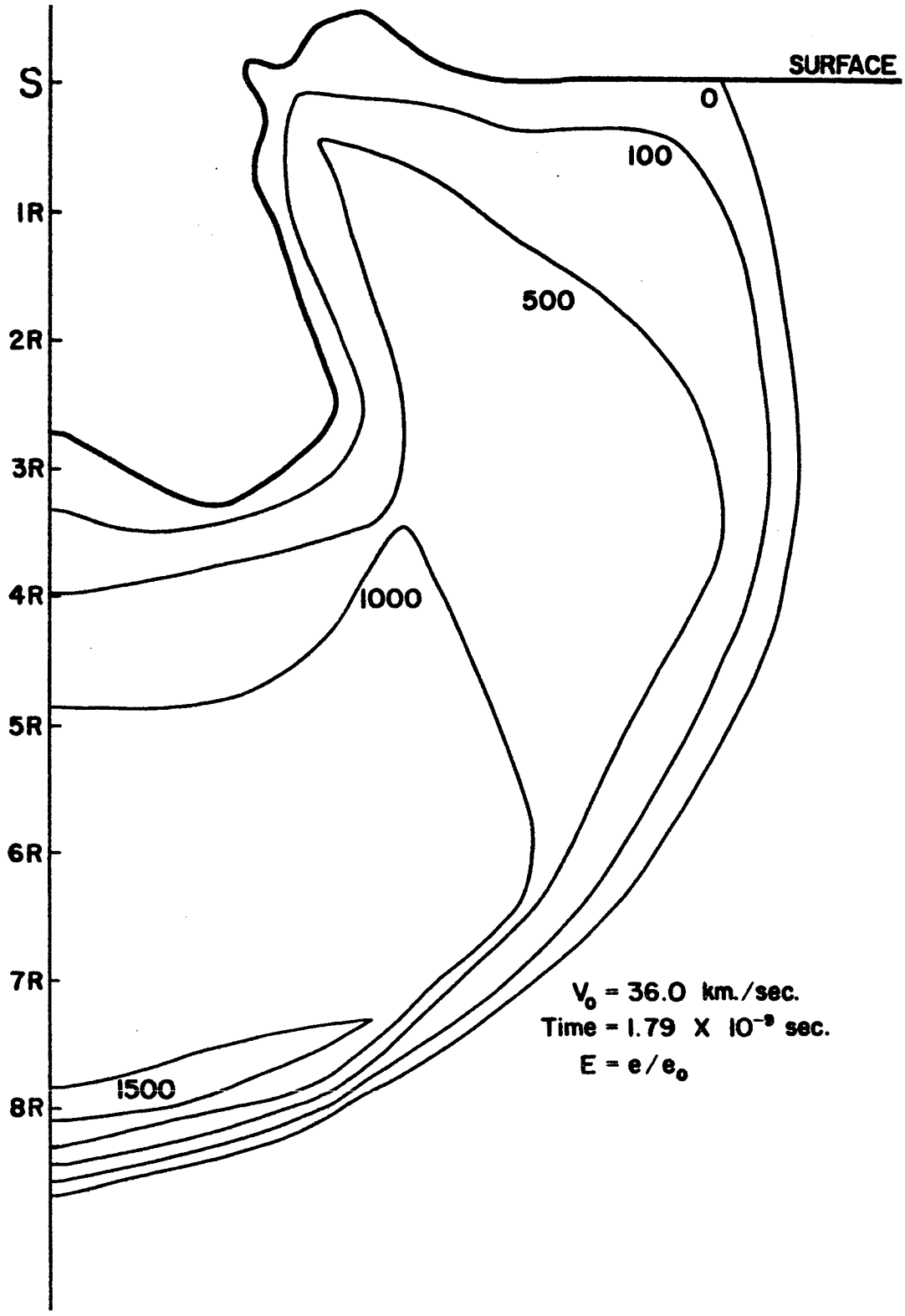

Figure 202. Energy Map (t = 1.79 x 10^{-9} sec) IV

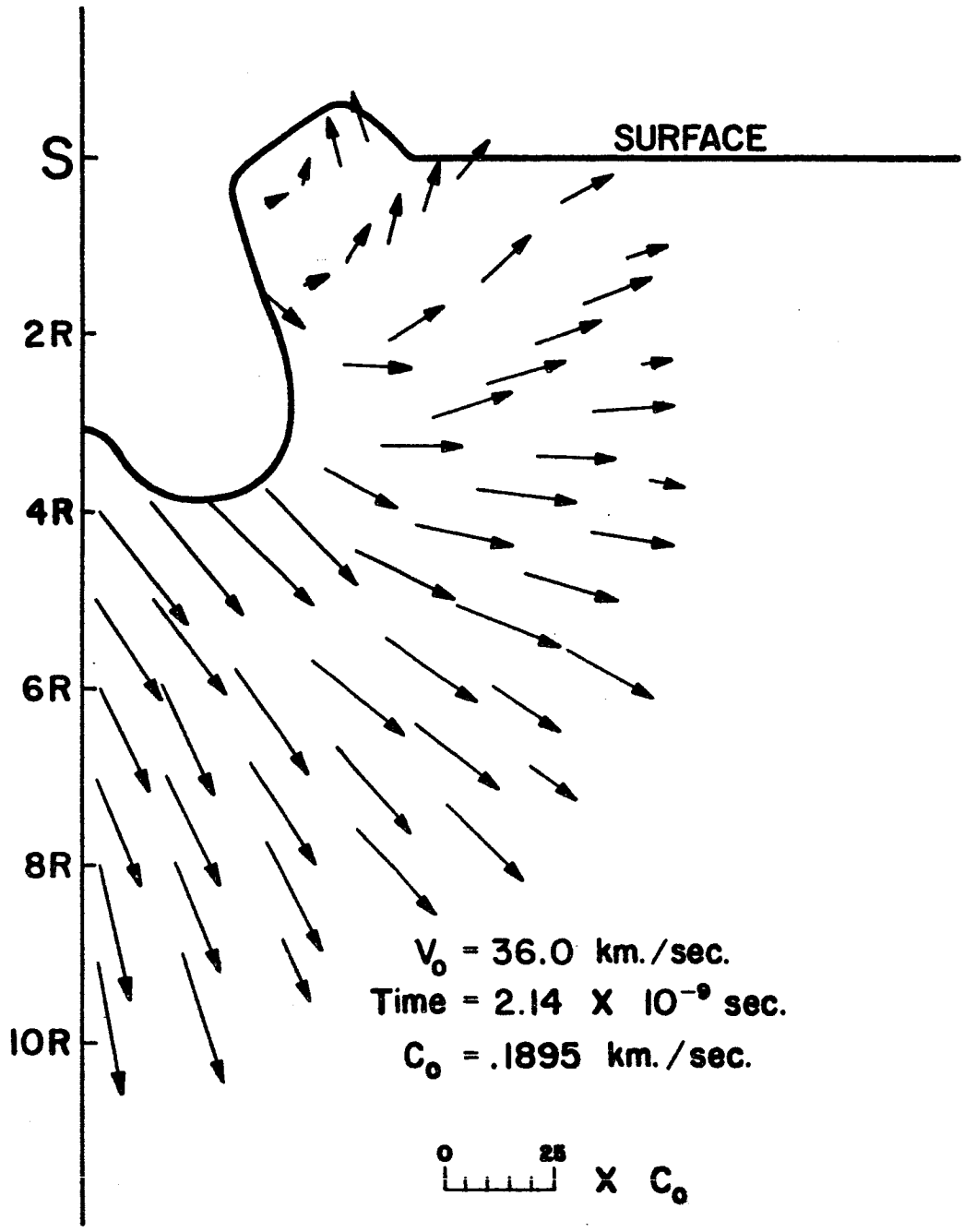

Figure 203. Velocity Map (t = 2.14 x 10^{-9} sec) IV

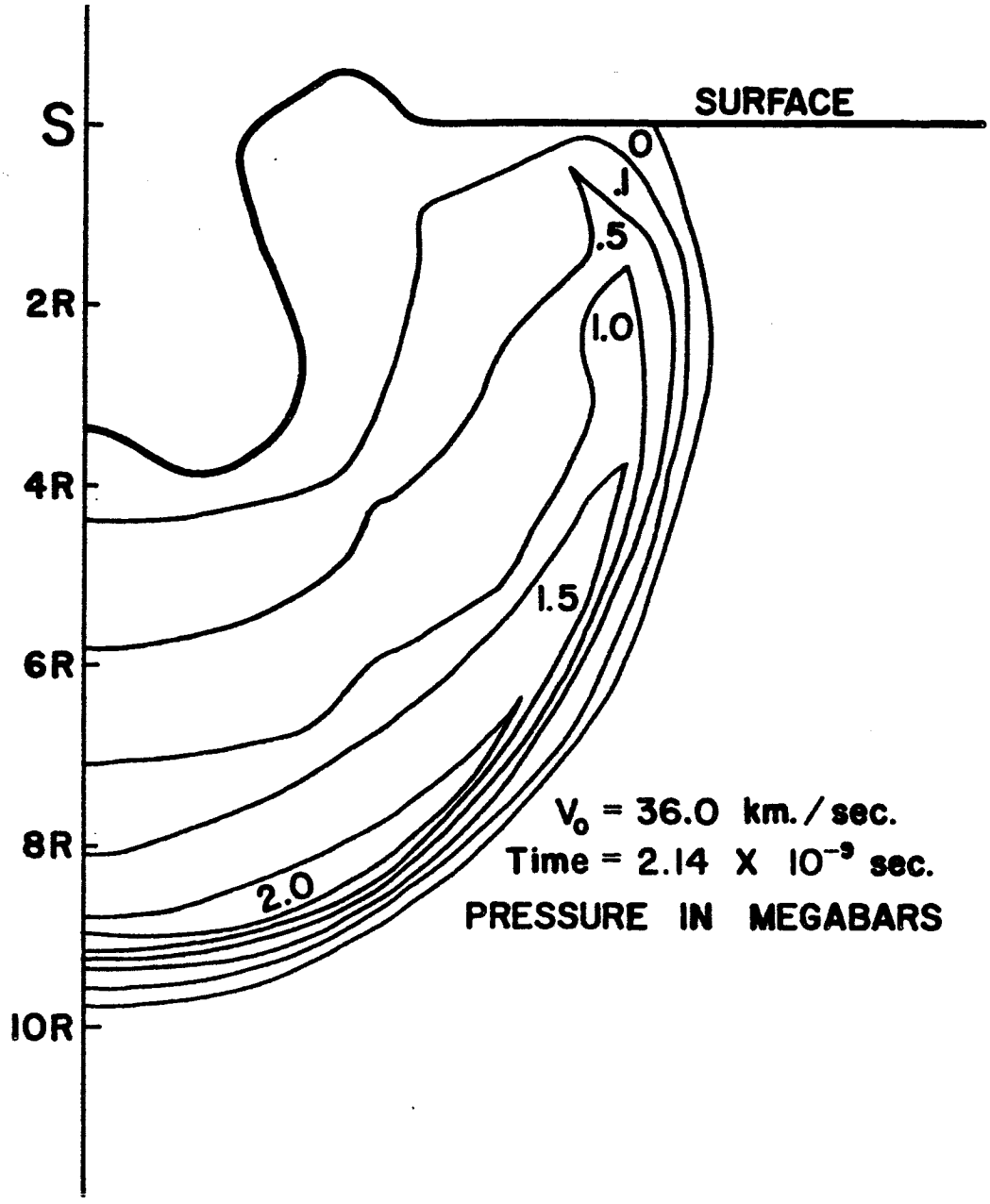

Figure 204. Pressure Map (t = 2.14 x 10^{-9} sec) IV

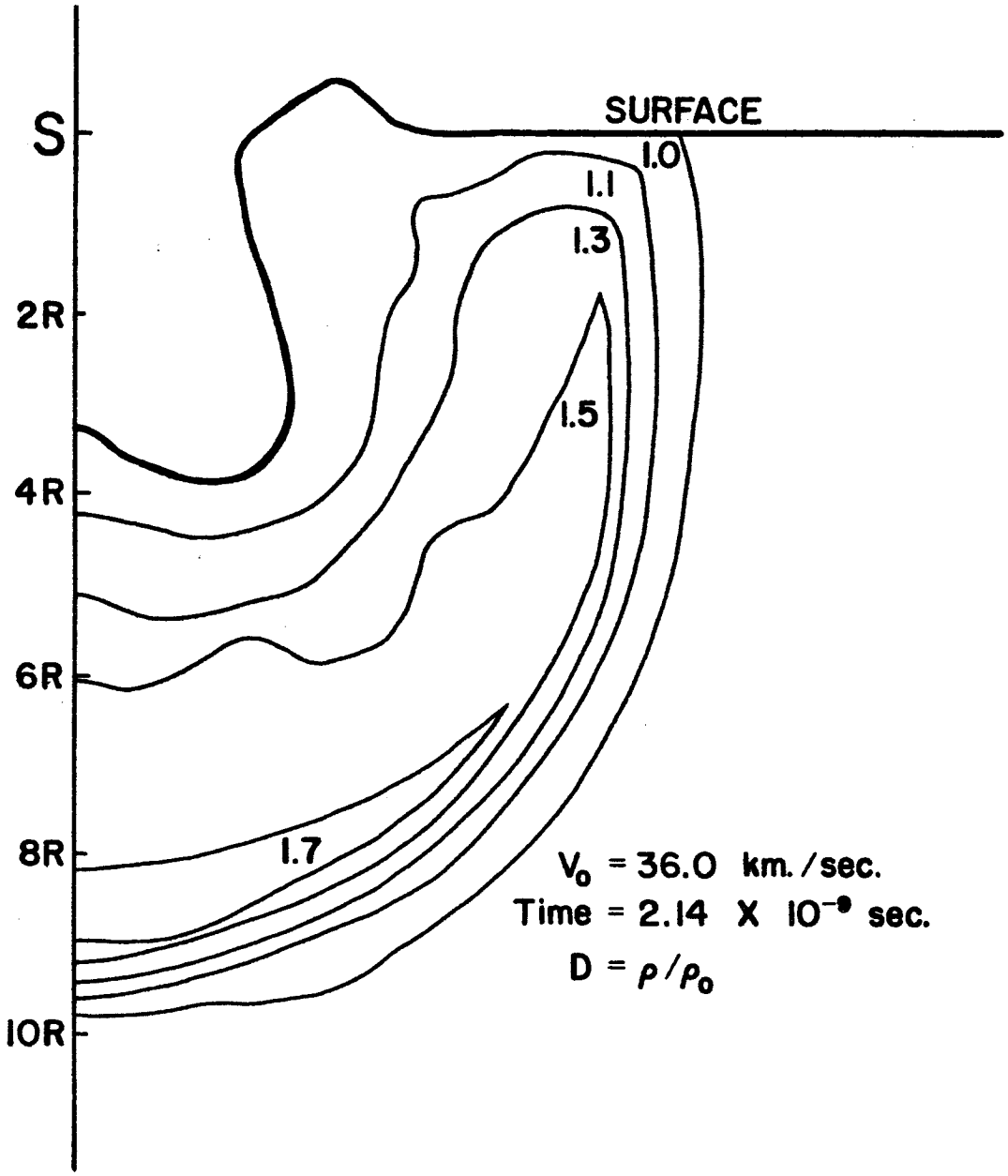

Figure 205. Density Map (t = 2.14 x 10^{-9} sec) IV

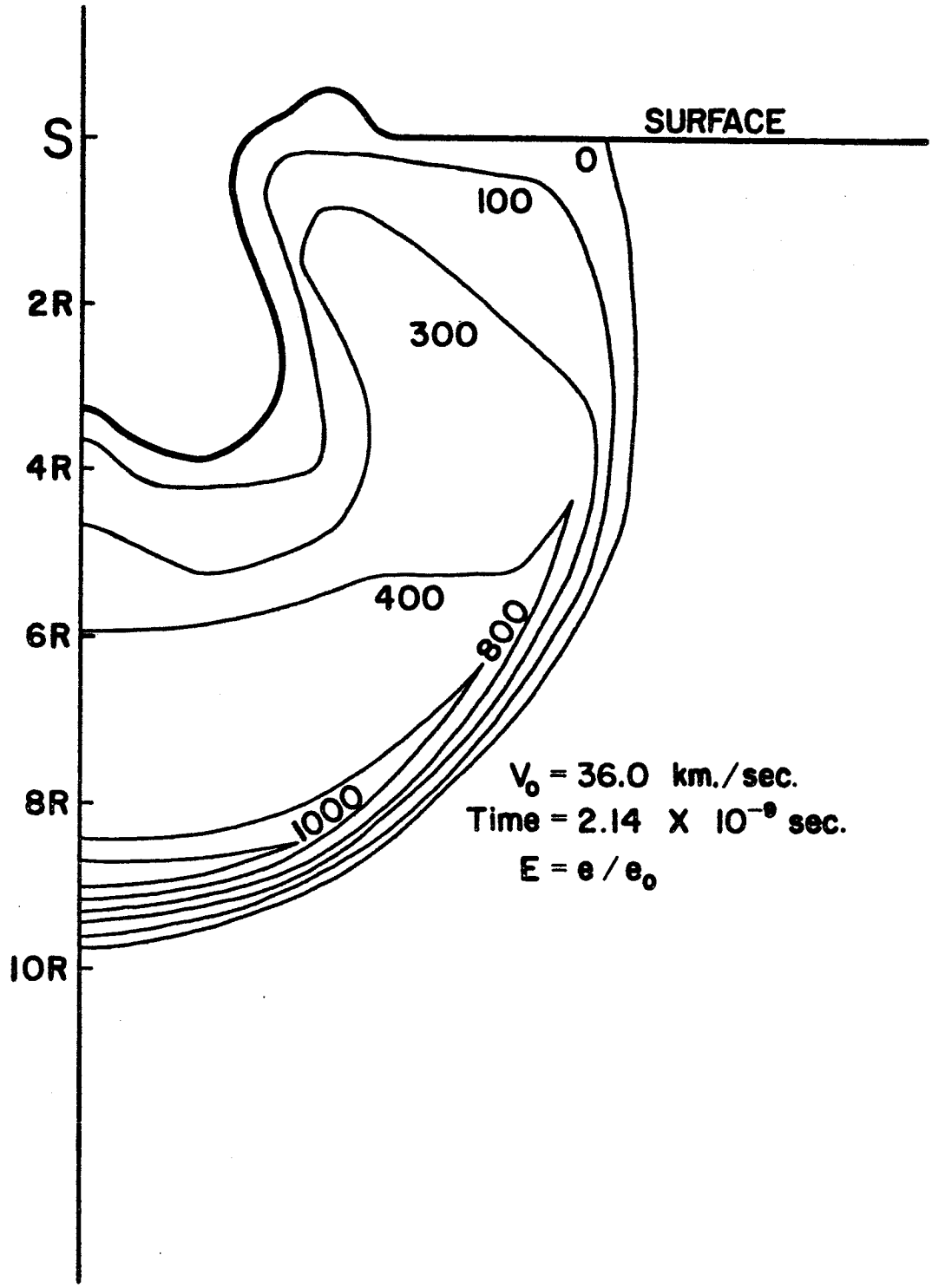

Figure 206. Energy Map (t = 2.14 x 10^{-9} sec) IV

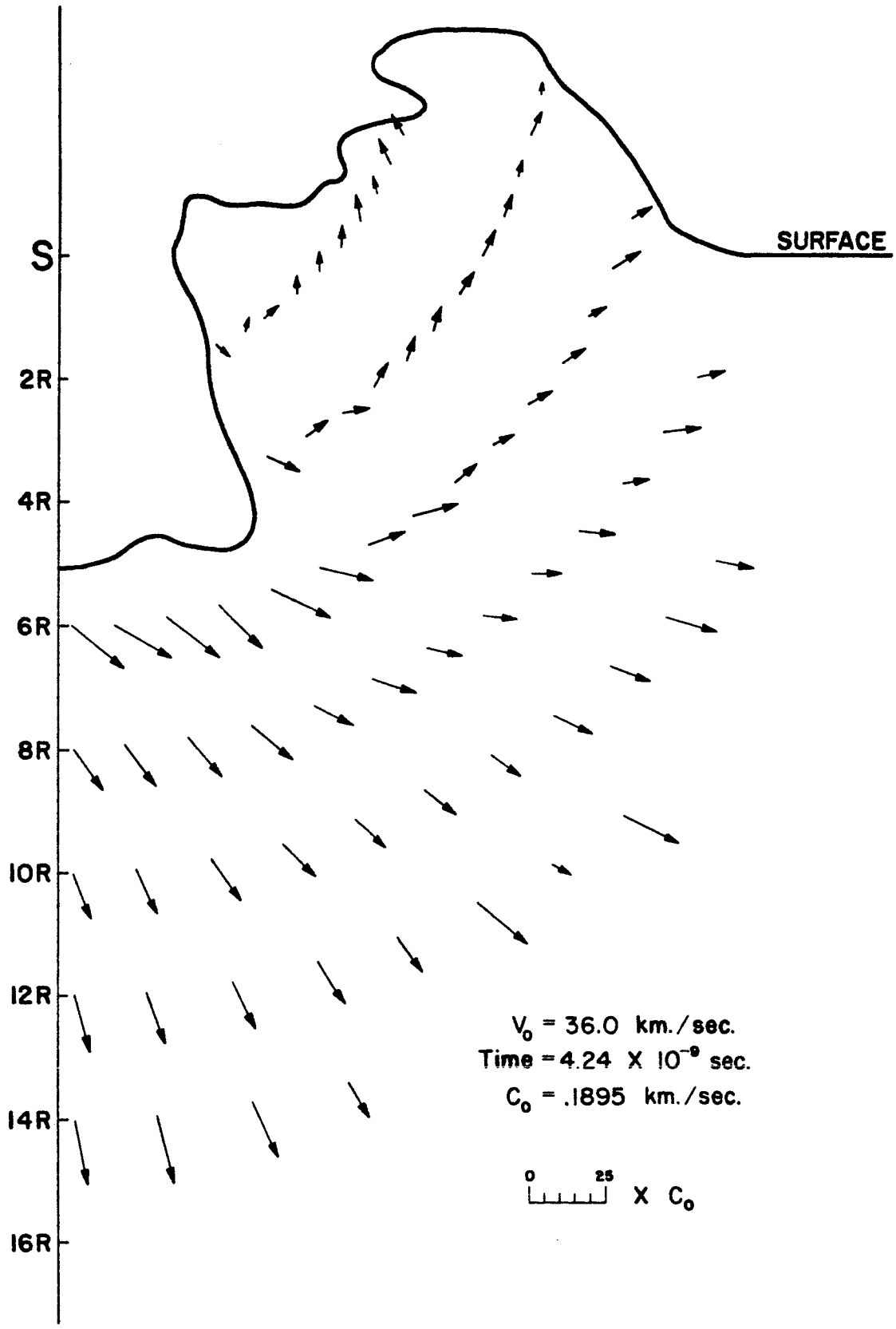

Figure 207. Velocity Map (t = 4.24 x 10^{-9} sec) IV

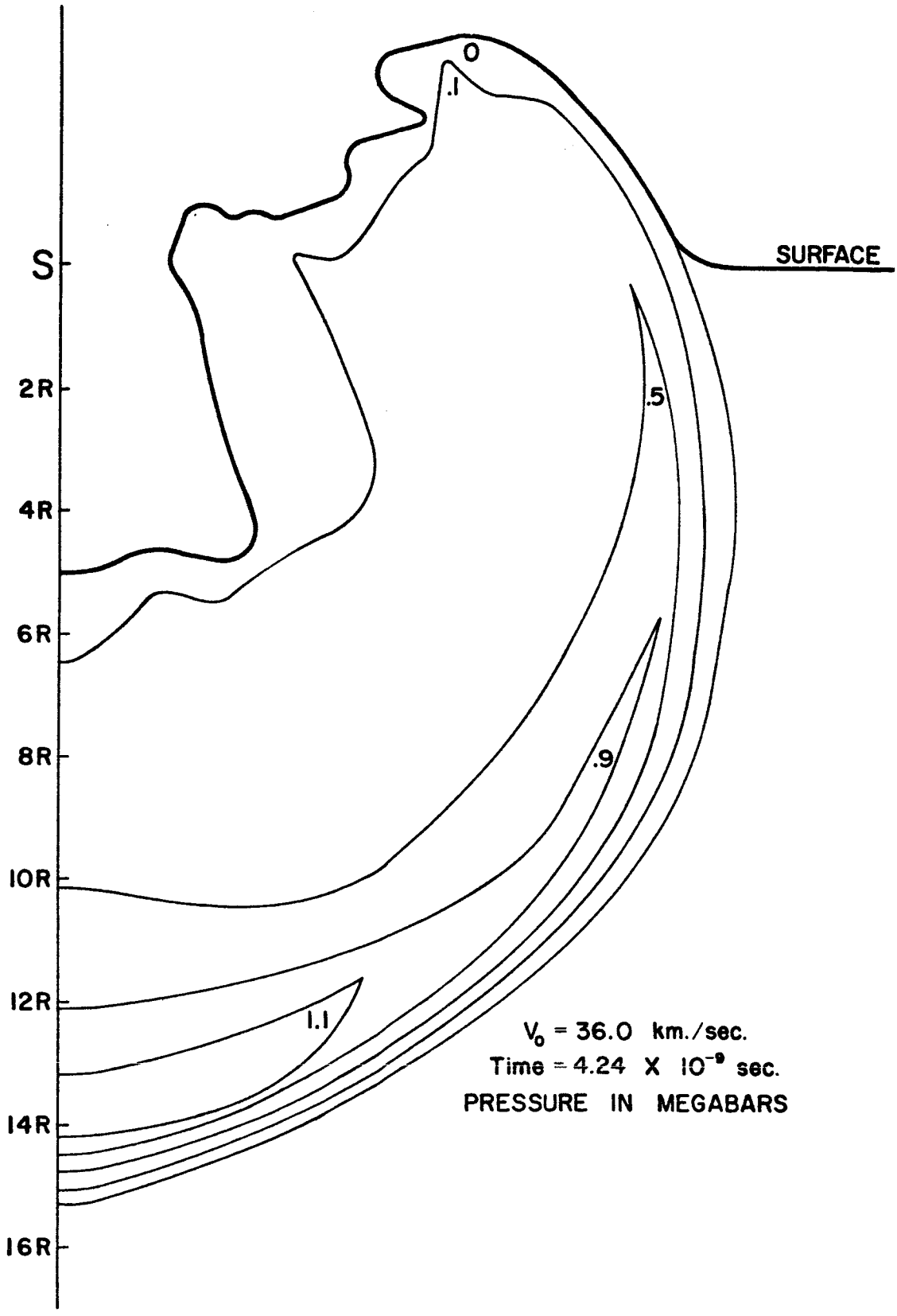

Figure 208. Pressure Map (t = 4.24 x 10^{-9} sec) IV

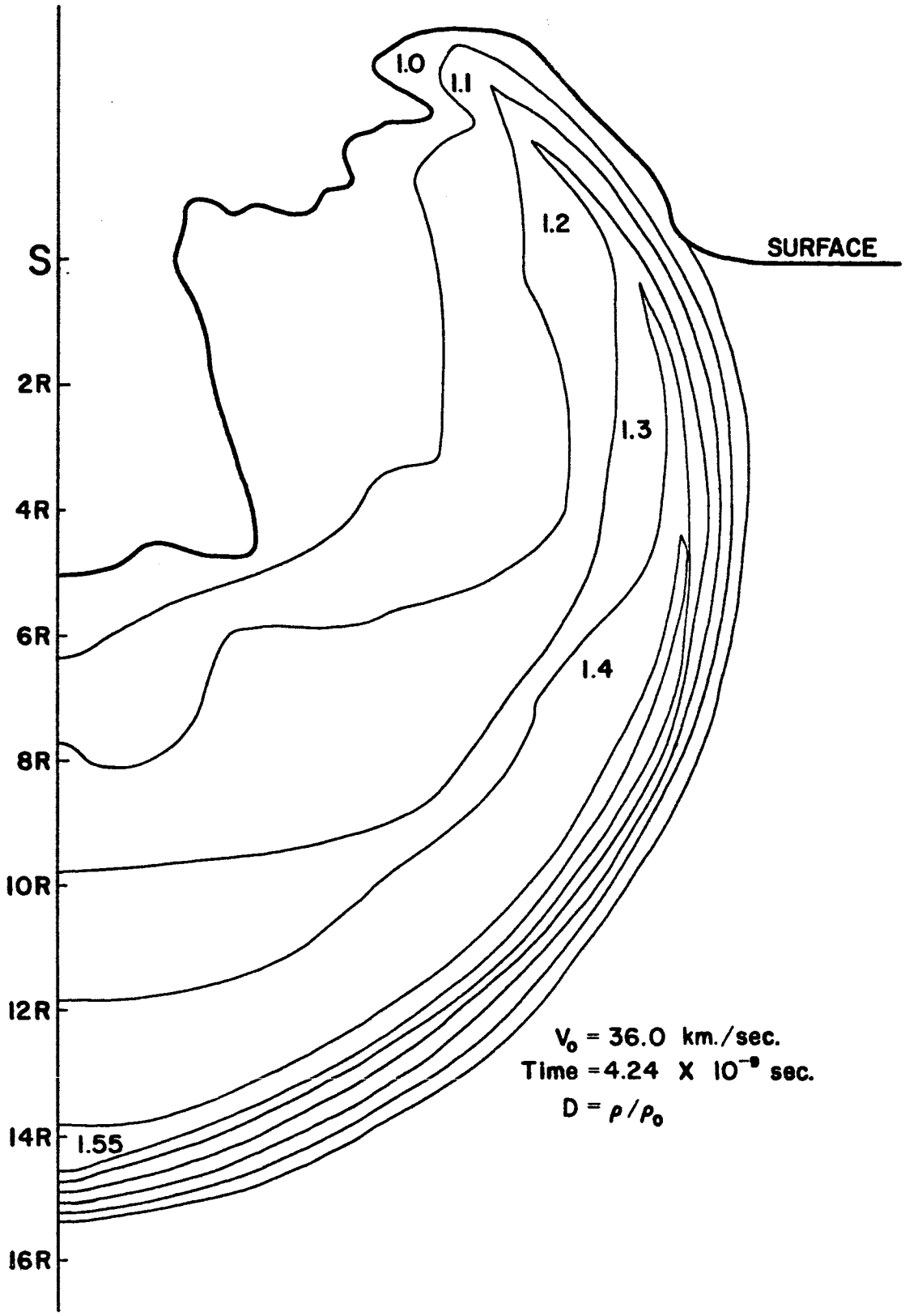

Figure 209. Density Map (t = 4.24 x 10^{-9} sec) IV

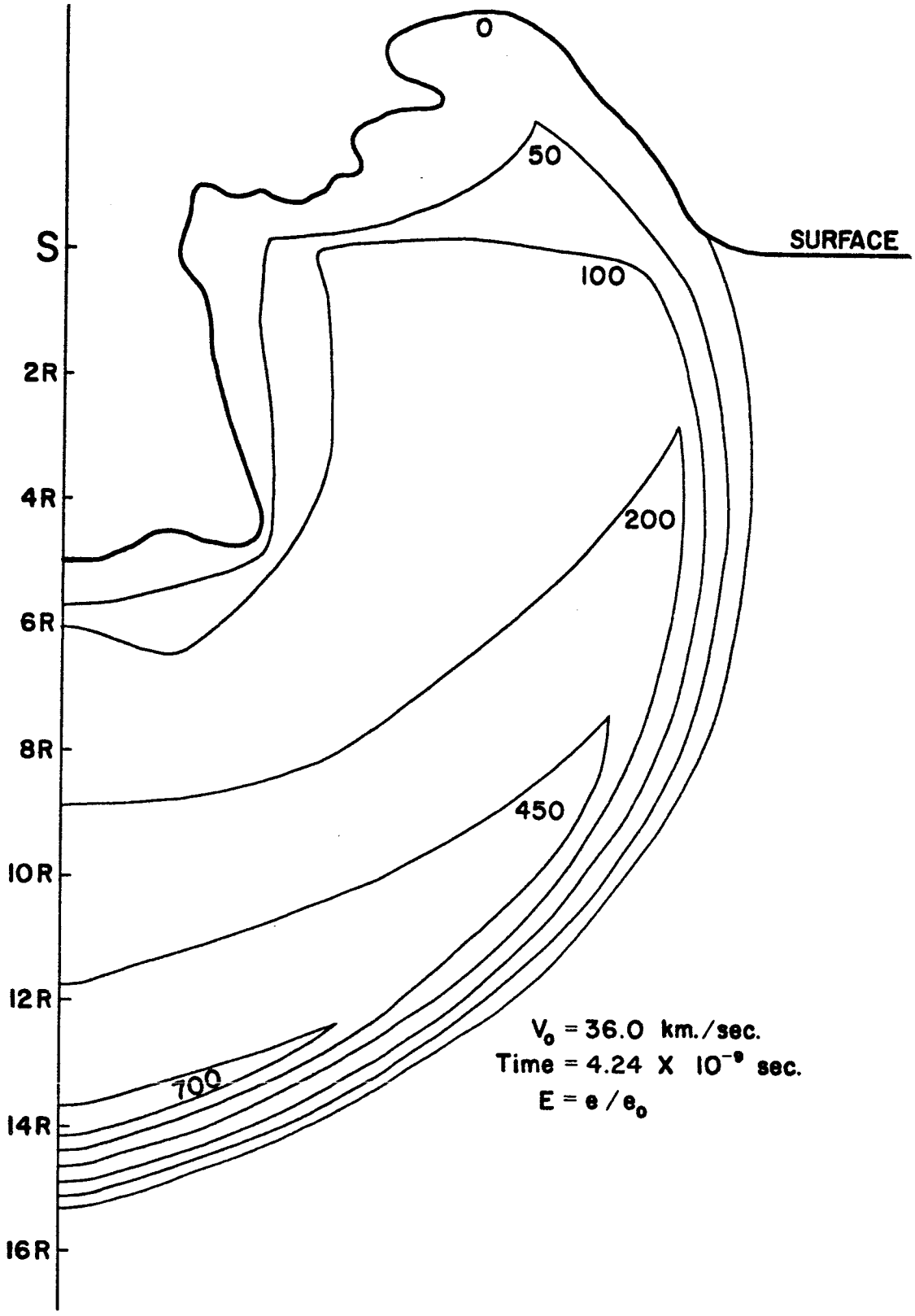

Figure 210. Energy Map (t = 4.24 x 10^{-9} sec) IV

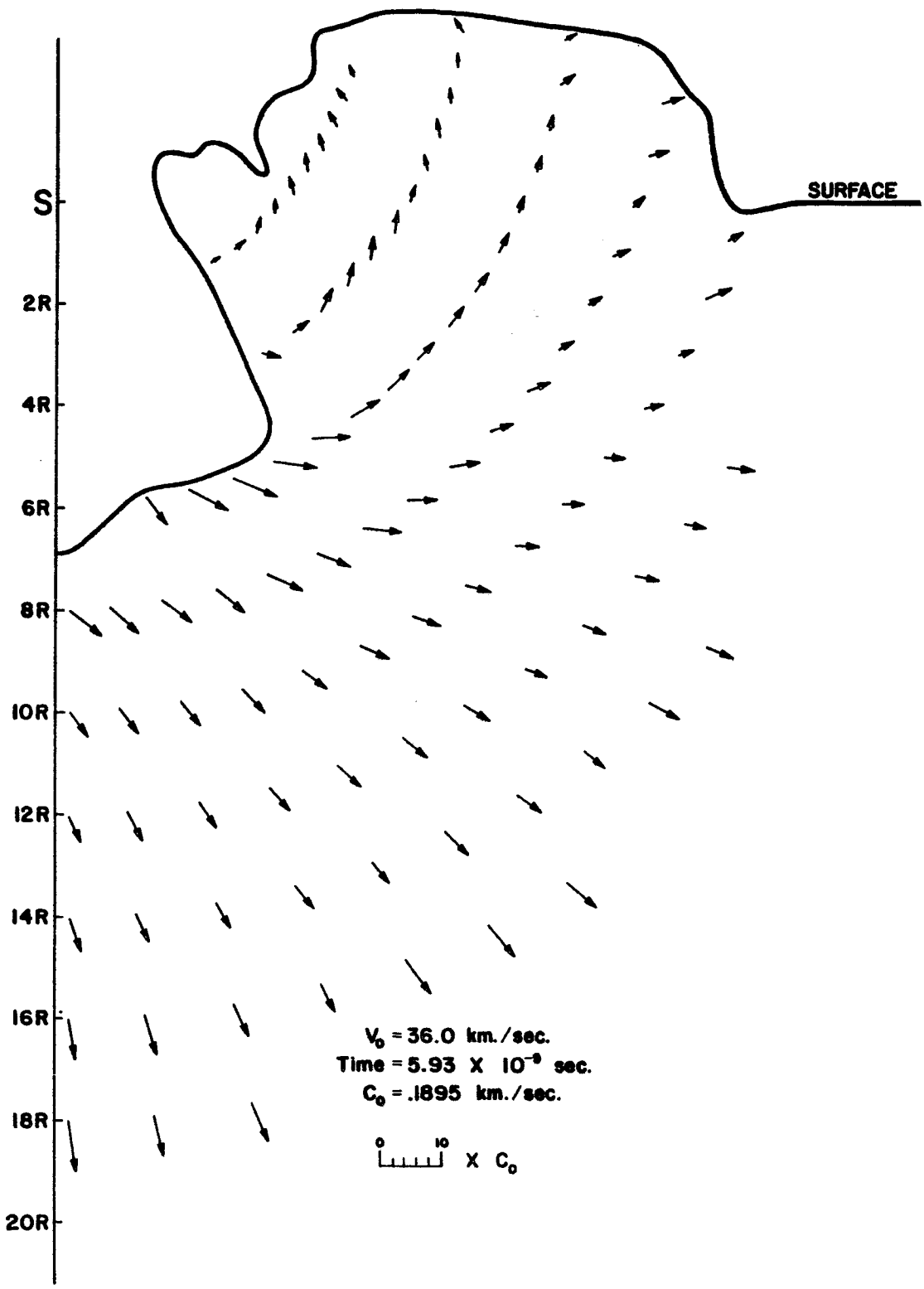

Figure 211. Velocity Map (t = 5.93 x 10^{-9} sec) IV

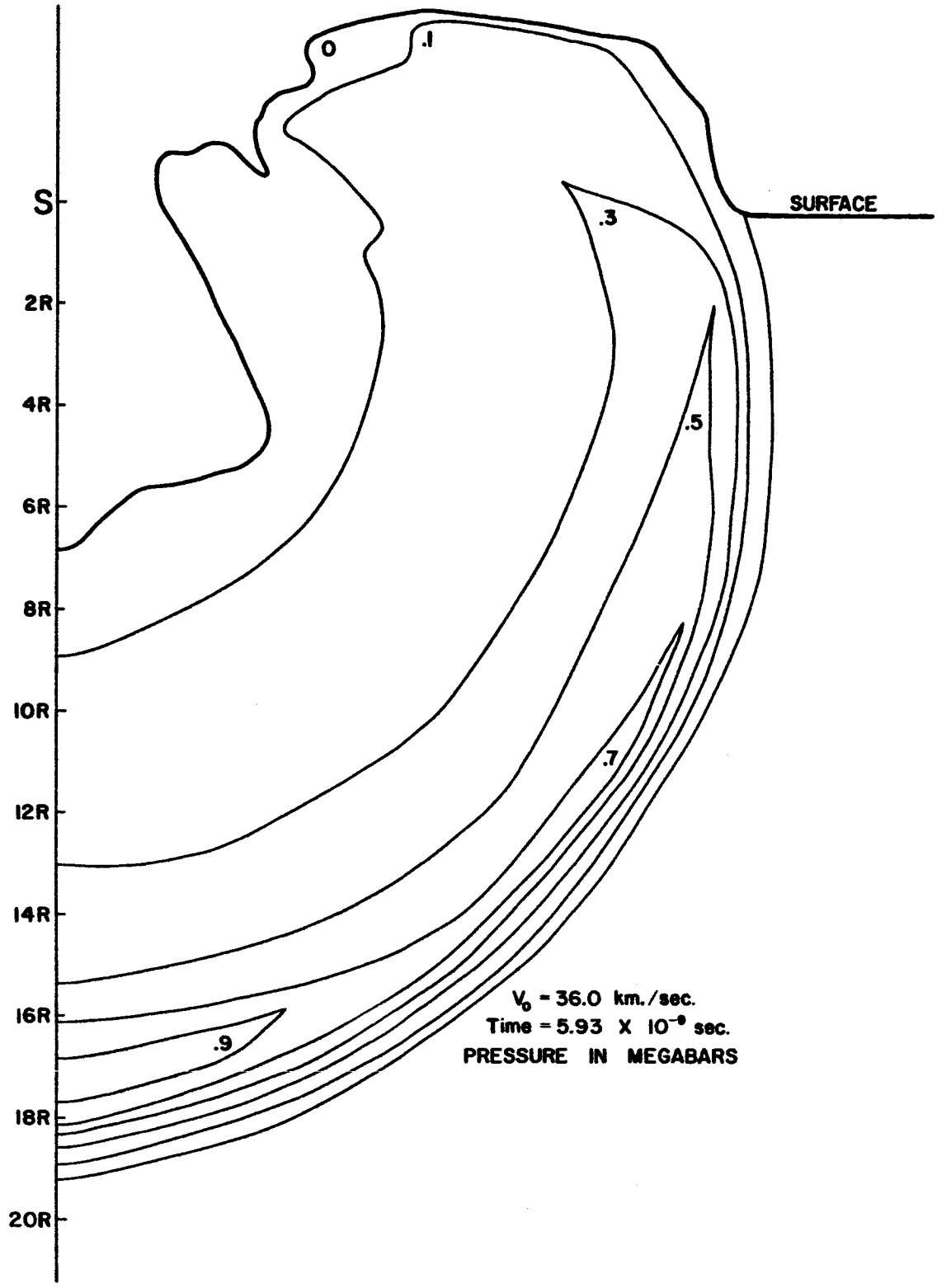

Figure 212. Pressure Map (t = 5.93 x 10^{-9} sec) IV

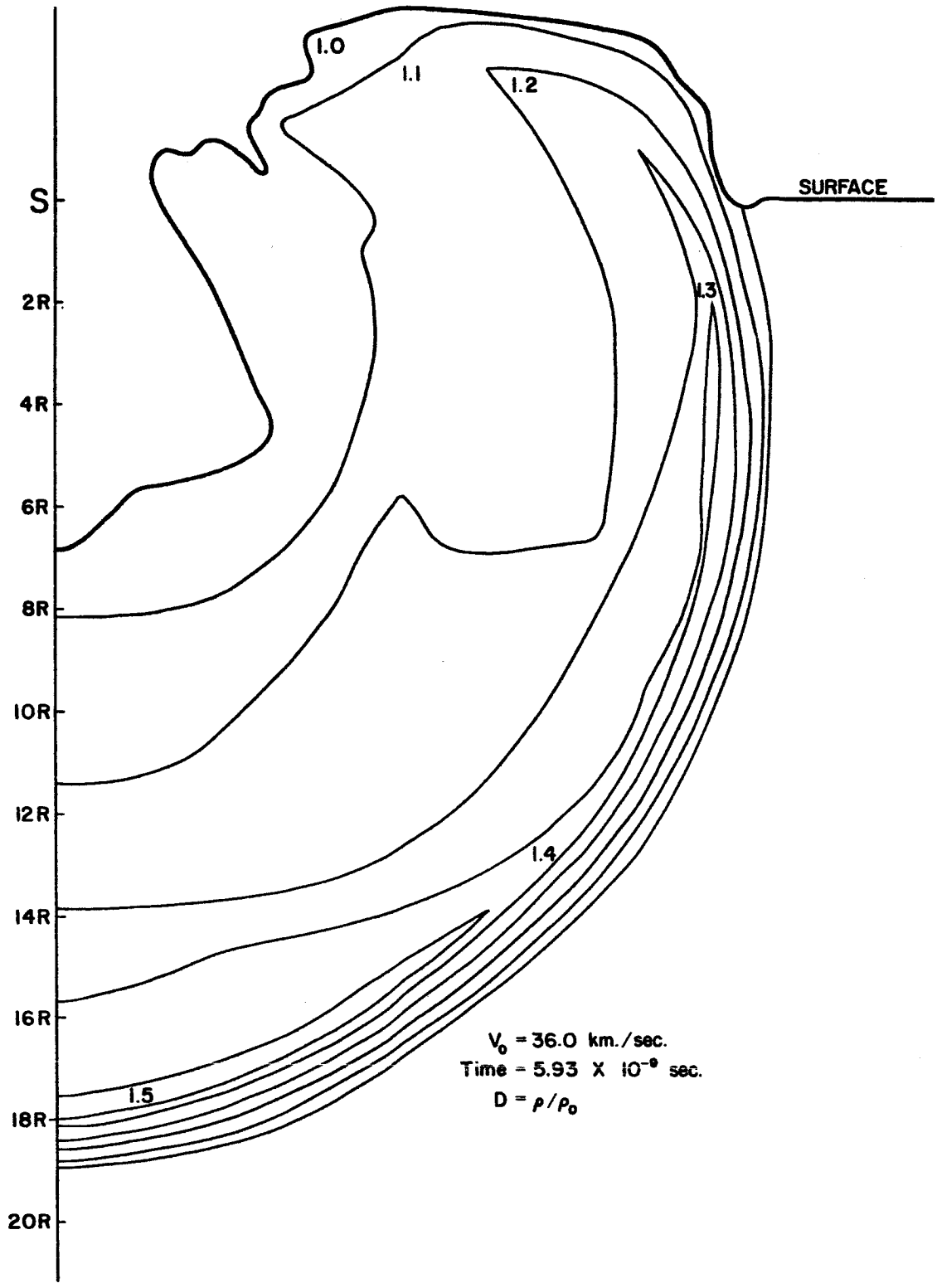

Figure 213. Density Map (t = 5.93 x 10^{-9} sec) IV

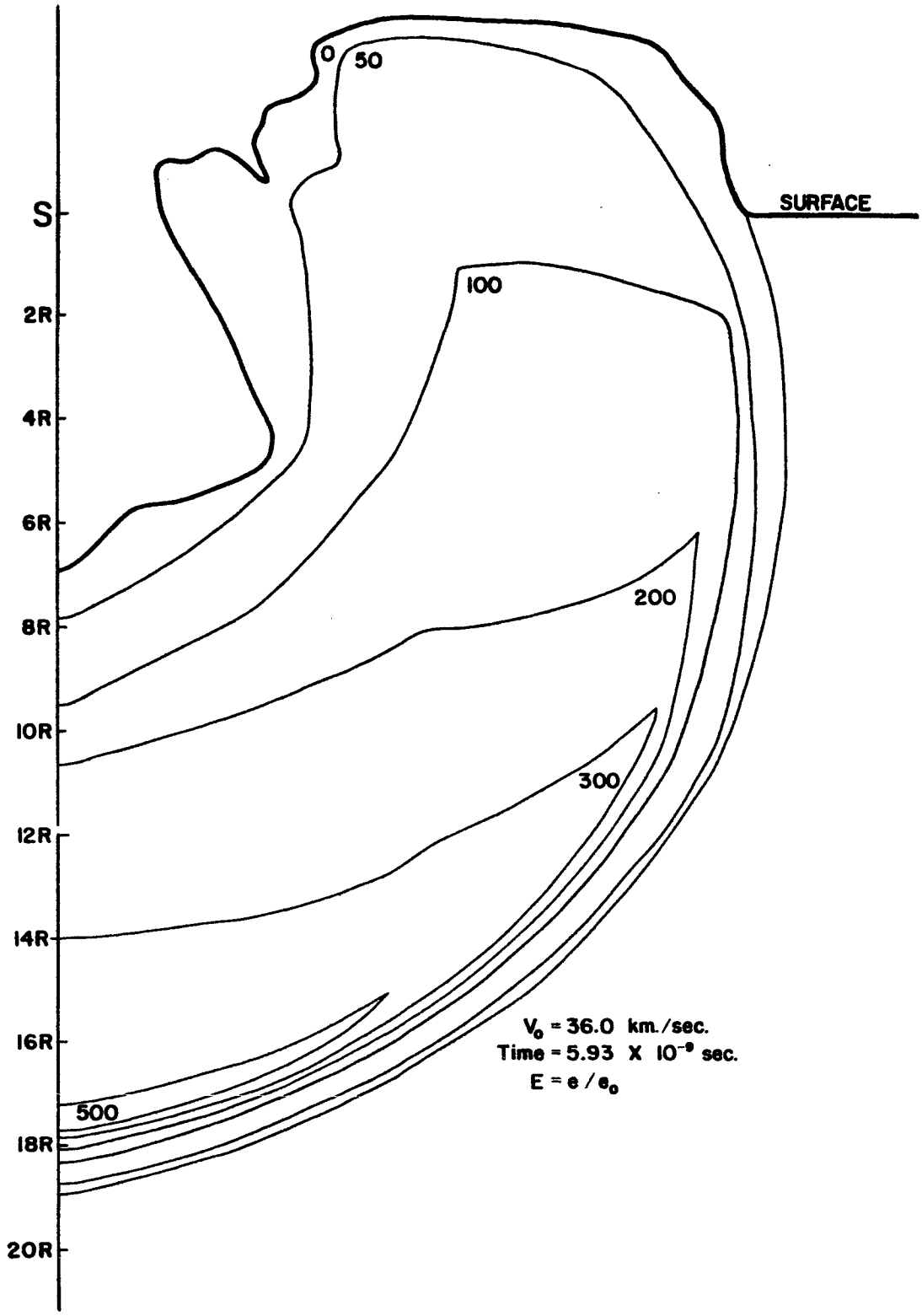

Figure 214.. Energy Map (t = 5.93 x 10^{-9} sec) IV

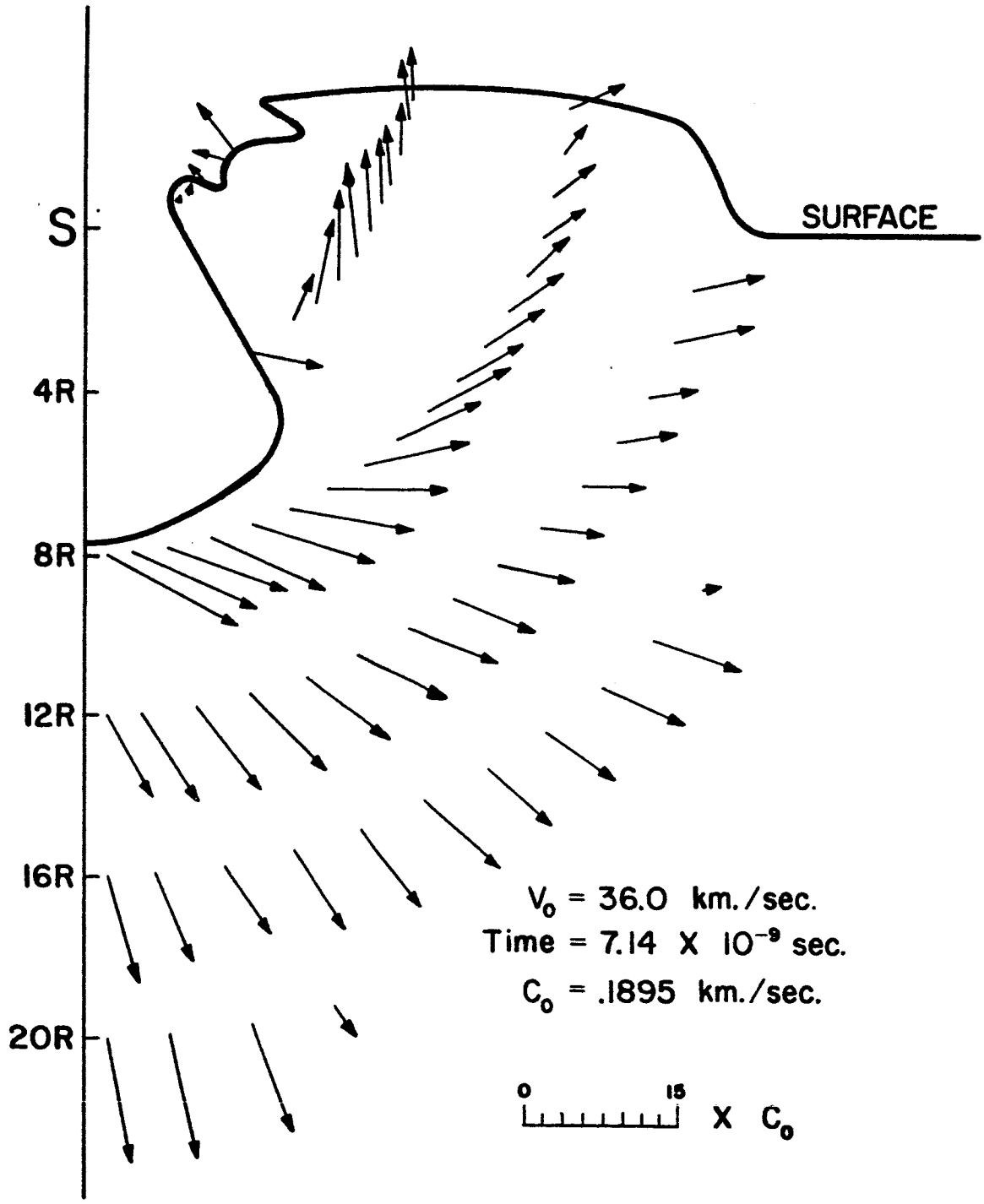

Figure 215. Velocity Map (t = 7.14 x 10^{-9} sec) IV

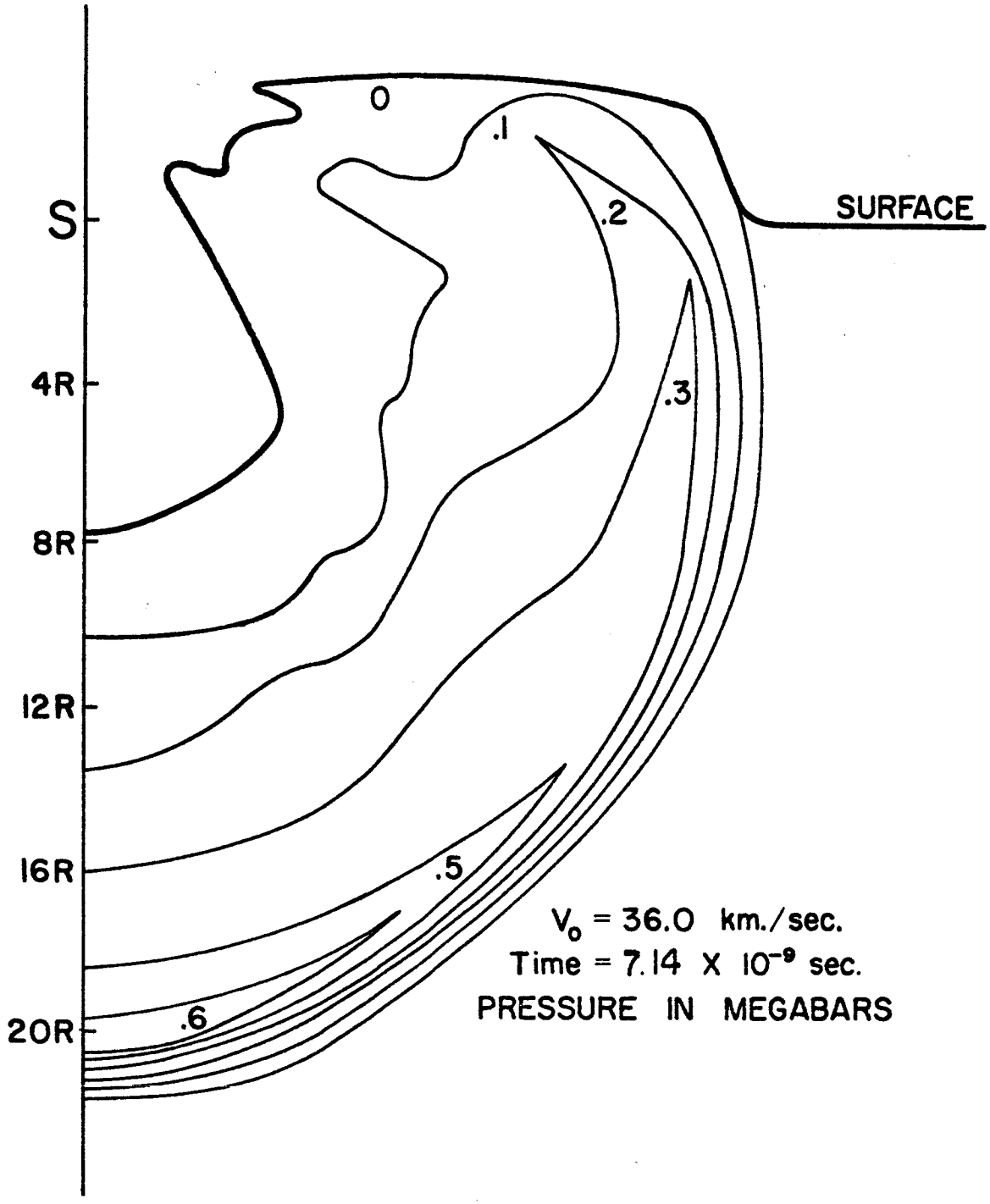

Figure 216. Pressure Map (t = 7.14 x 10^{-9} sec) IV

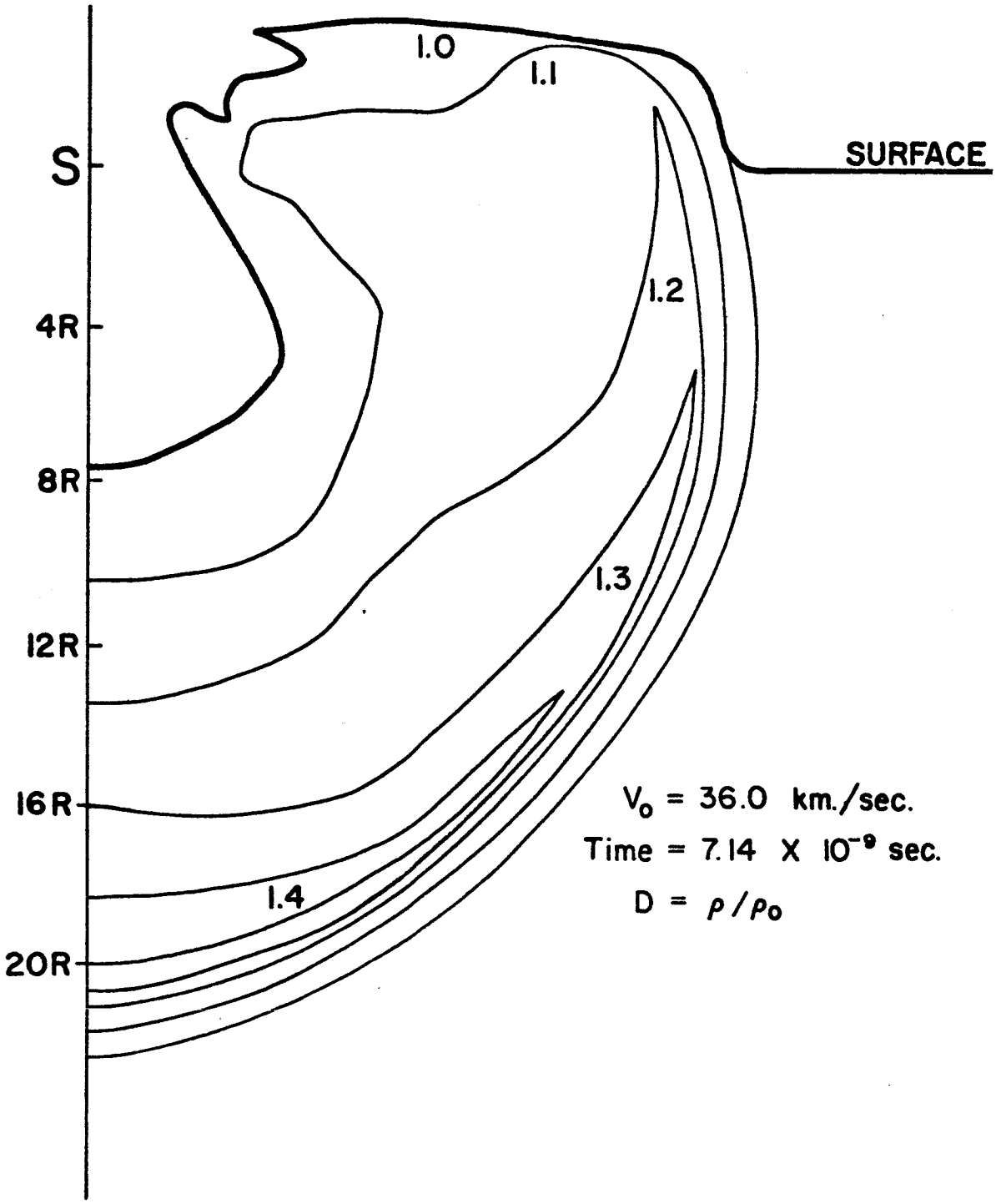

Figure 217. Density Map (t = 7.14 x 10^{-9} sec) IV

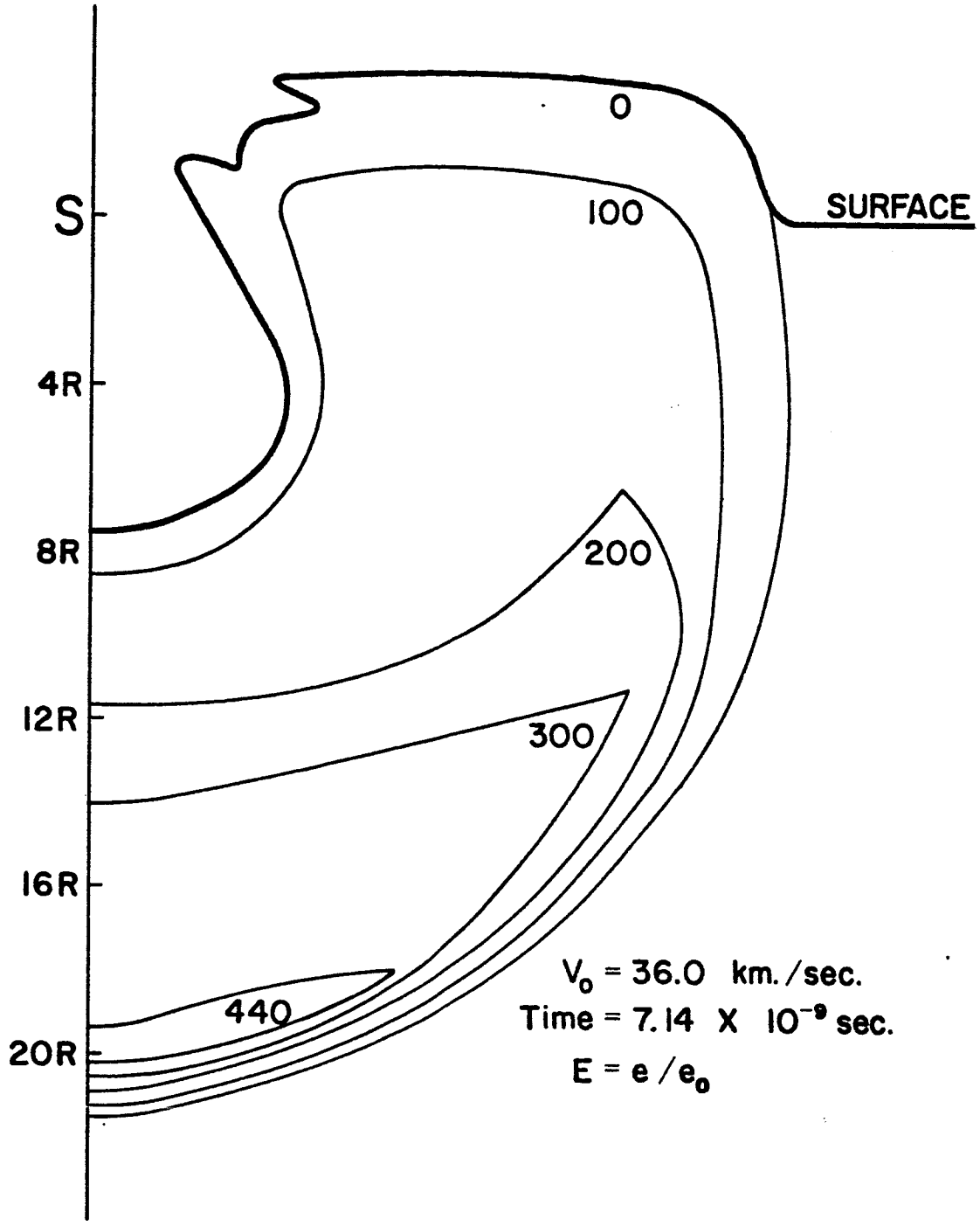

Figure 218. Energy Map (t = 7.14 x 10^{-9} sec) IV

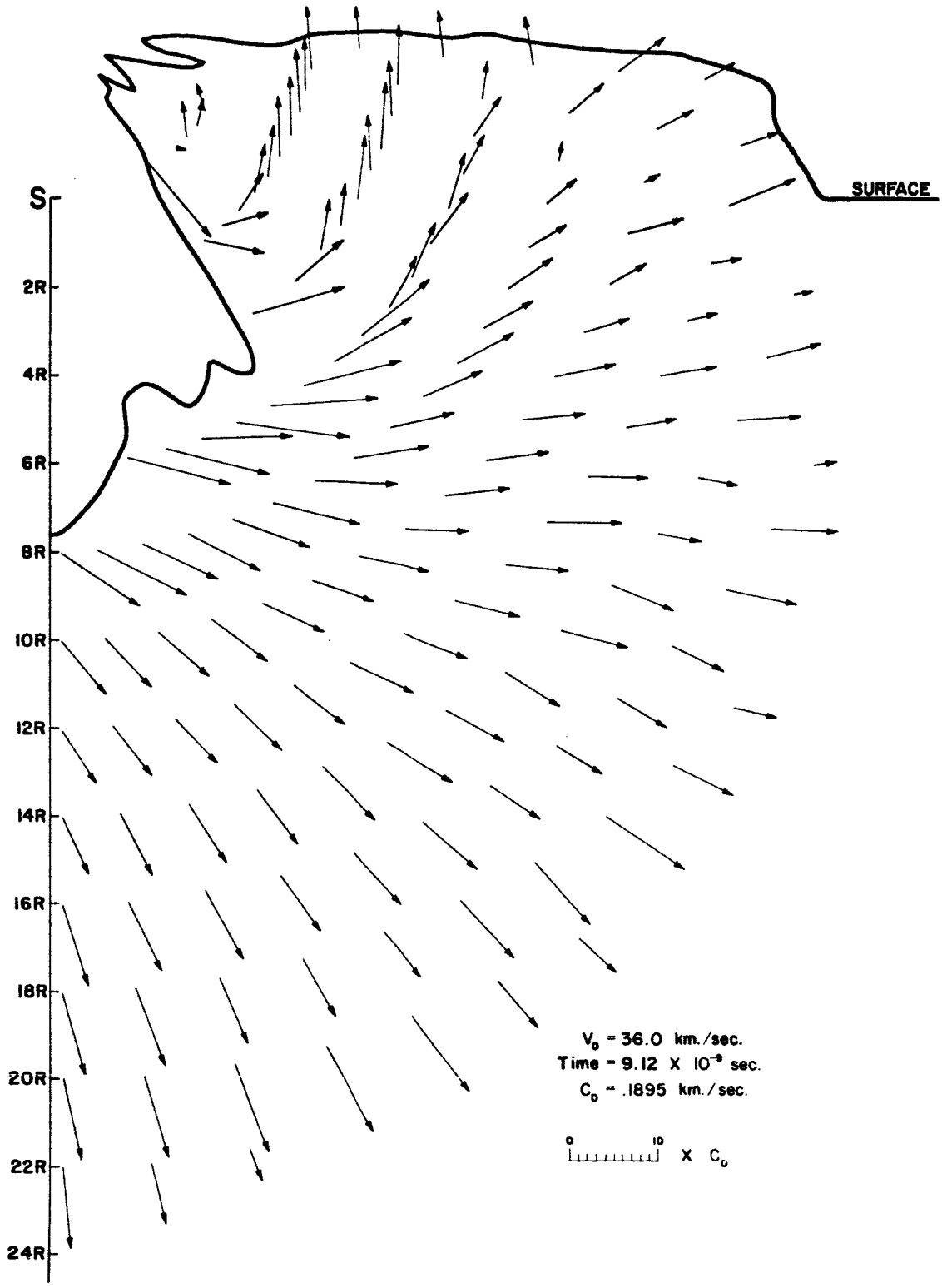

Figure 219. Velocity Map (t = 9.12 x 10^{-9} sec) IV

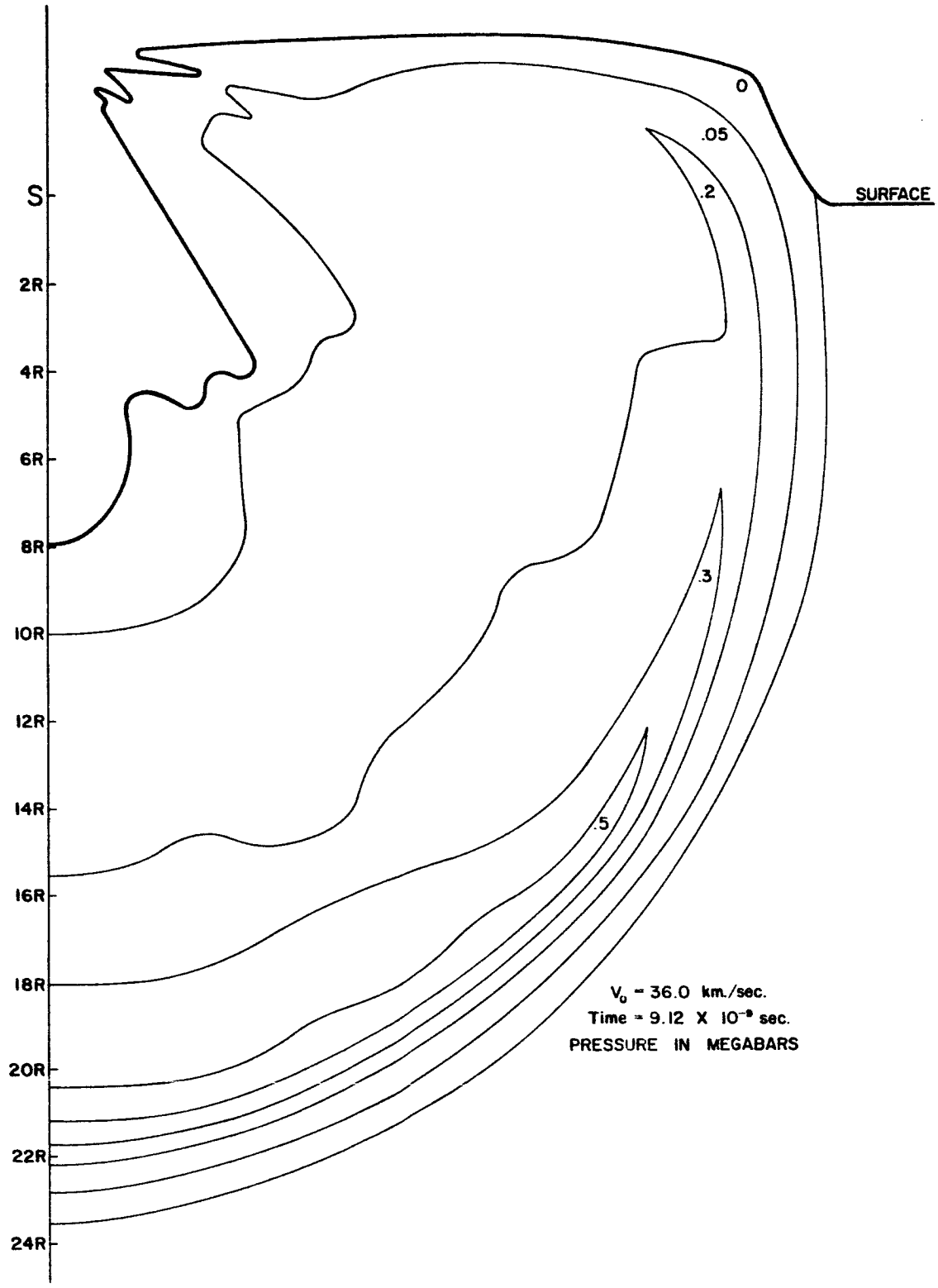

Figure 220. Pressure Map (t = 9.12 x 10^{-9} sec) IV

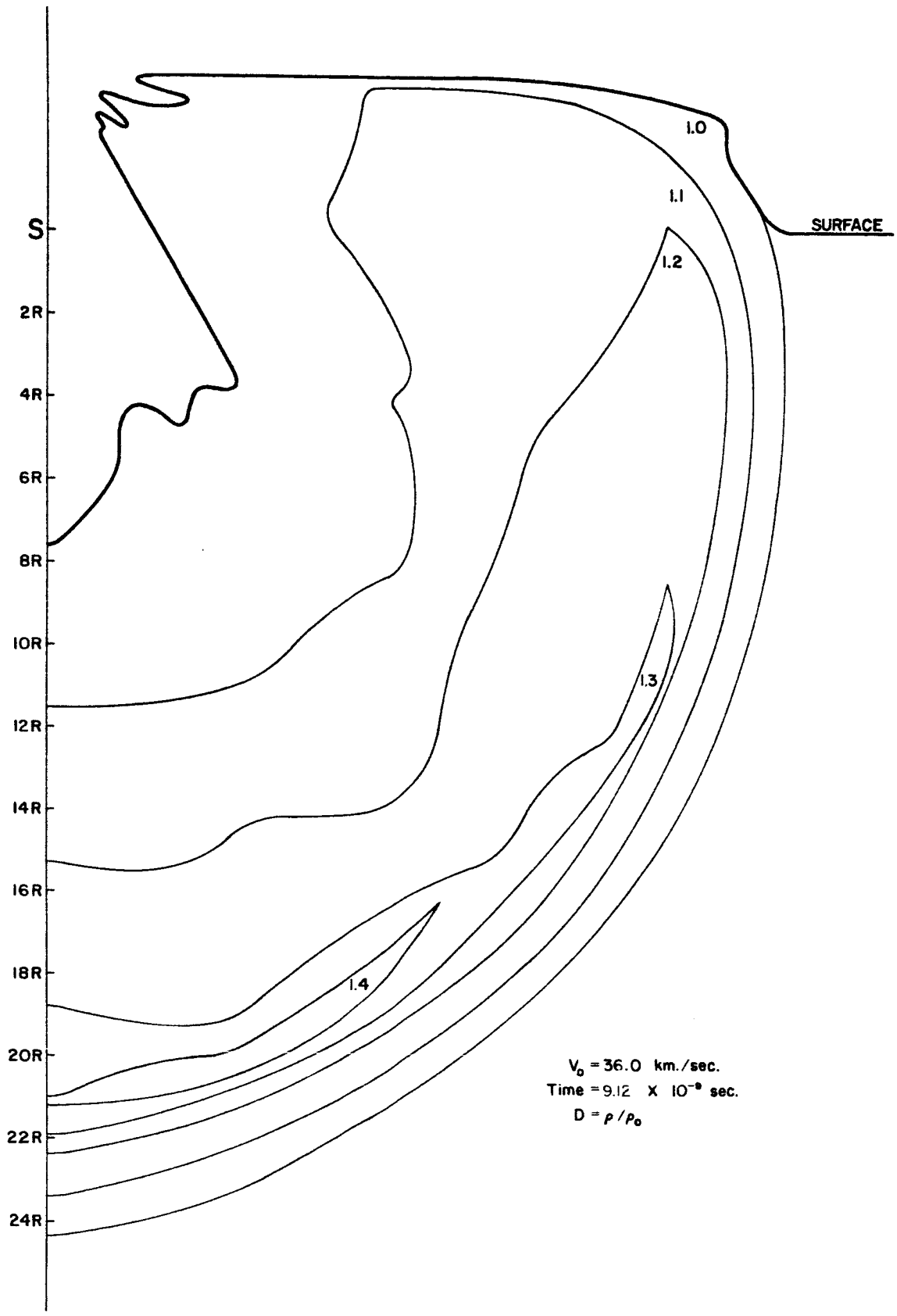

Figure 221. Density Map (t = 9.12 x 10^{-9} sec) IV

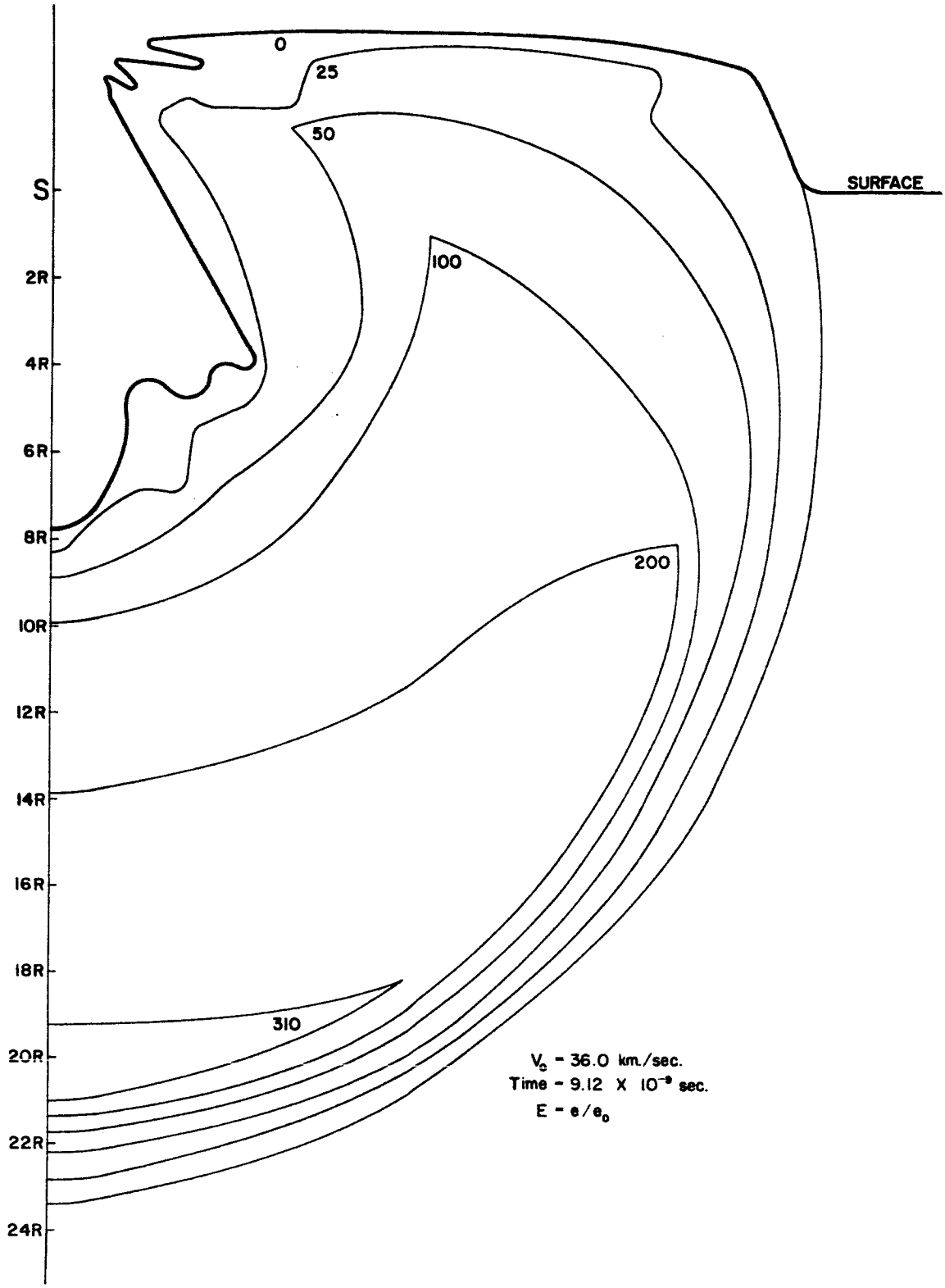

Figure 222. Energy Map (t = 9.12 x 10^{-9} sec) IV

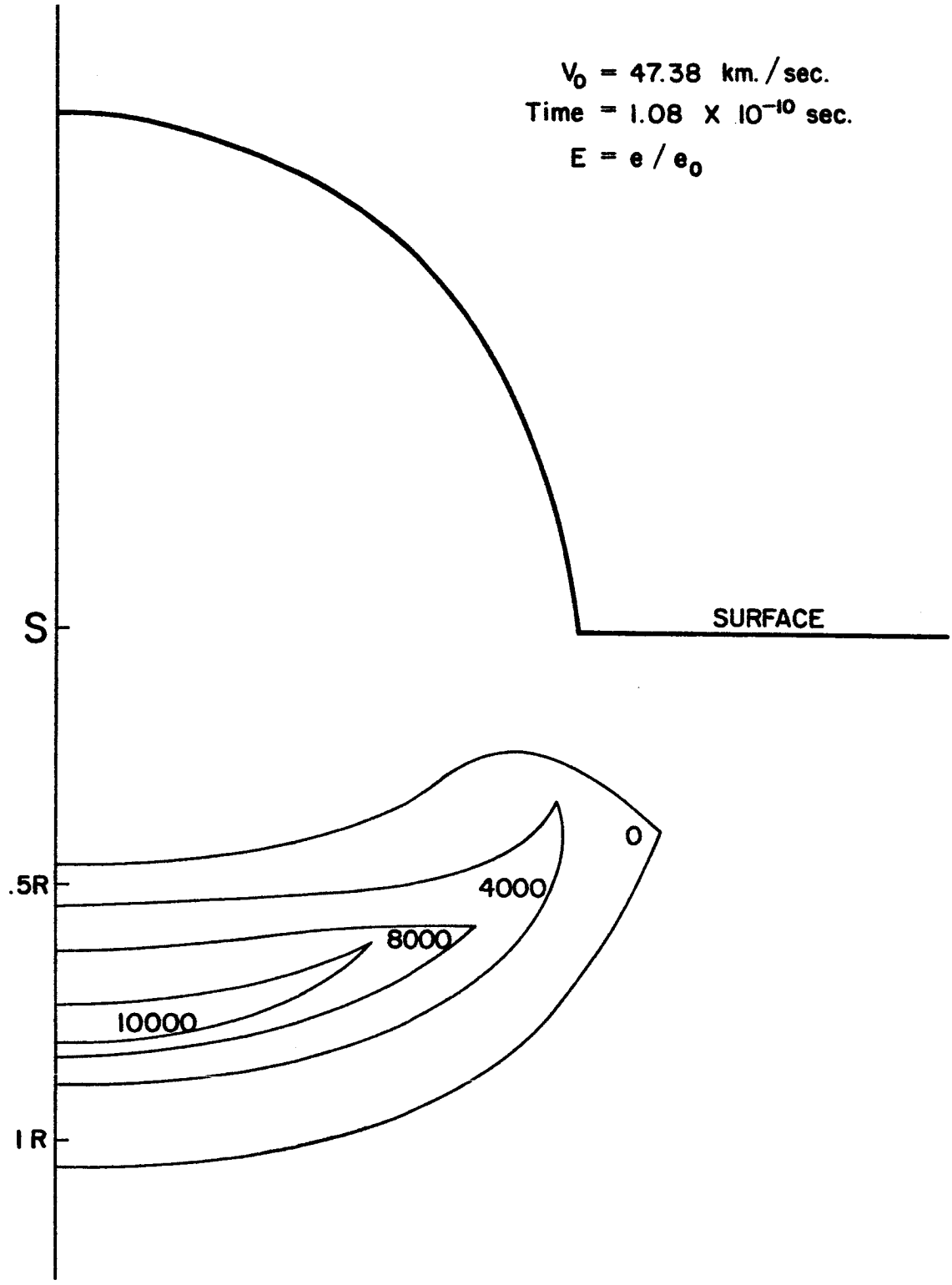

Figure 223. Energy Map (t = 1.08 x 10^{-10} sec) V

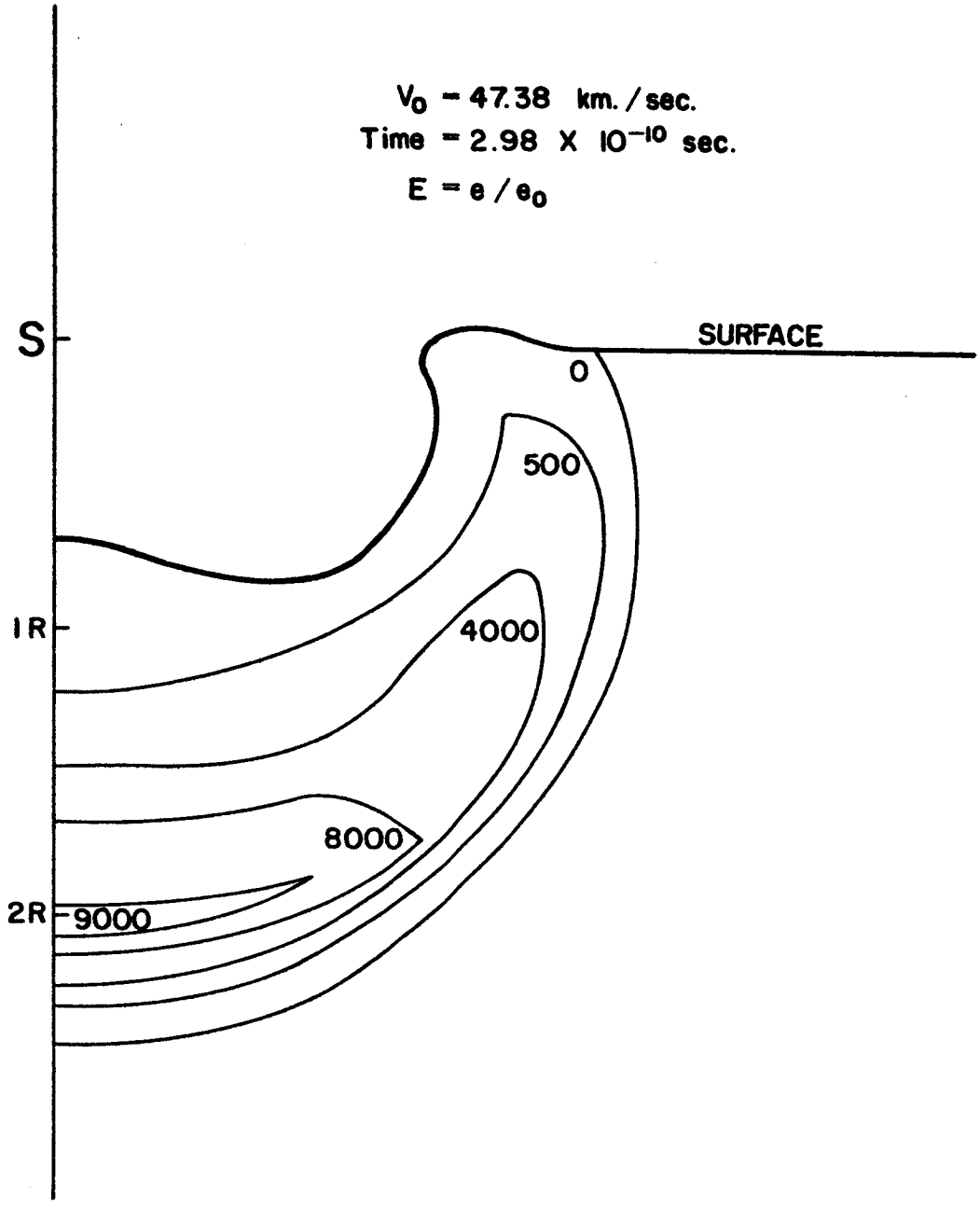

Figure 224. Energy Map (t = 2.98 x 10^{-10} sec) V

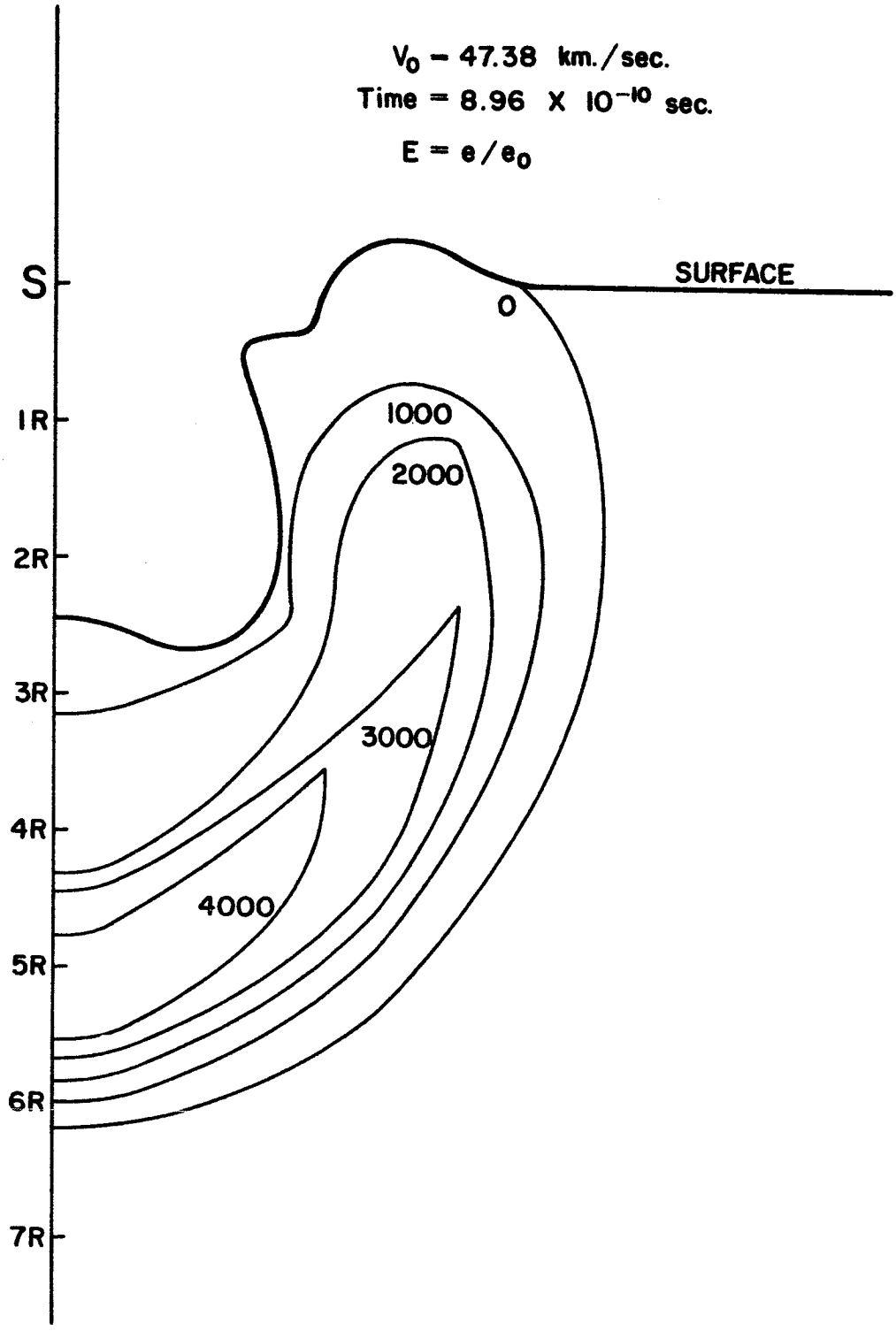

Figure 225. Energy Map (t = 8.96 x 10^{-10} sec) V

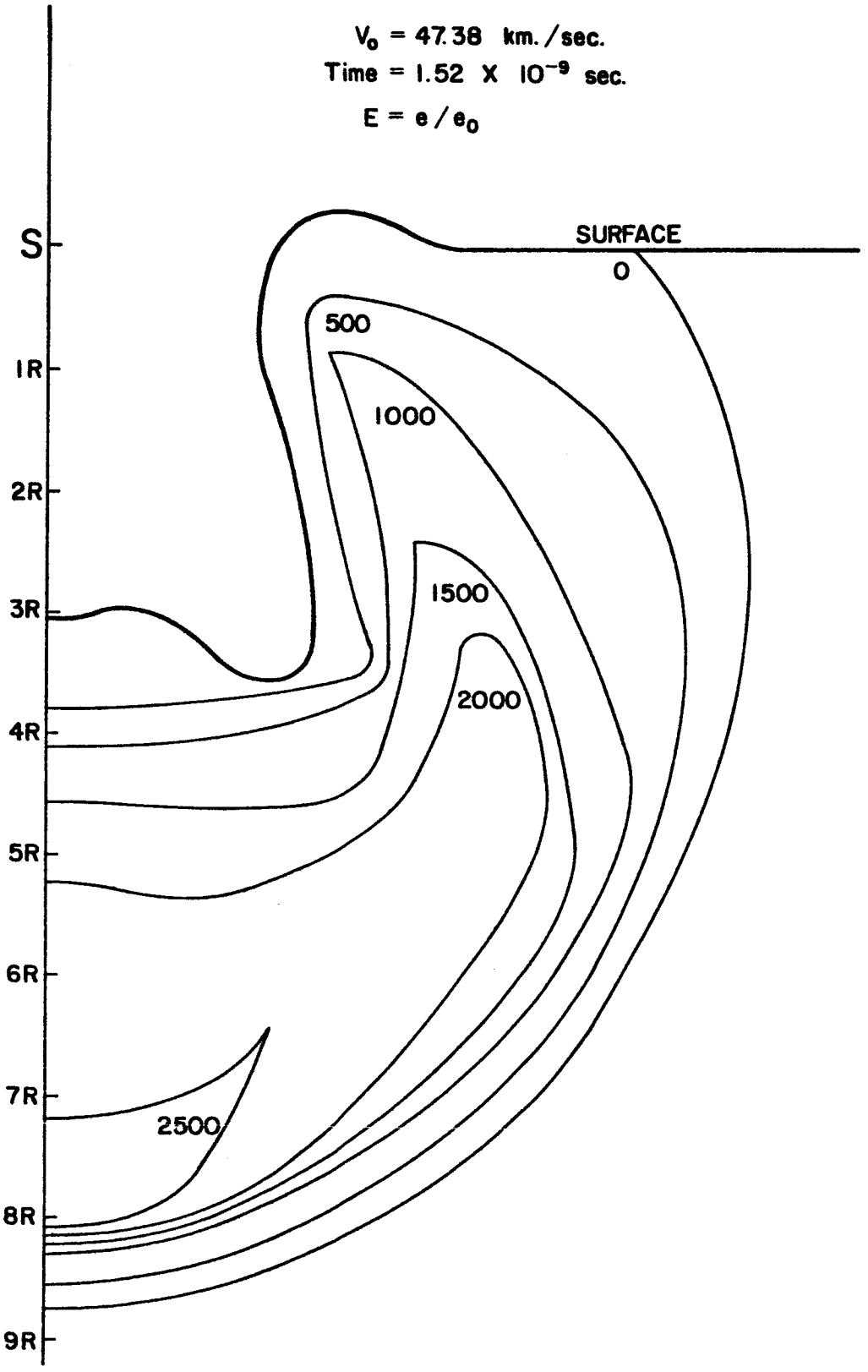

Figure 226. Energy Map (t = 1.52 x 10^{-9} sec) V

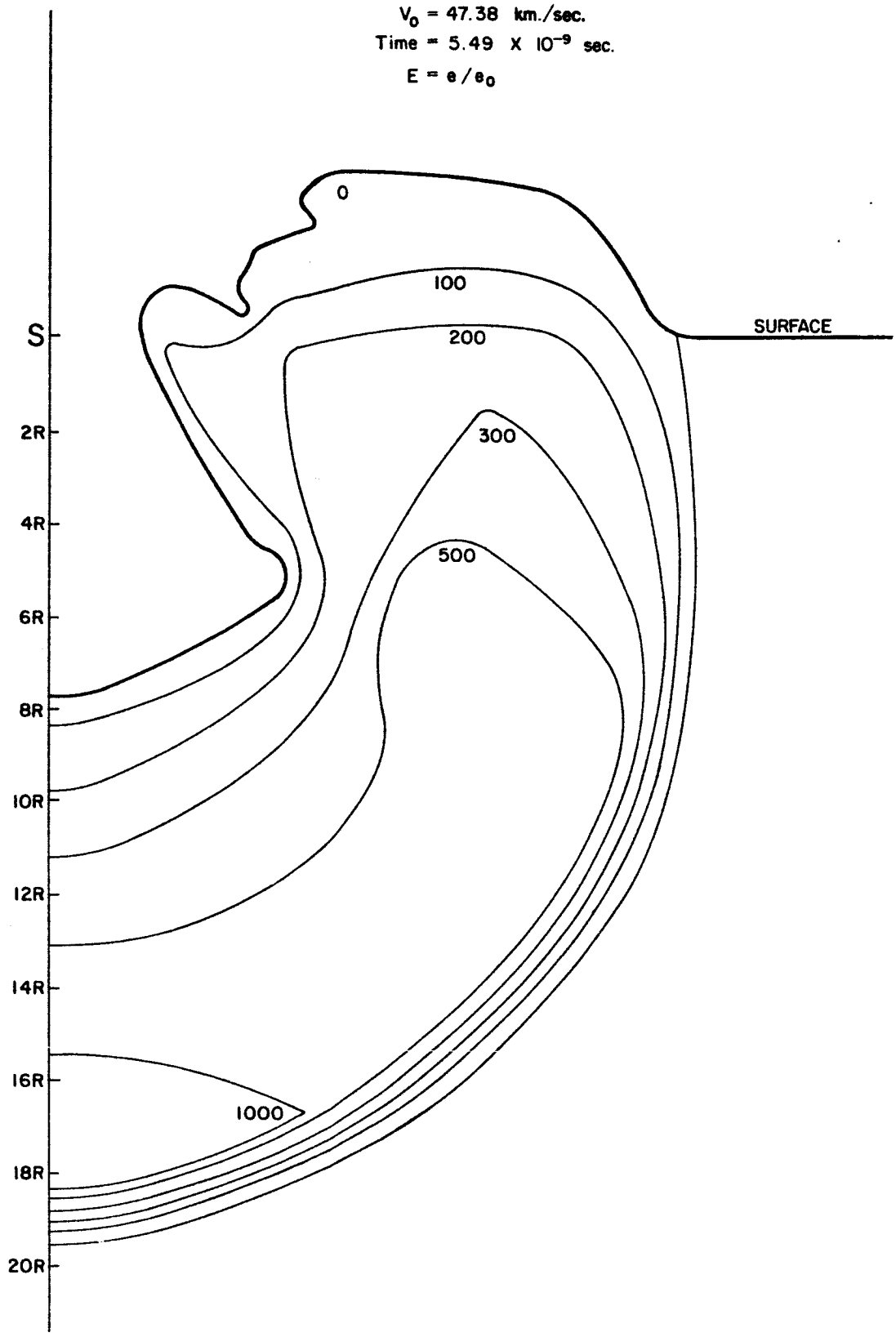

Figure 227. Energy Map (t = 5.49 x 10^{-9} sec) V

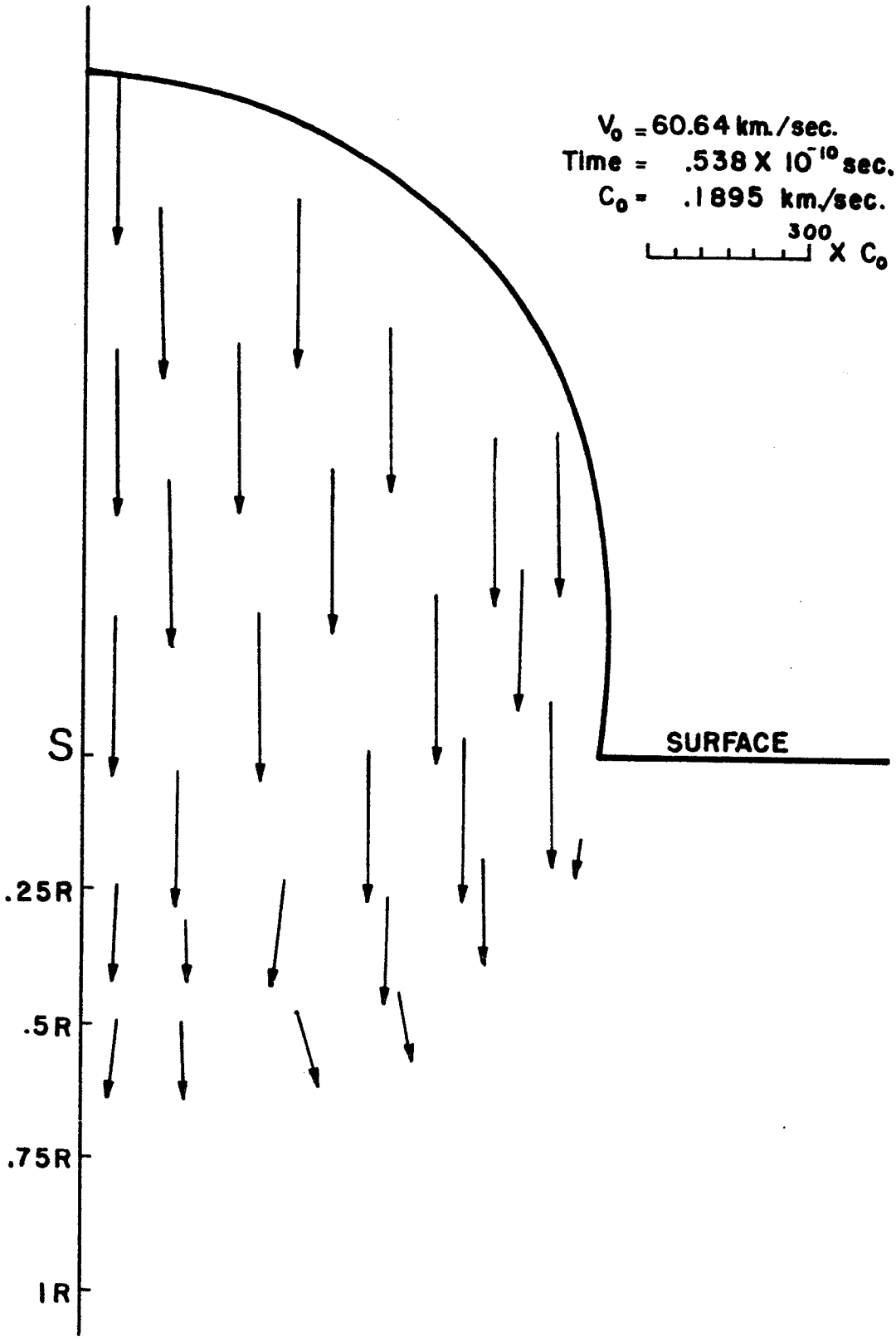

Figure 228. Velocity Map (t = .538 x 10^{-10} sec) VI

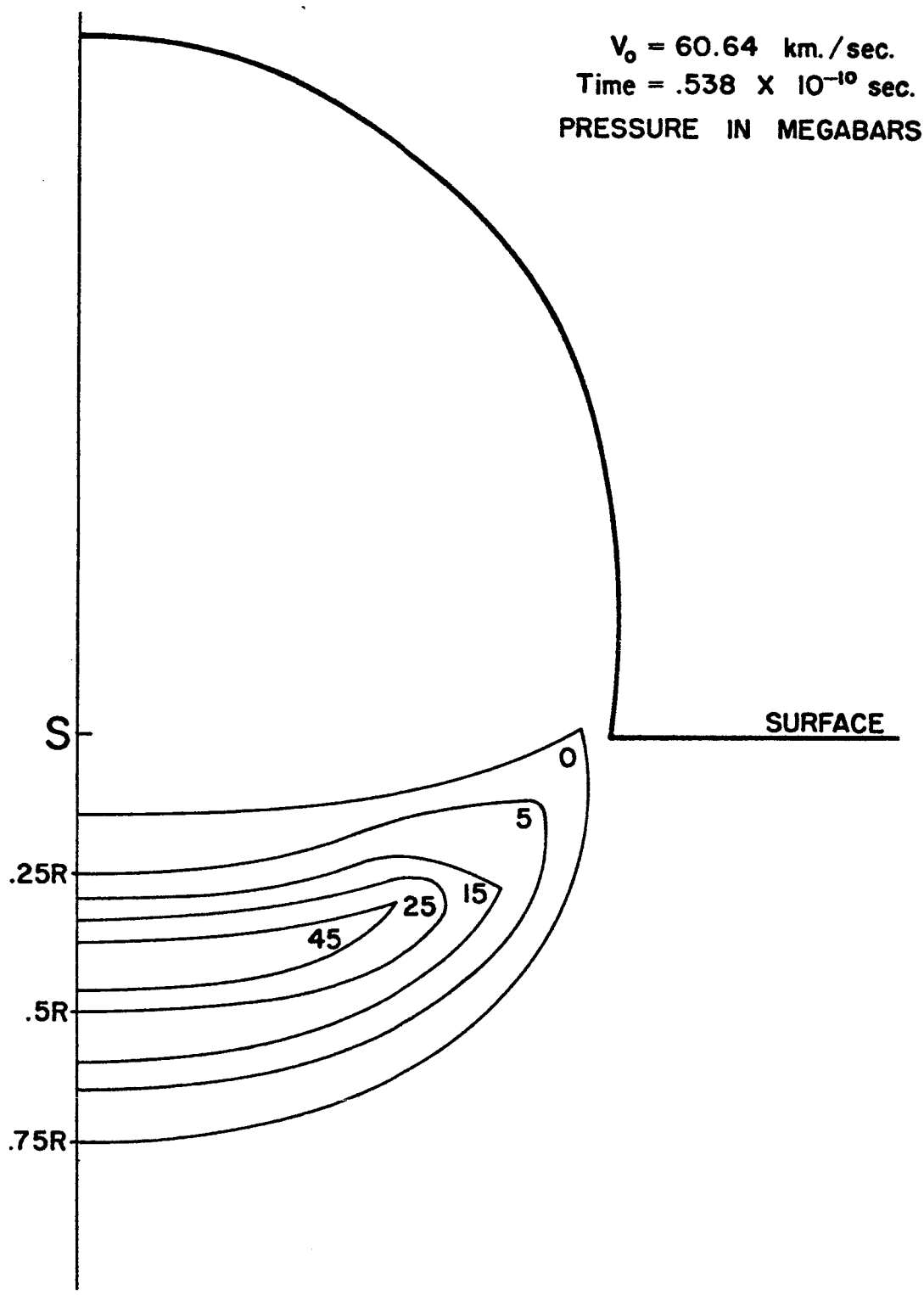

Figure 229. Pressure Map (t = .538 x 10^{-10} sec) VI

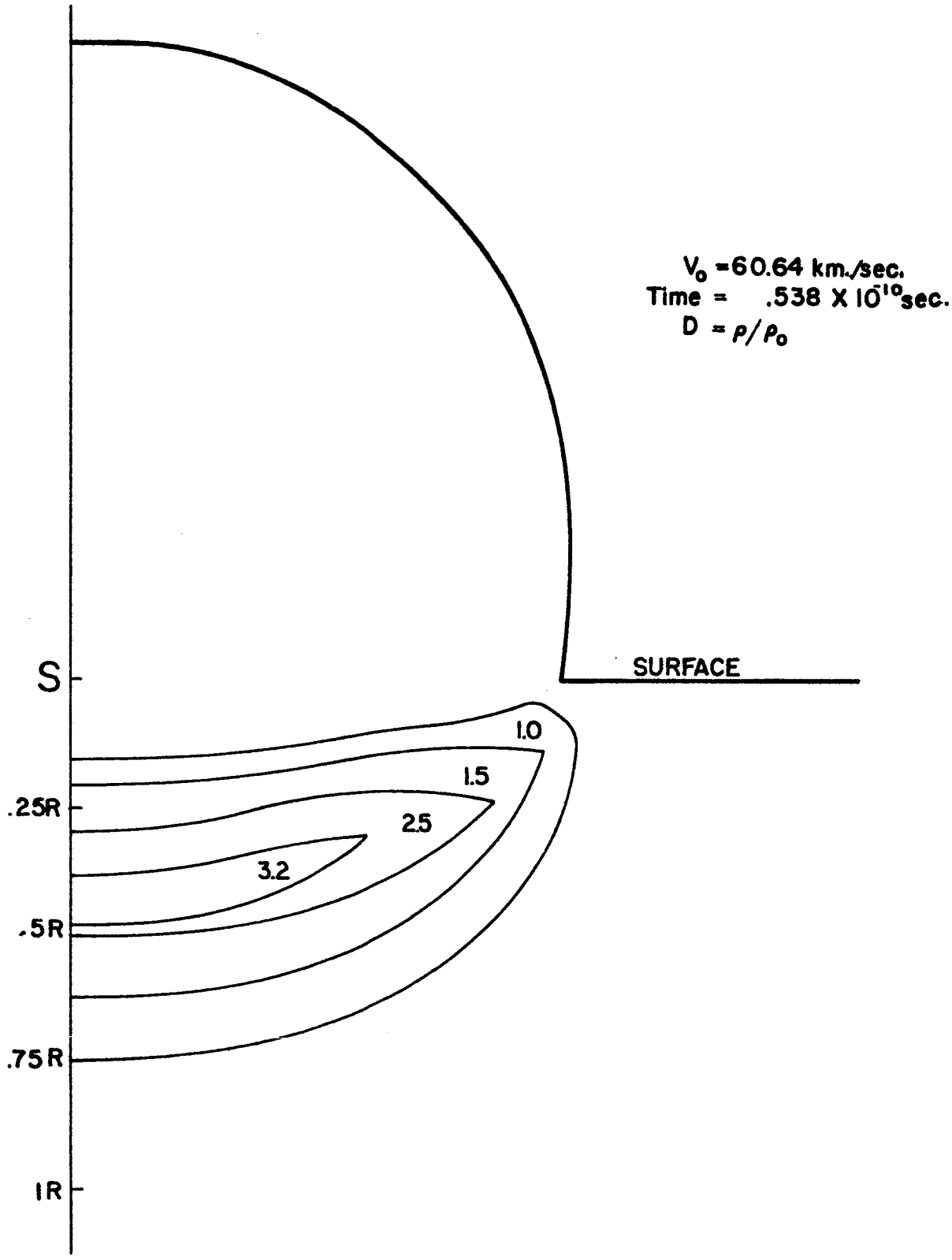

Figure 230. Density Map (t = .538 x 10^{-10} sec) VI

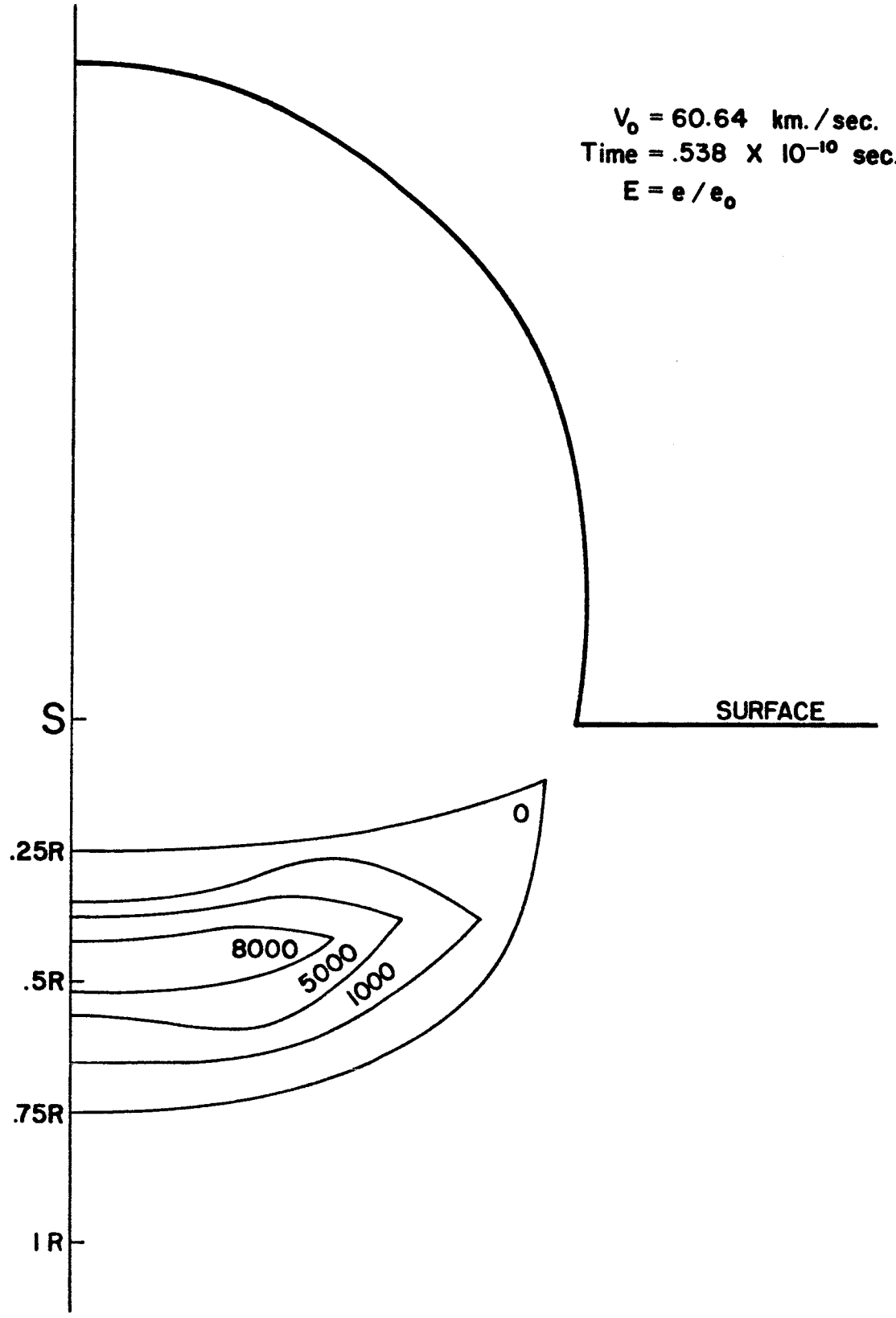

Figure 231. Energy Map (t = .538 x 10^{-10} sec) VI

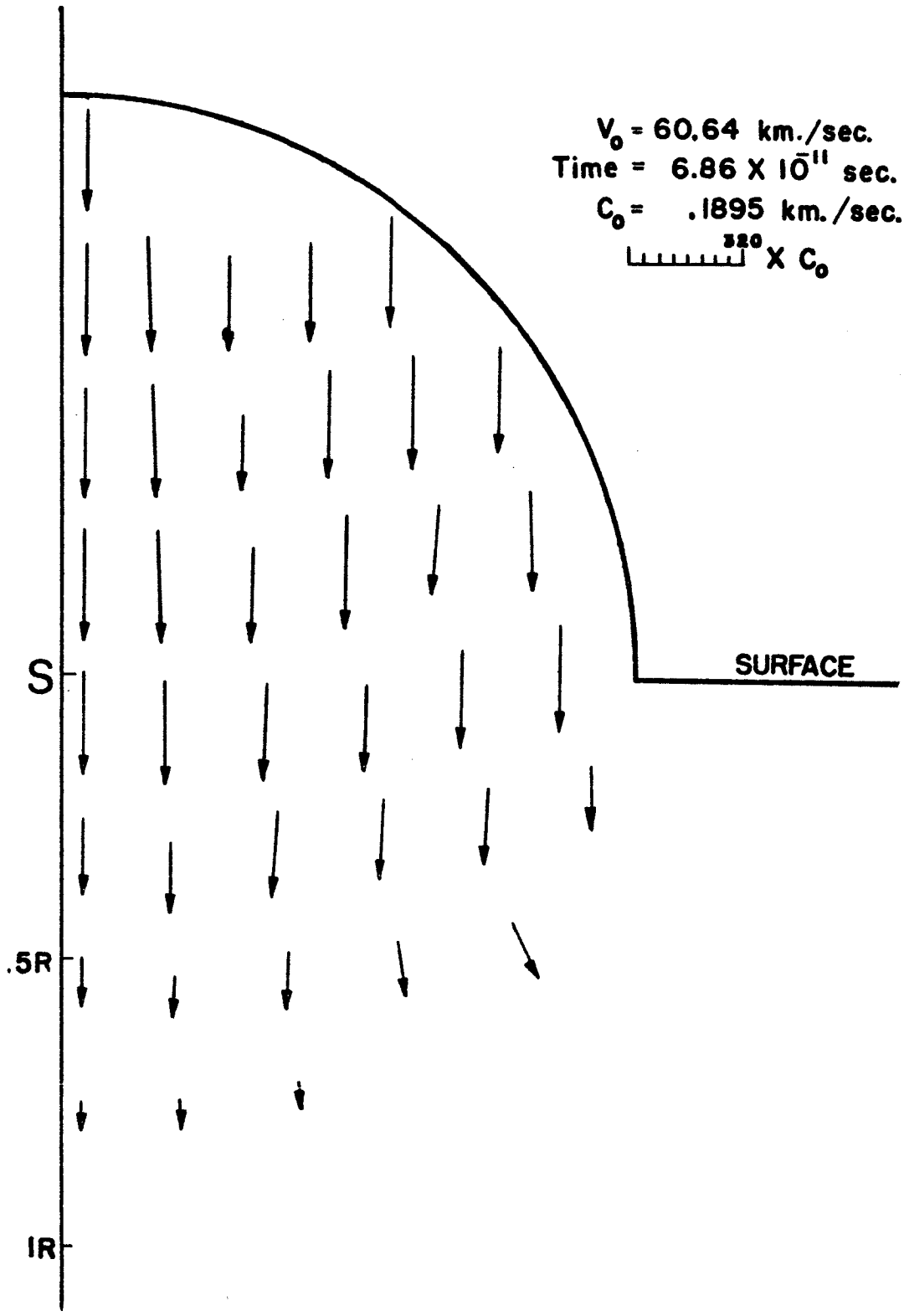

Figure 232. Velocity Map (t = 6.86 x 10^{-11} sec) VI

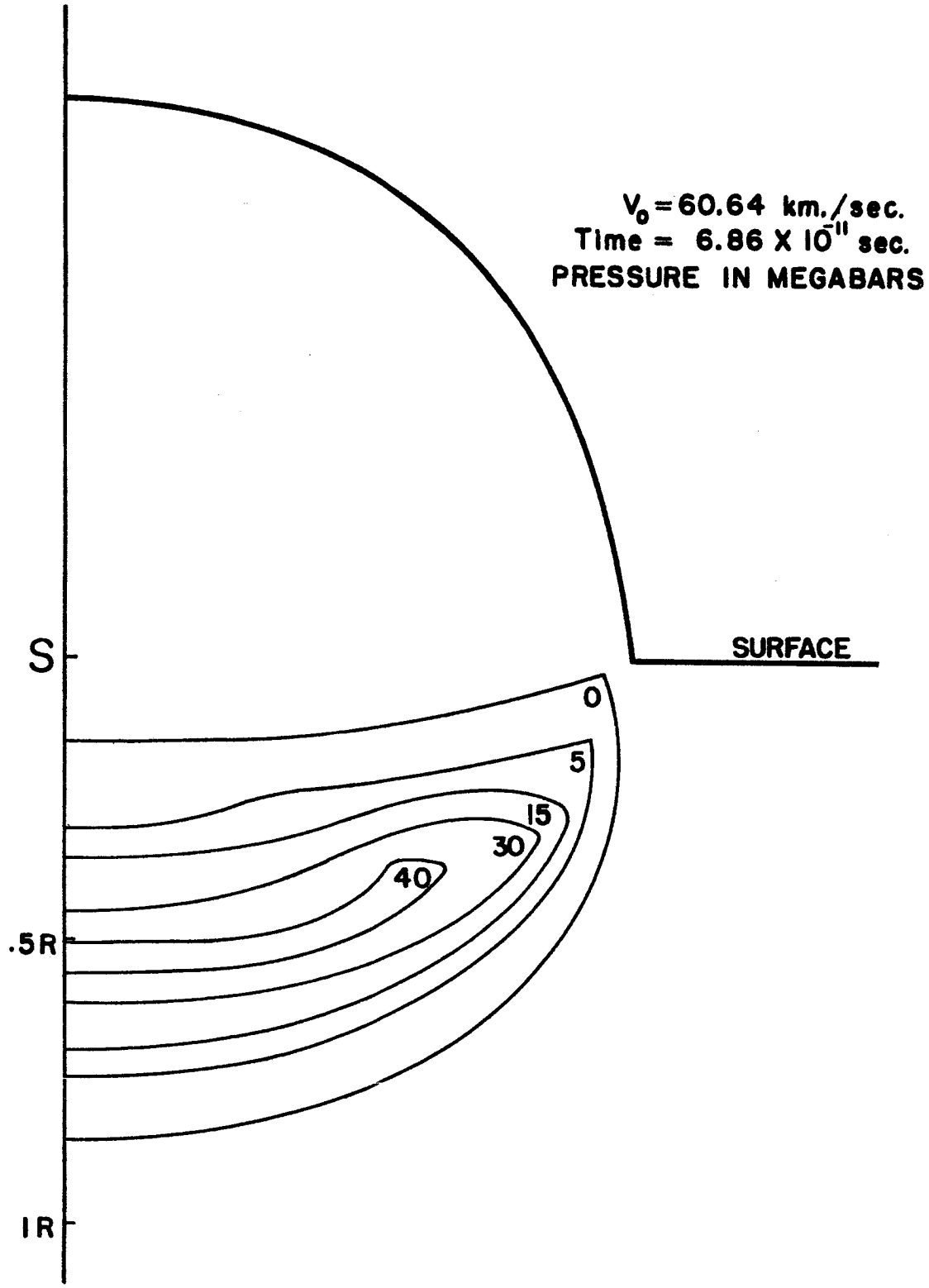

Figure 233. Pressure Map ($t = 6.86 \times 10^{-11}$ sec) VI

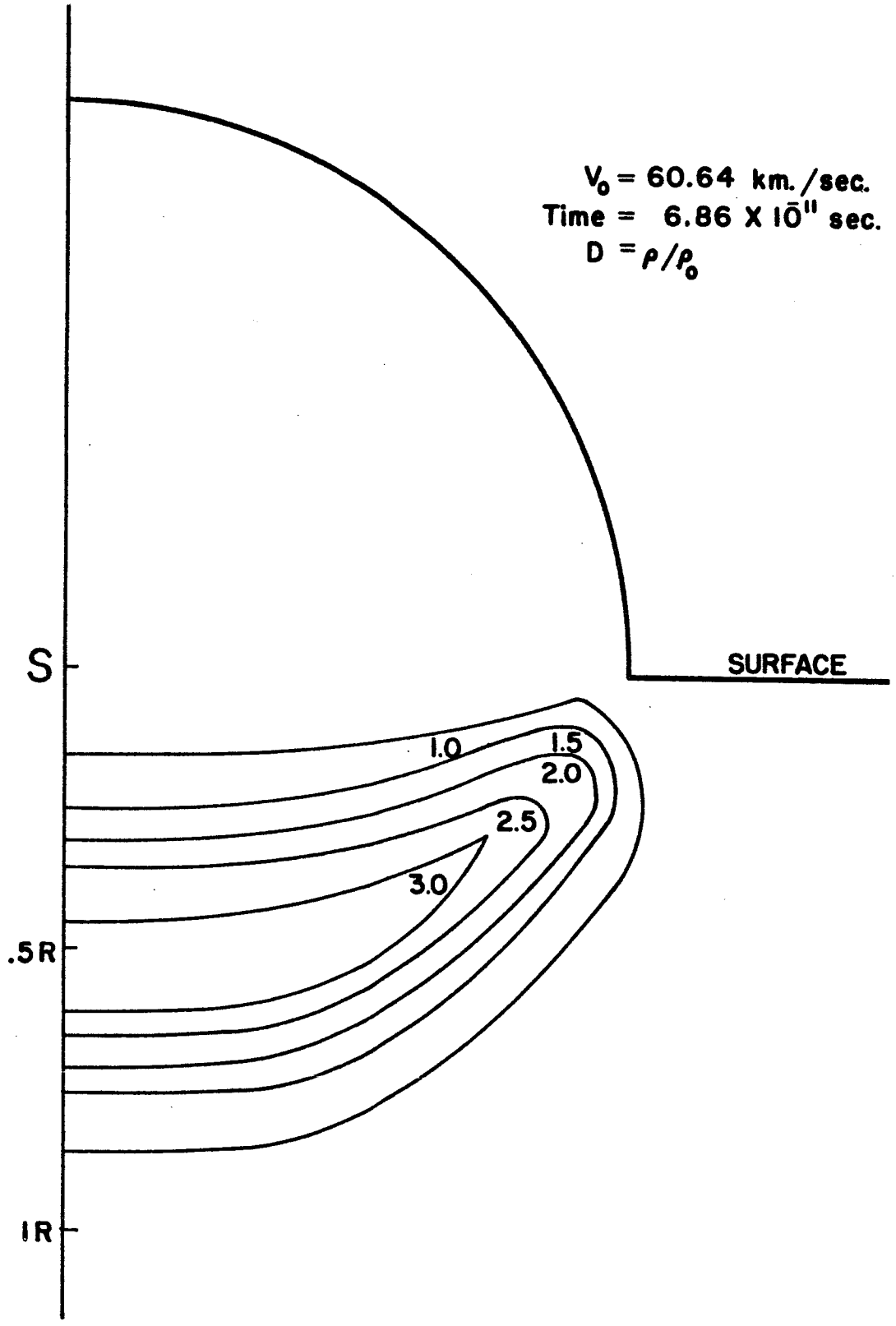

Figure 234. Density Map (t = 6.86 x 10^{-11} sec) VI

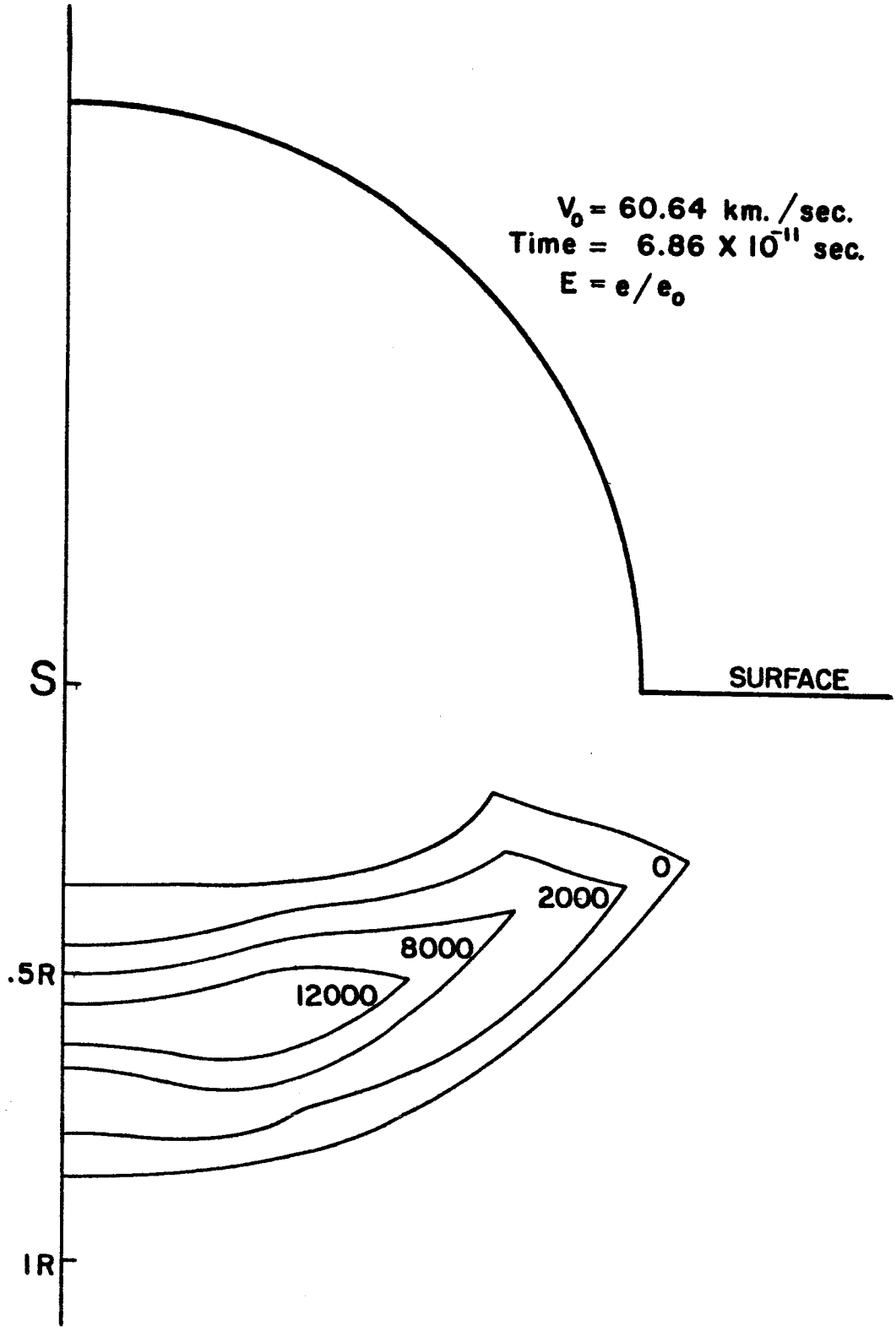

Figure 235. Energy Map (t = 6.86 x 10^{-11} sec) VI

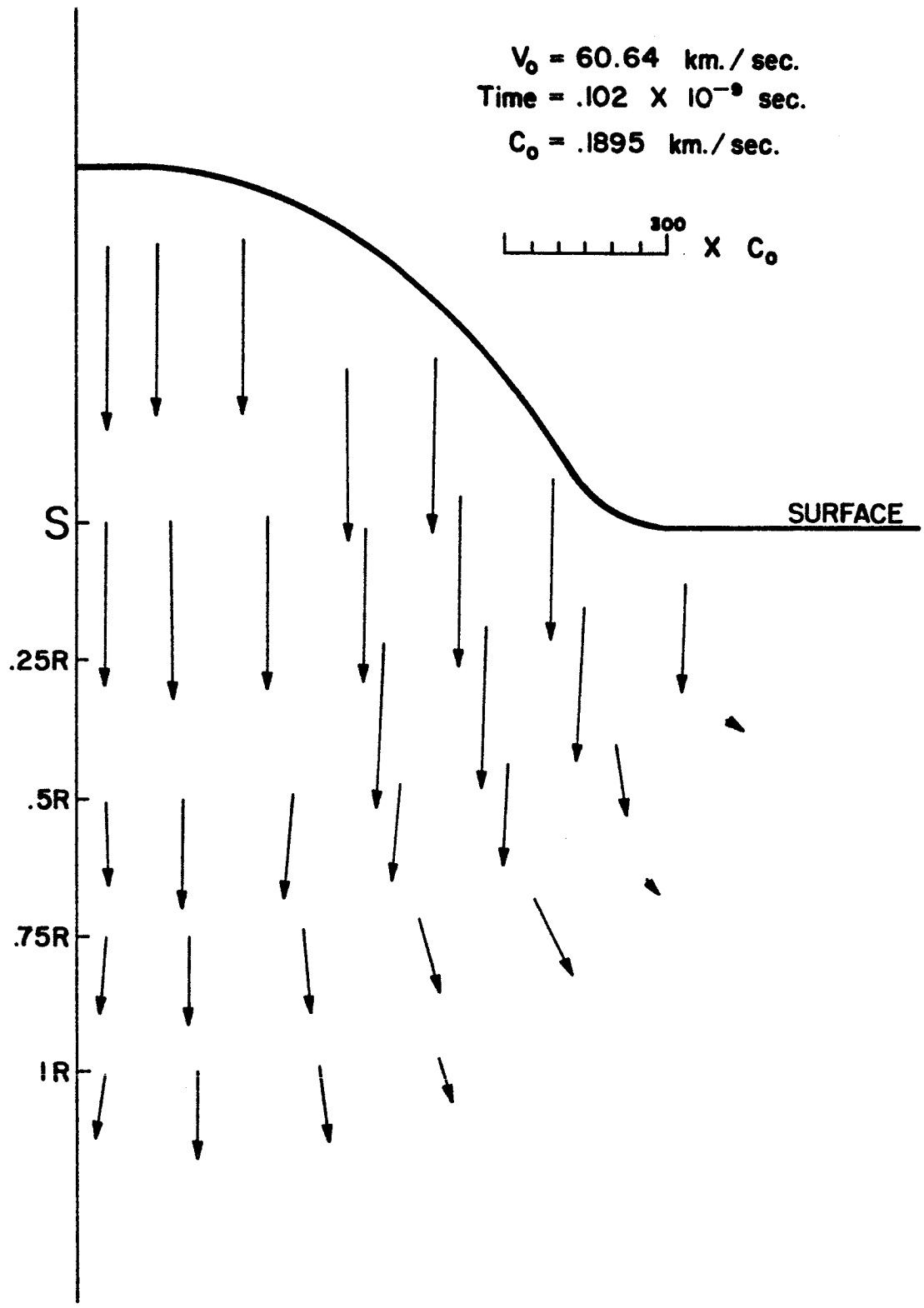

Figure 236. Velocity Map (t = .102 x 10^{-9} sec) VI

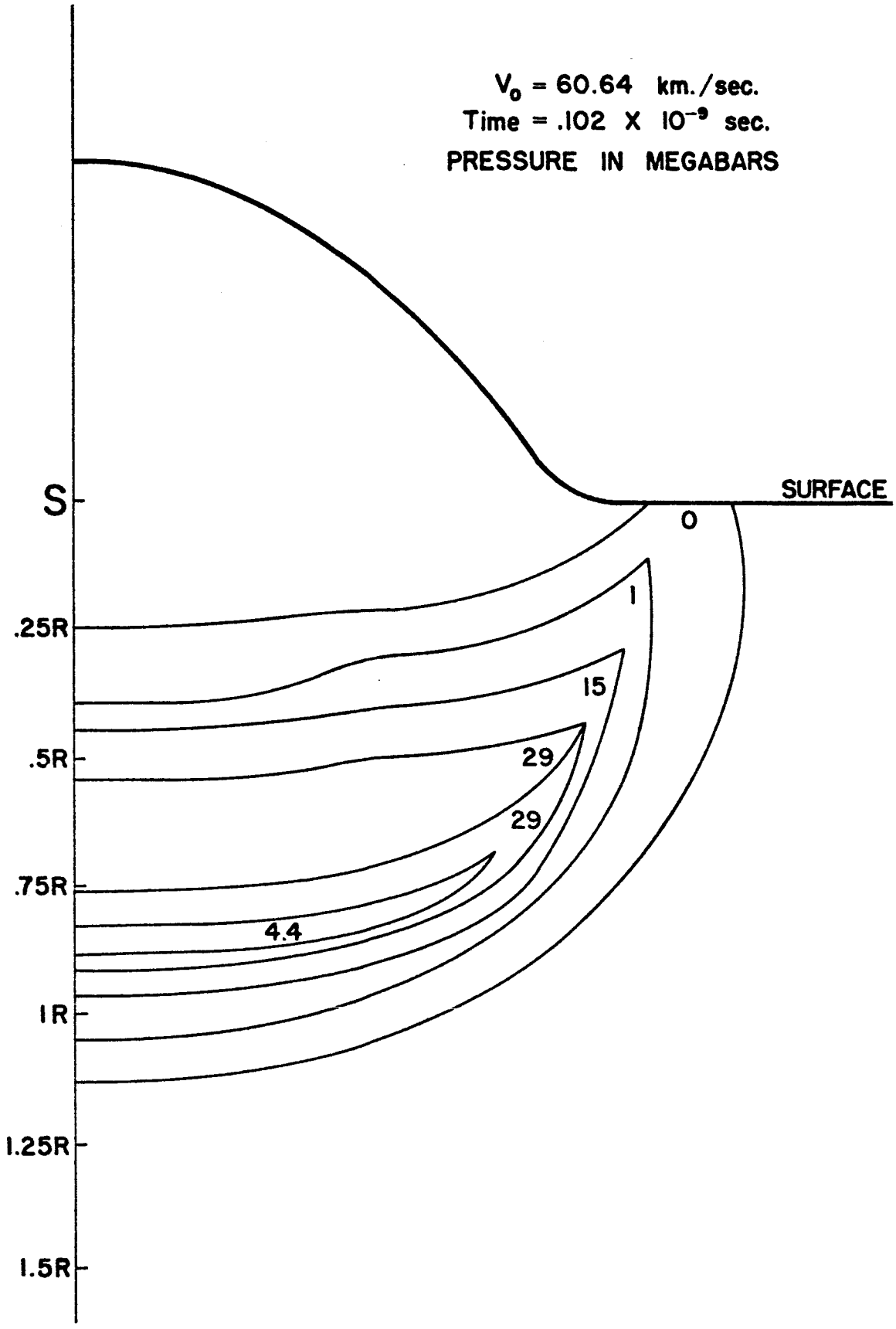

Figure 237. Pressure Map (t = .102 x 10^{-9} sec) VI

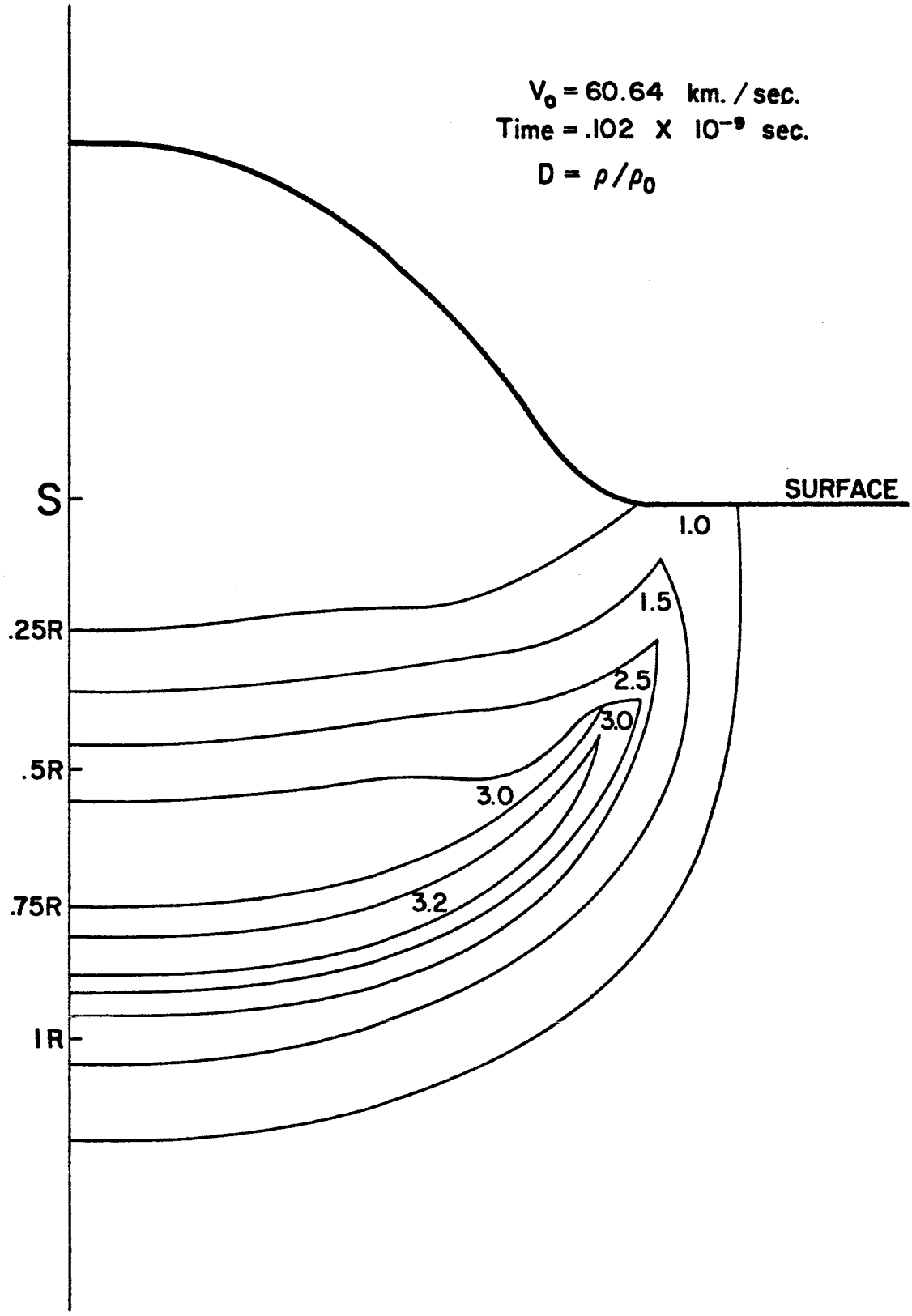

Figure 238. Density Map (t = .102 x 10^{-9} sec) VI

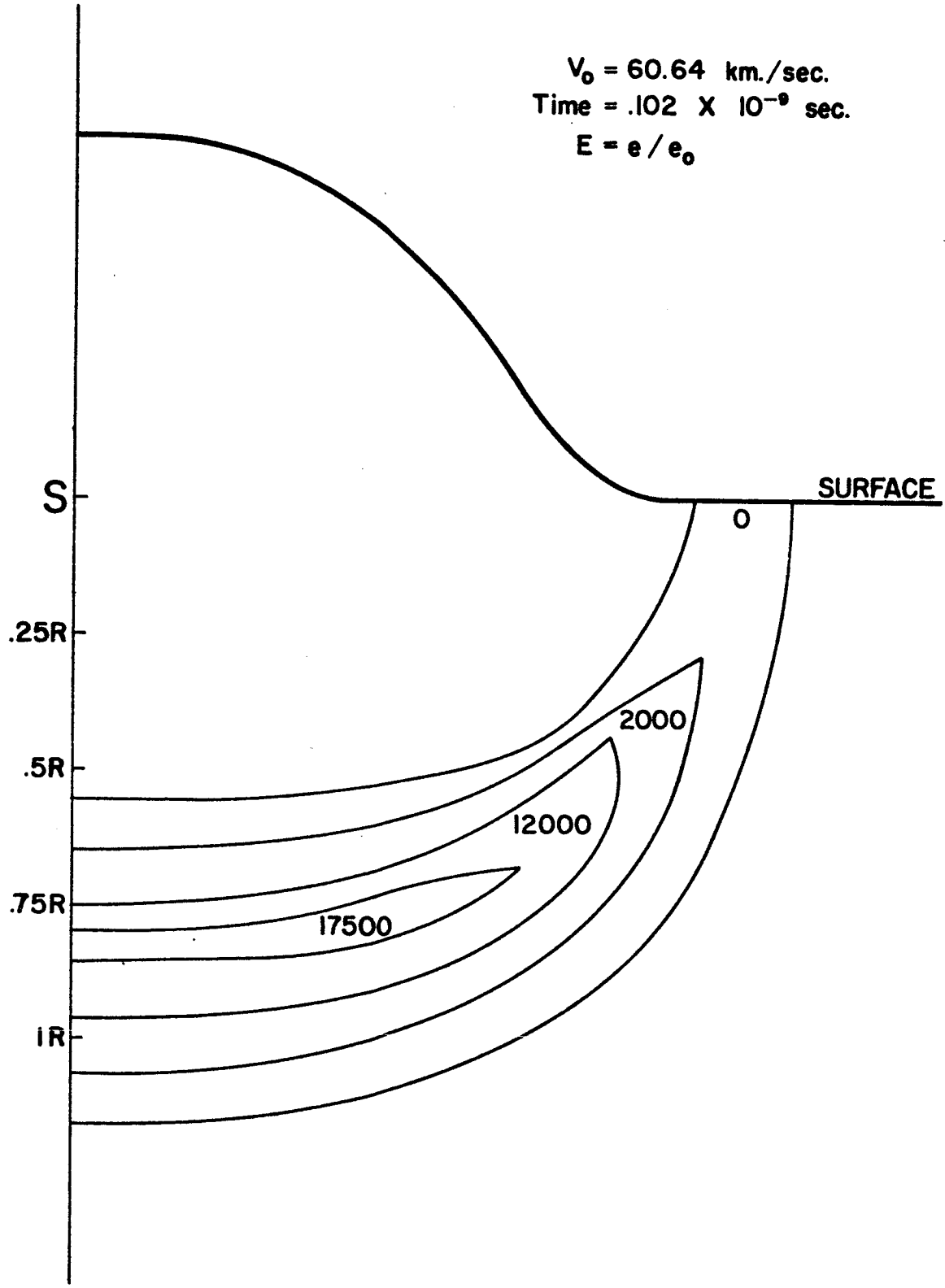

Figure 239. Energy Map (t = .102 x 10^{-9} sec)VI

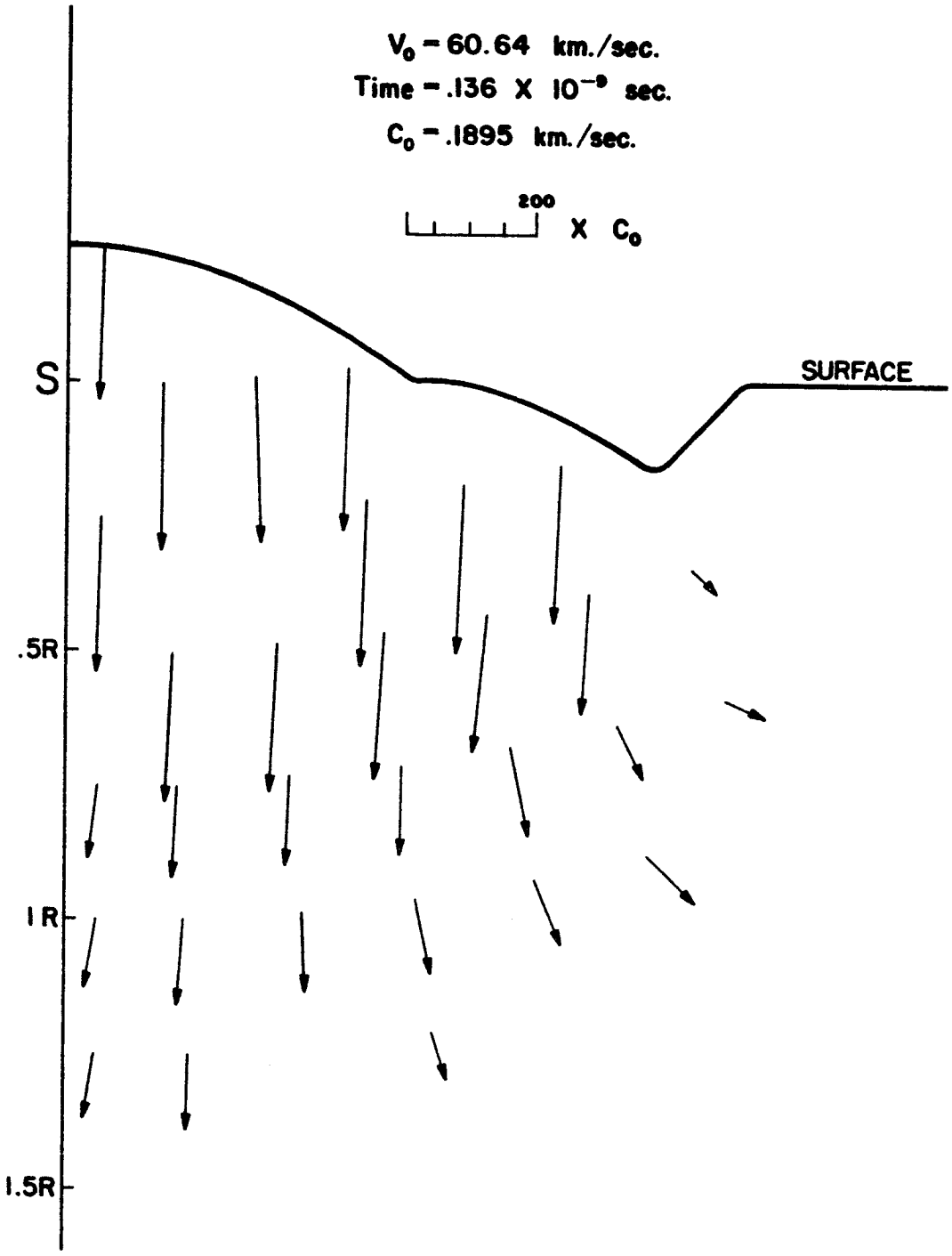

Figure 240. Velocity Map (t = .136 x 10^{-9} sec) VI

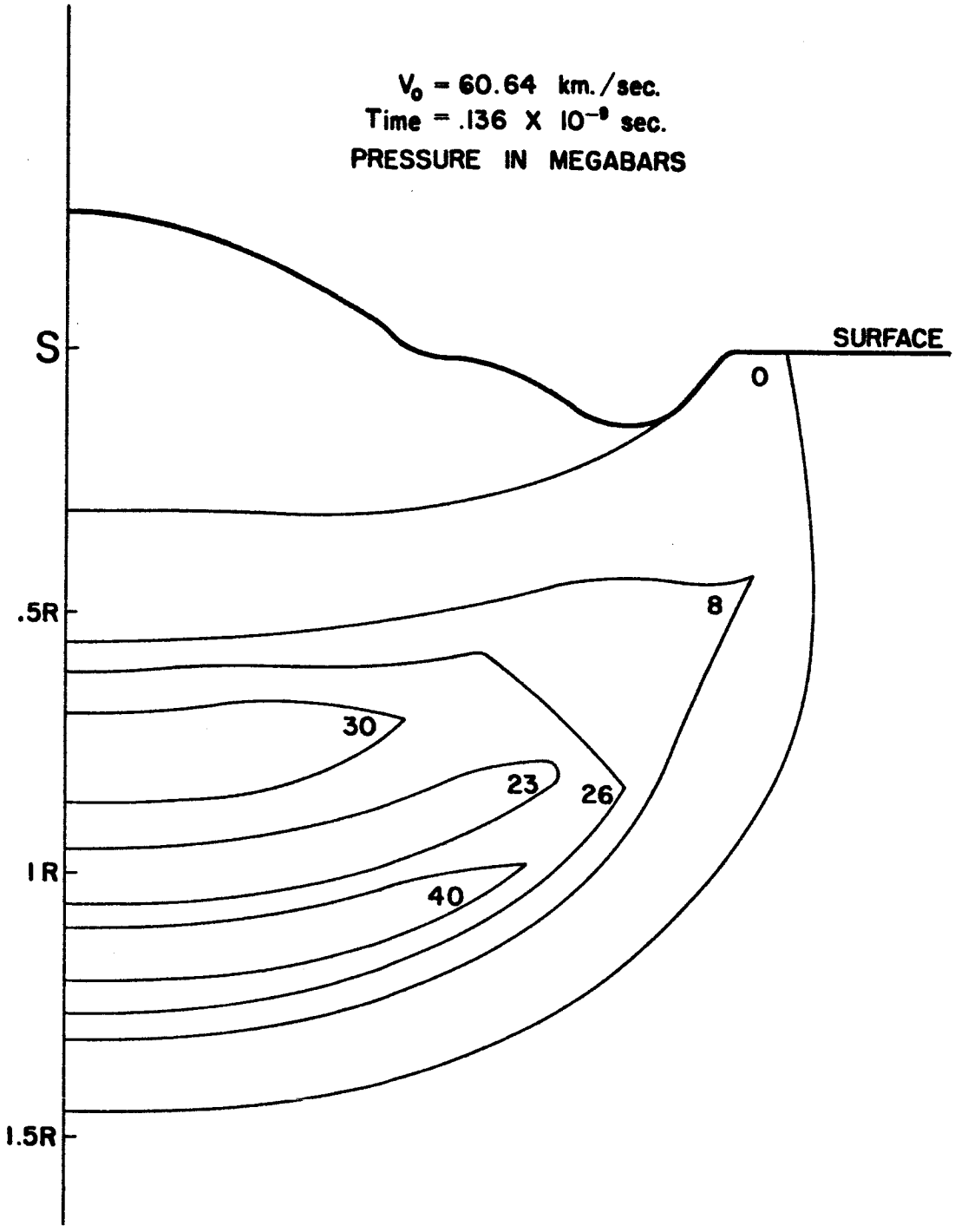

Figure 241. Pressure Map (t = .136 x 10^{-9} sec) VI

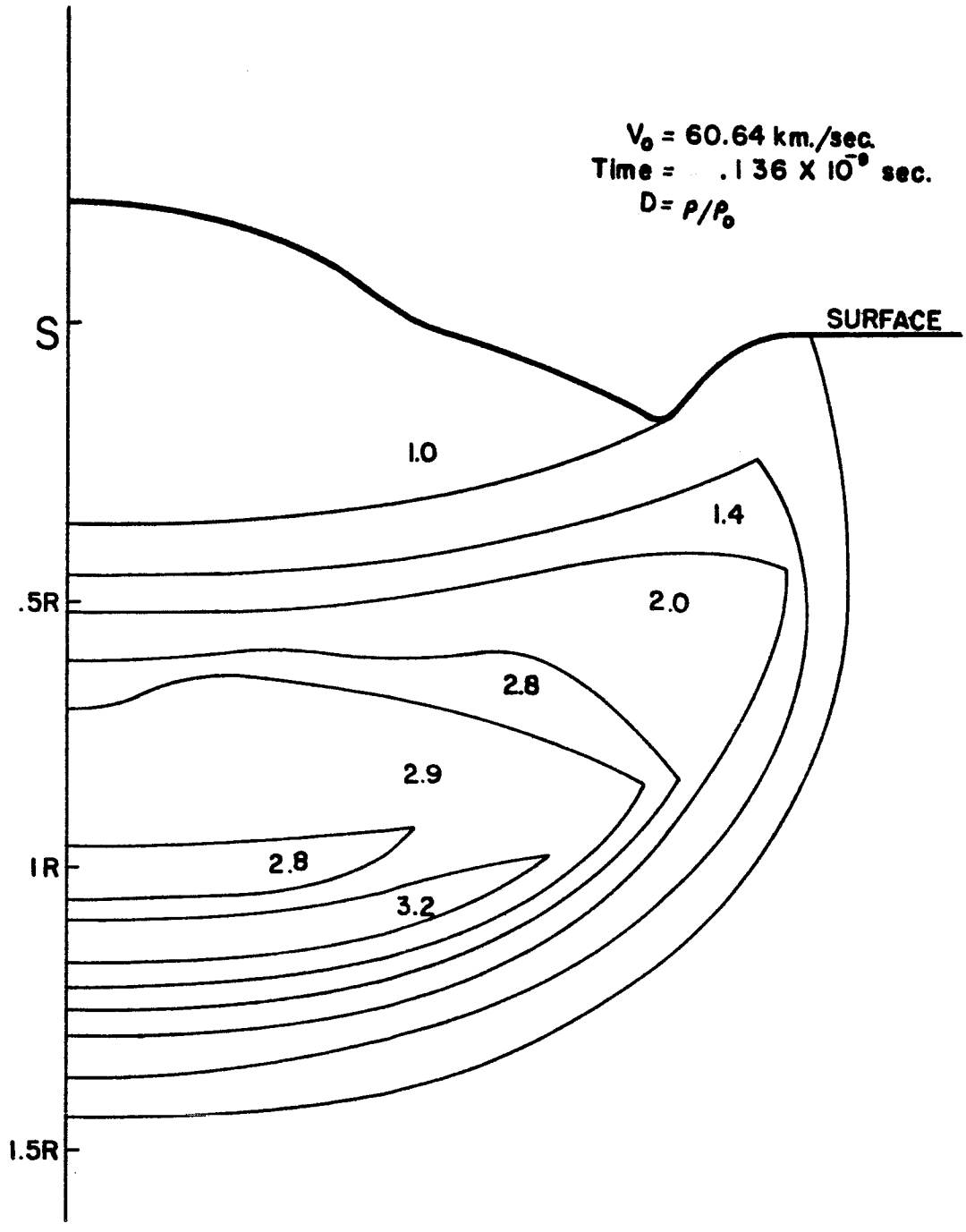

Figure 242. Density Map (t = .136 x 10^{-9} sec) VI

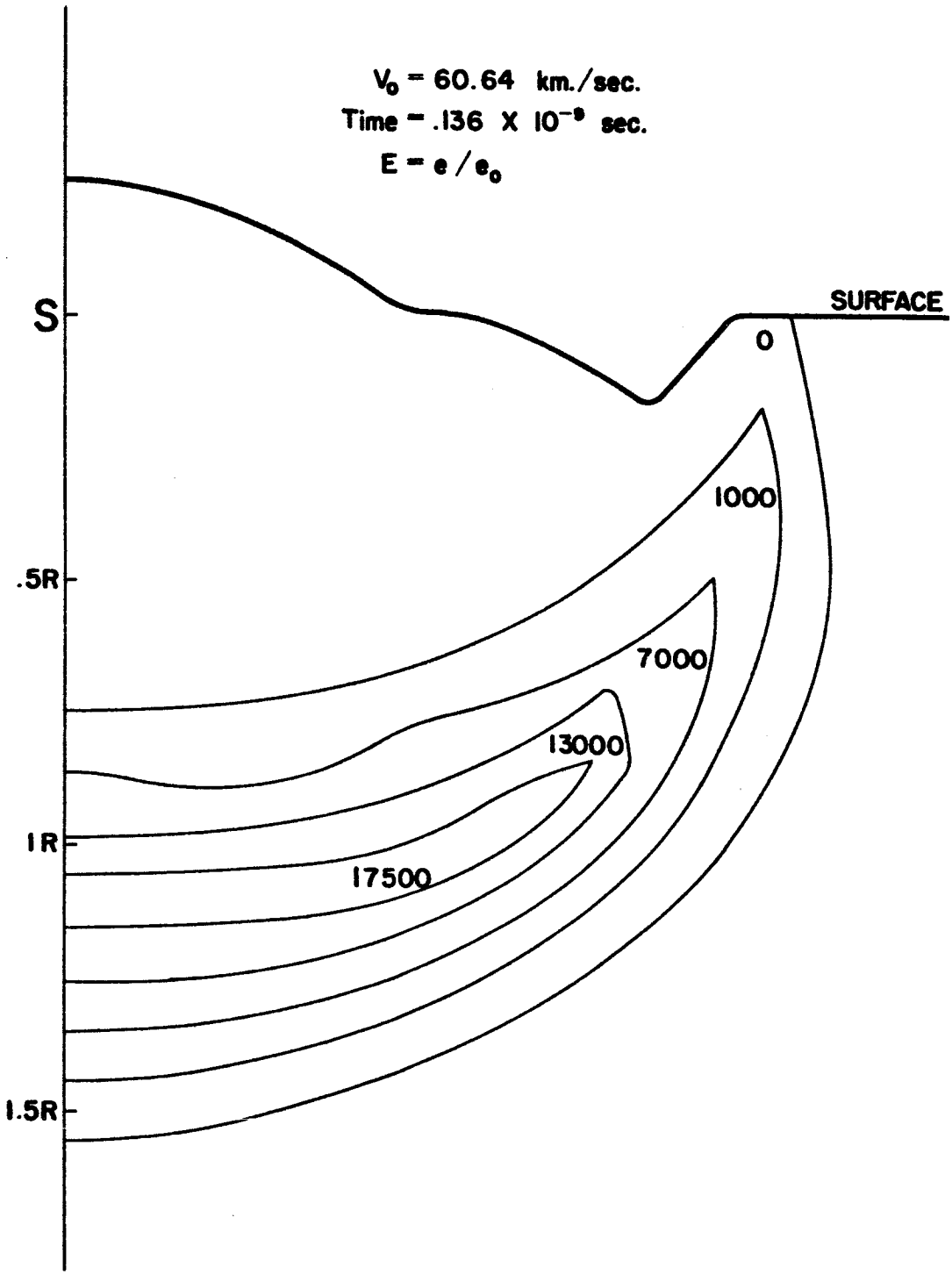

Figure 243. Energy Map (t = .136 x 10^{-9} sec) VI

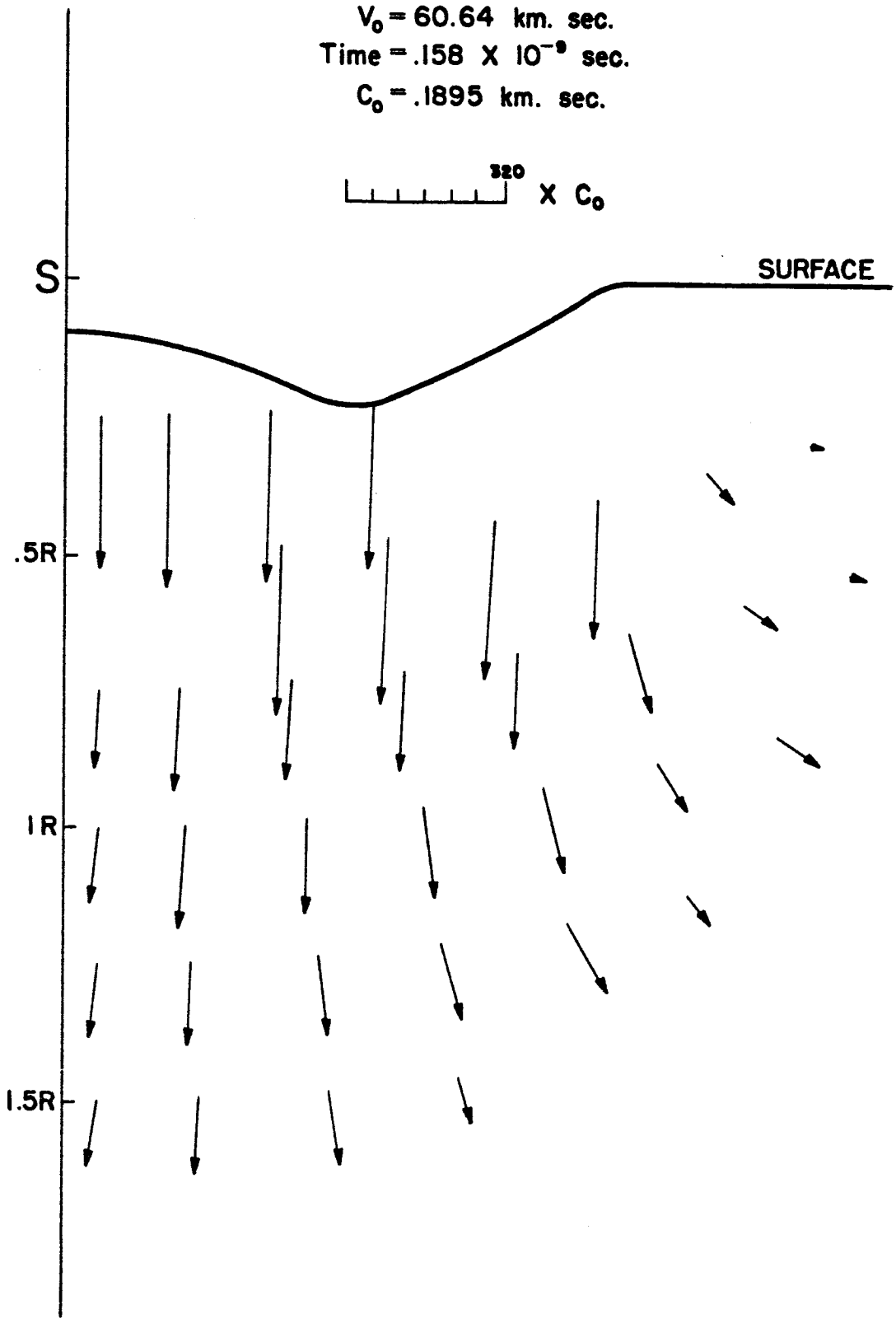

Figure 244. Velocity Map (t = .158 x 10^{-9} sec) VI

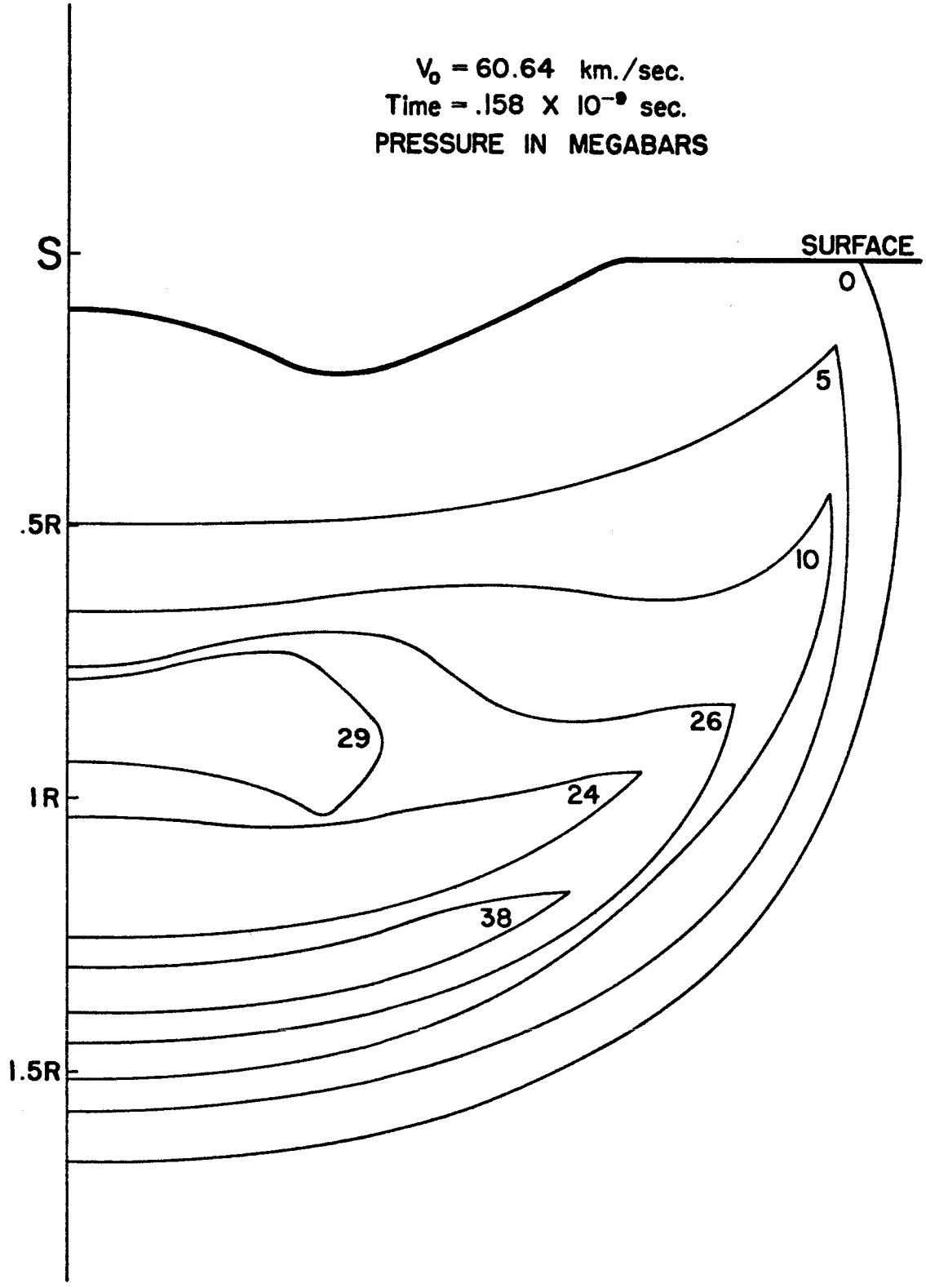

Figure 245. Pressure Map (t = .158 x 10^{-9} sec) VI

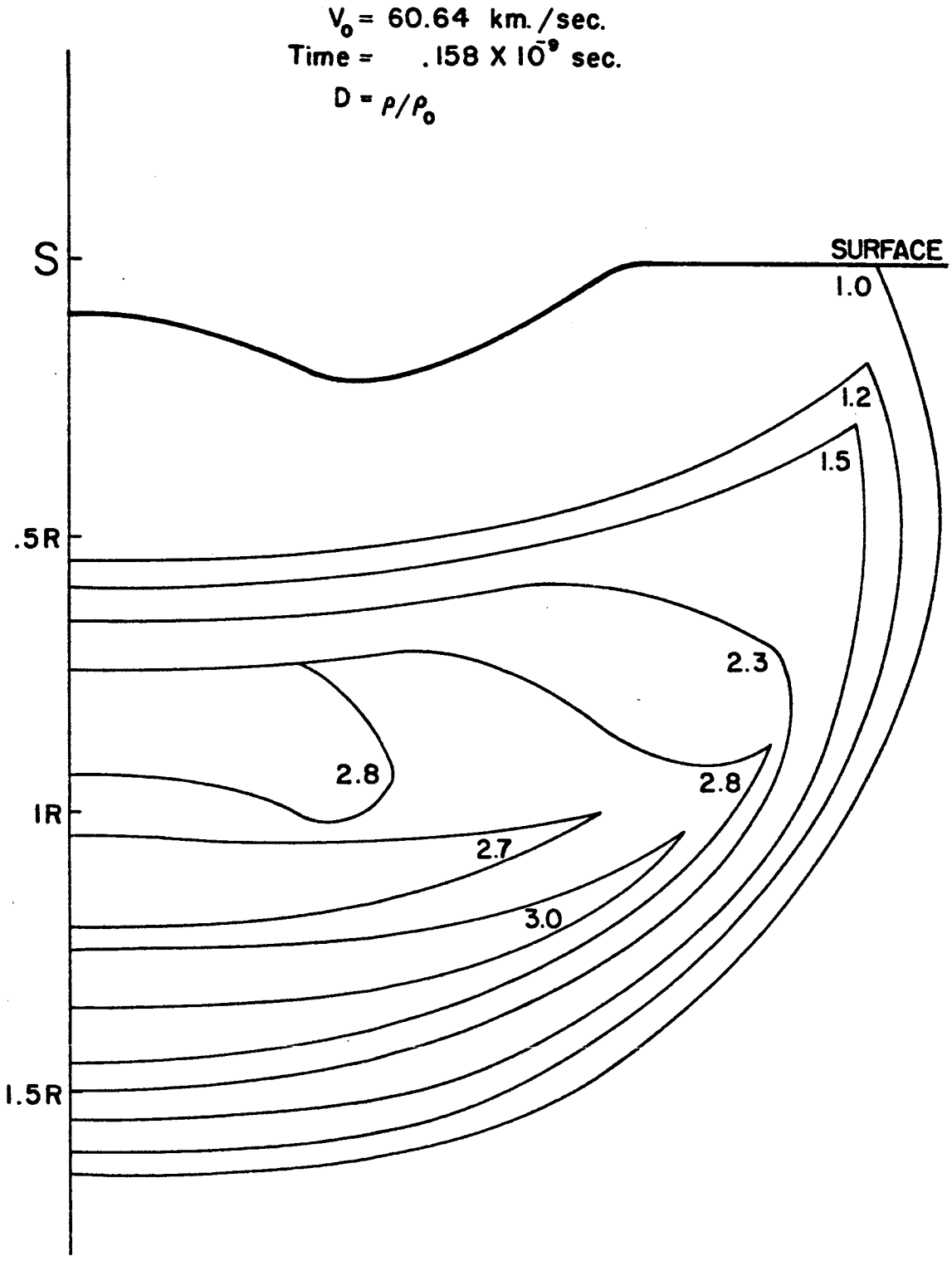

Figure 246. Density Map (t = .158 x 10^{-9} sec) VI

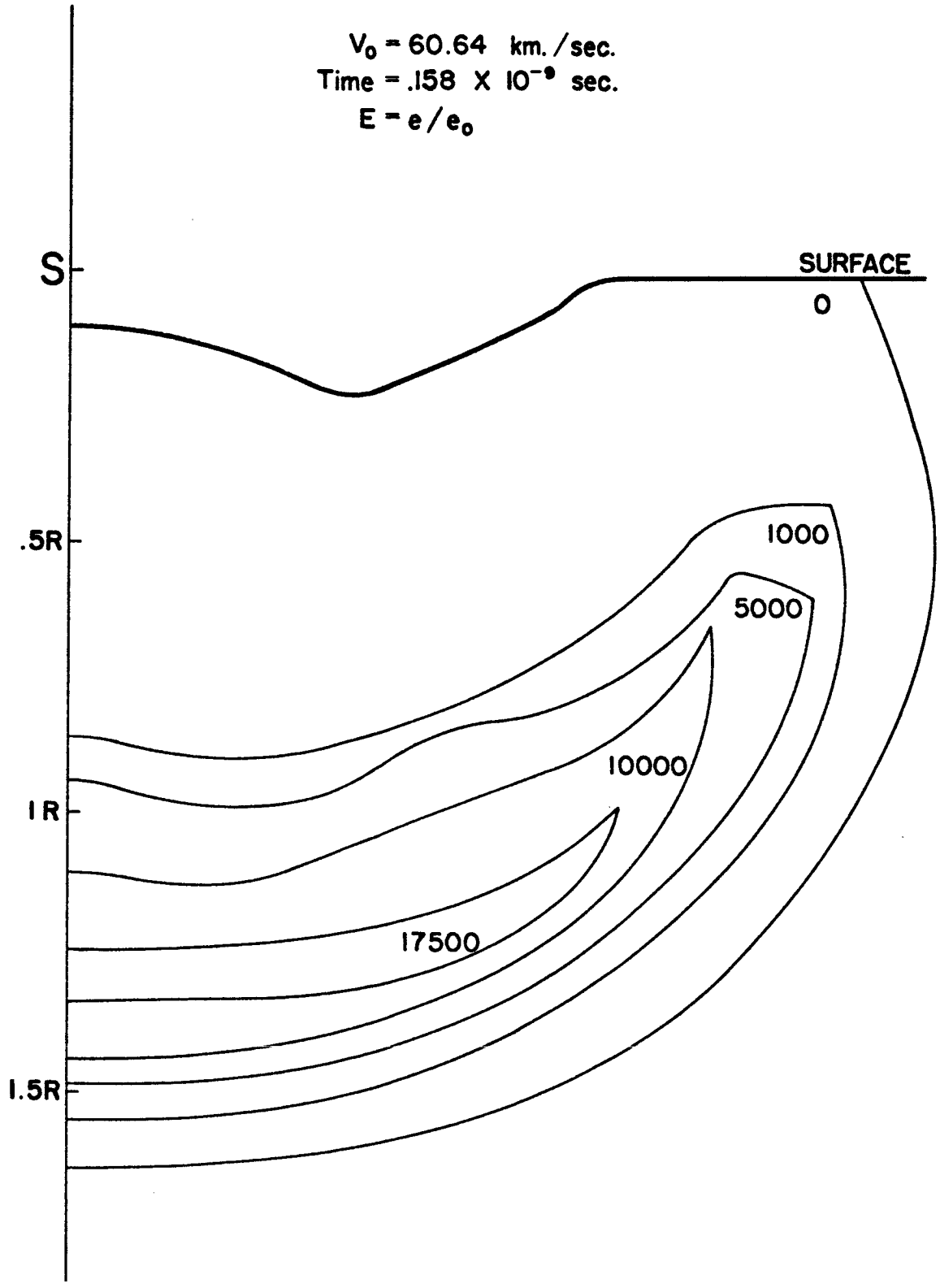

Figure 247. Energy Map (t = .158 x 10^{-9} sec) VI

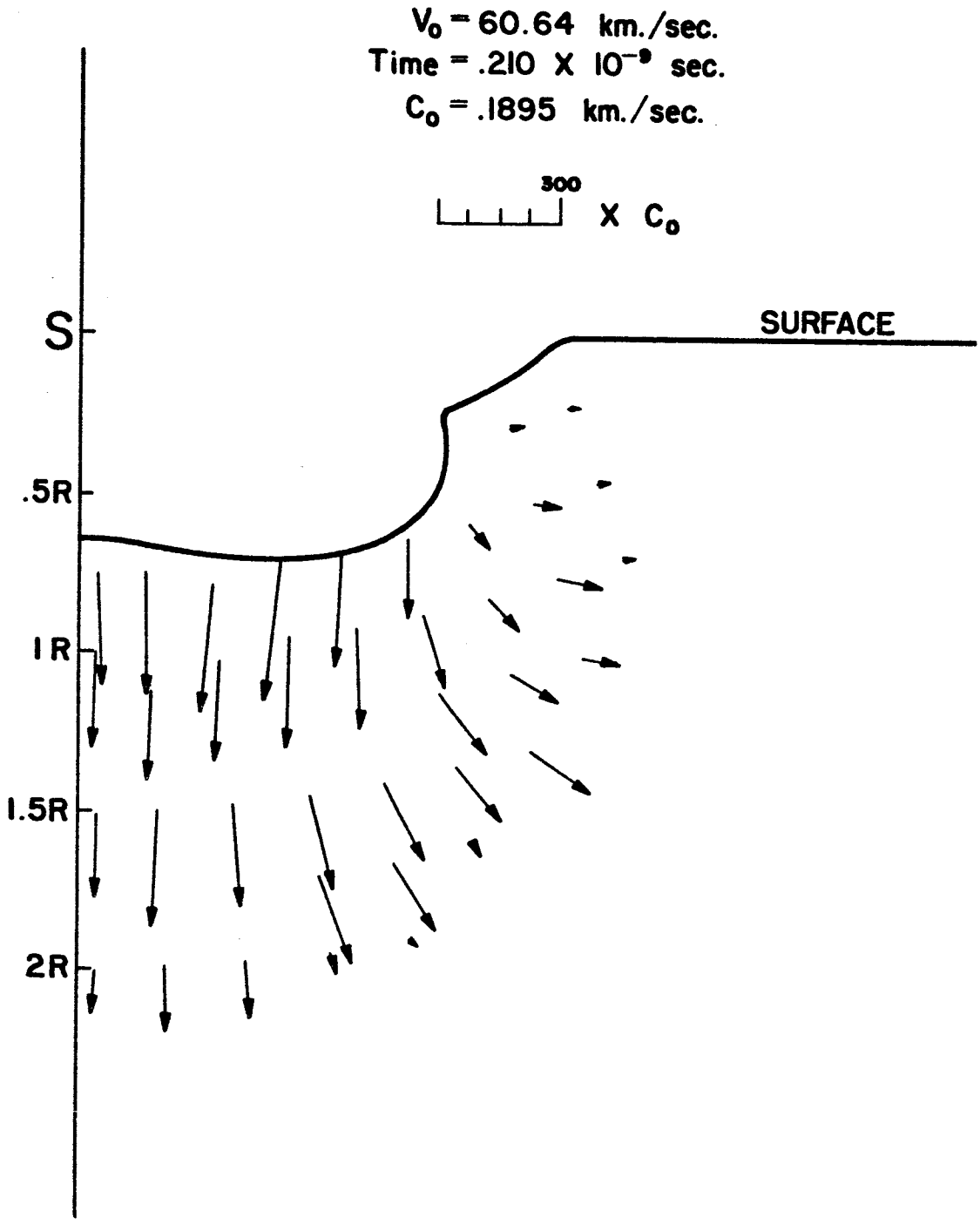

Figure 248. Velocity Map (t = .210 x 10^{-9} sec) VI

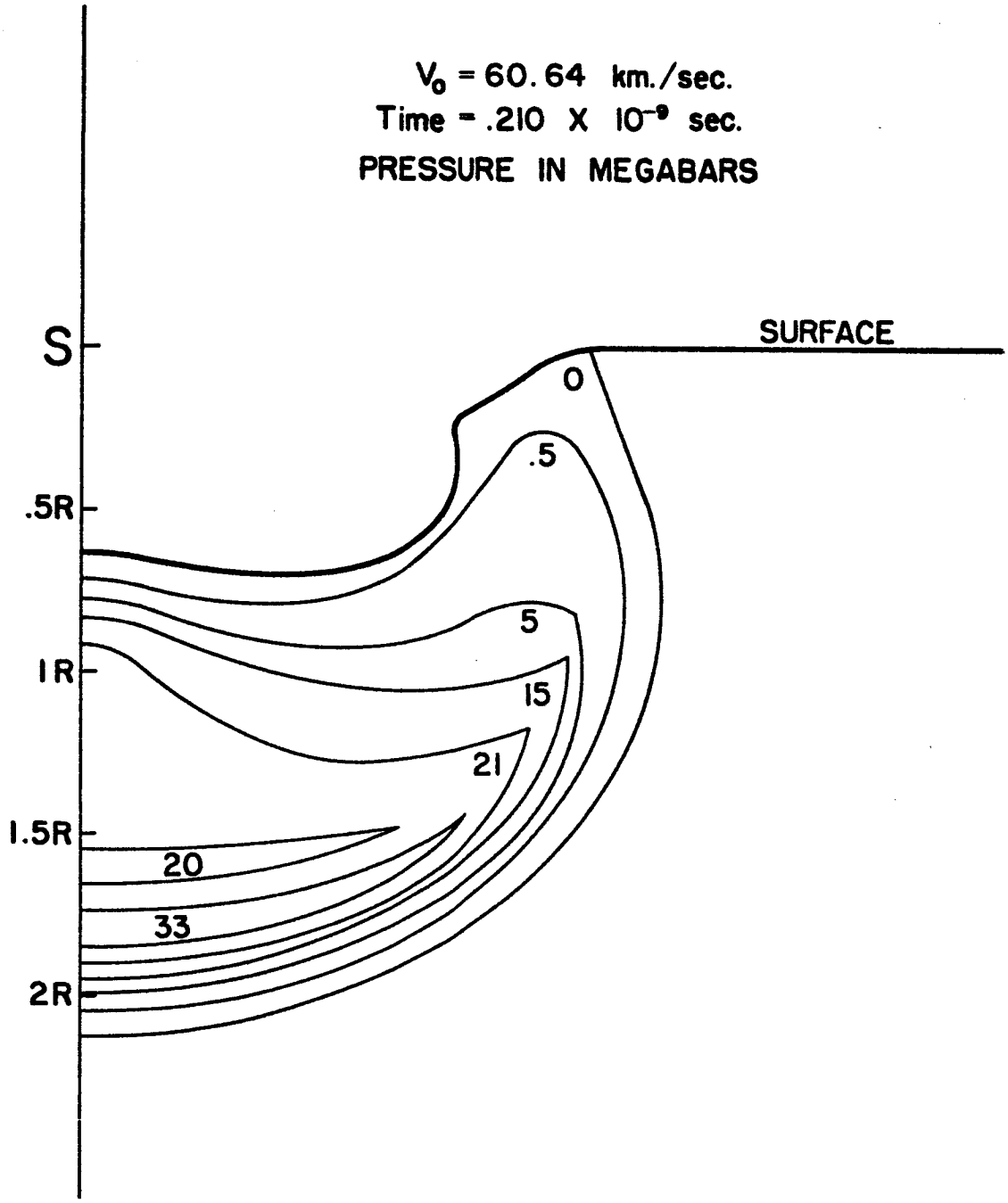

Figure 249. Pressure Map (t = .210 x 10^{-9} sec) VI

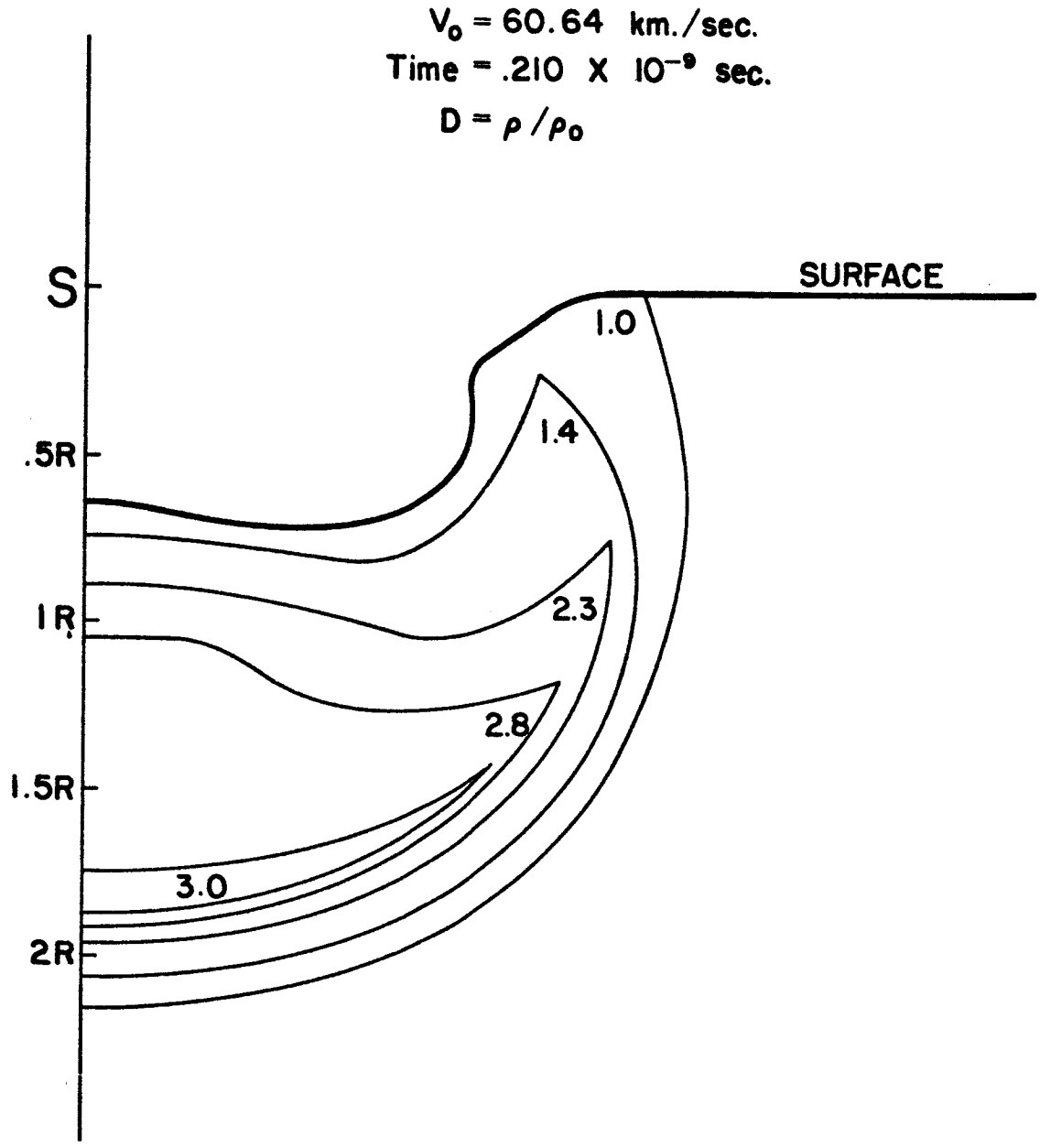

Figure 250. Density Map (t = .210 x 10^{-9} sec) VI

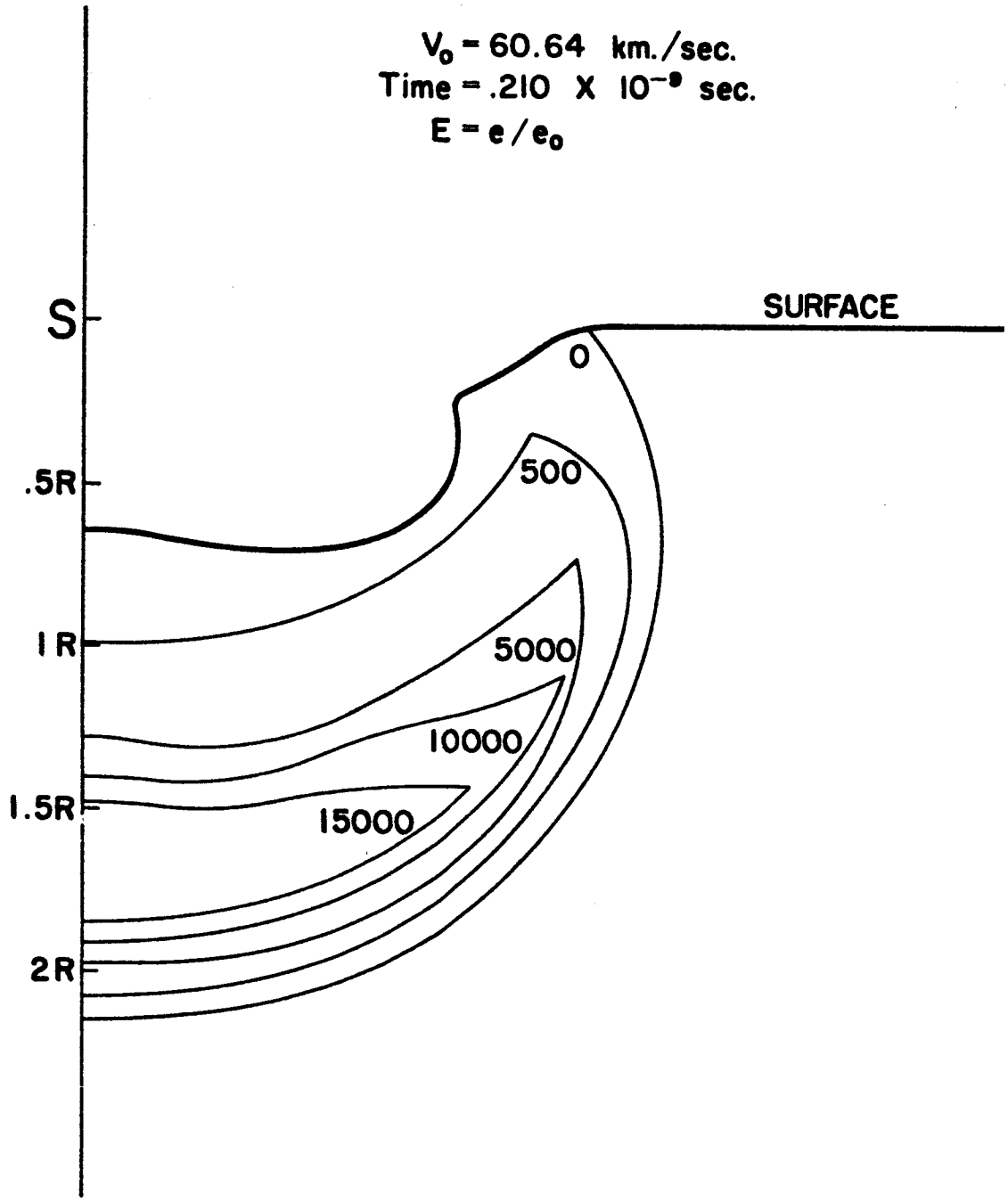

Figure 251. Energy Map (t = .210 x 10^{-9} sec) VI

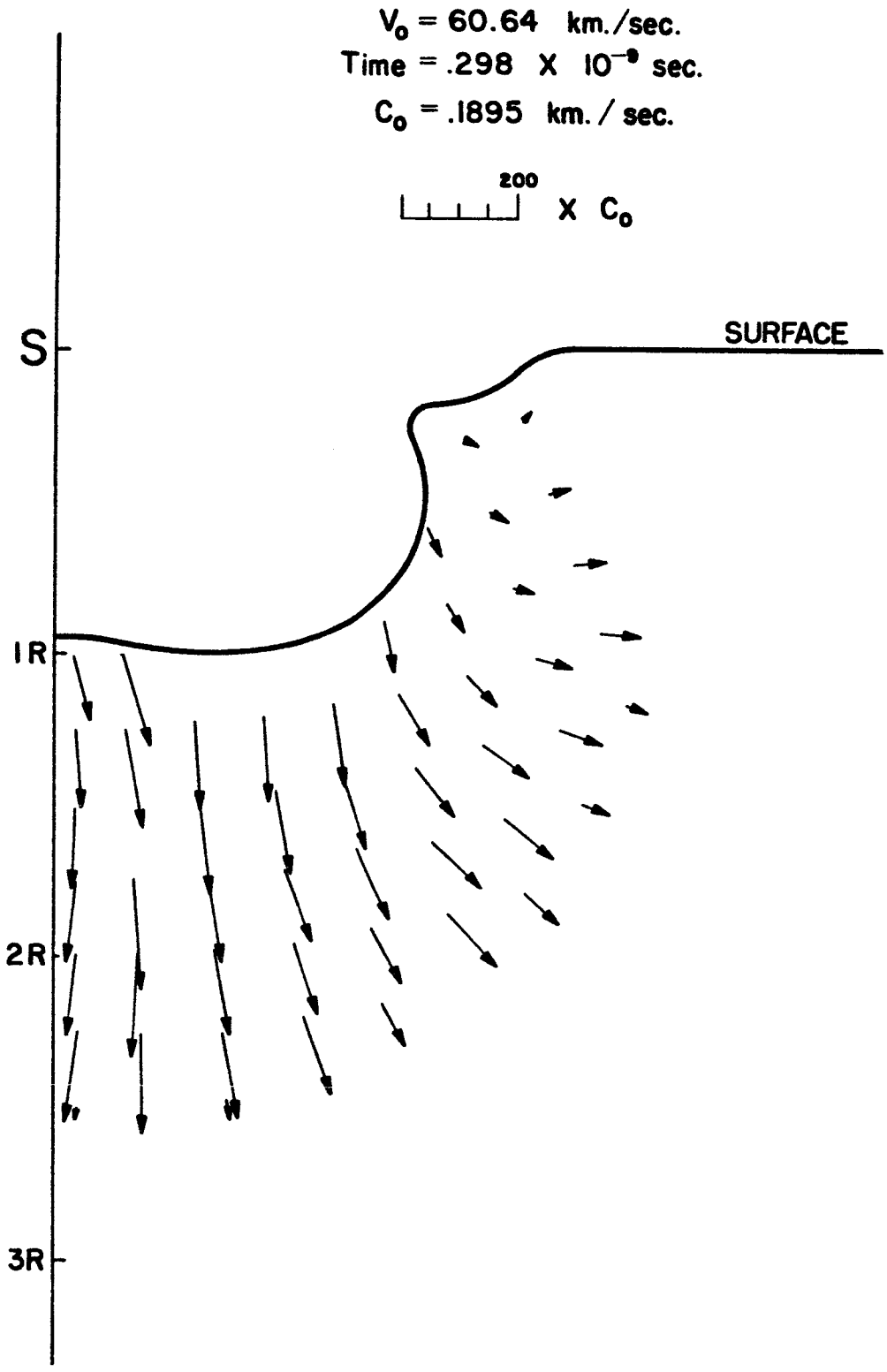

Figure 252. Velocity Map (t = .298 x 10^{-9} sec) VI

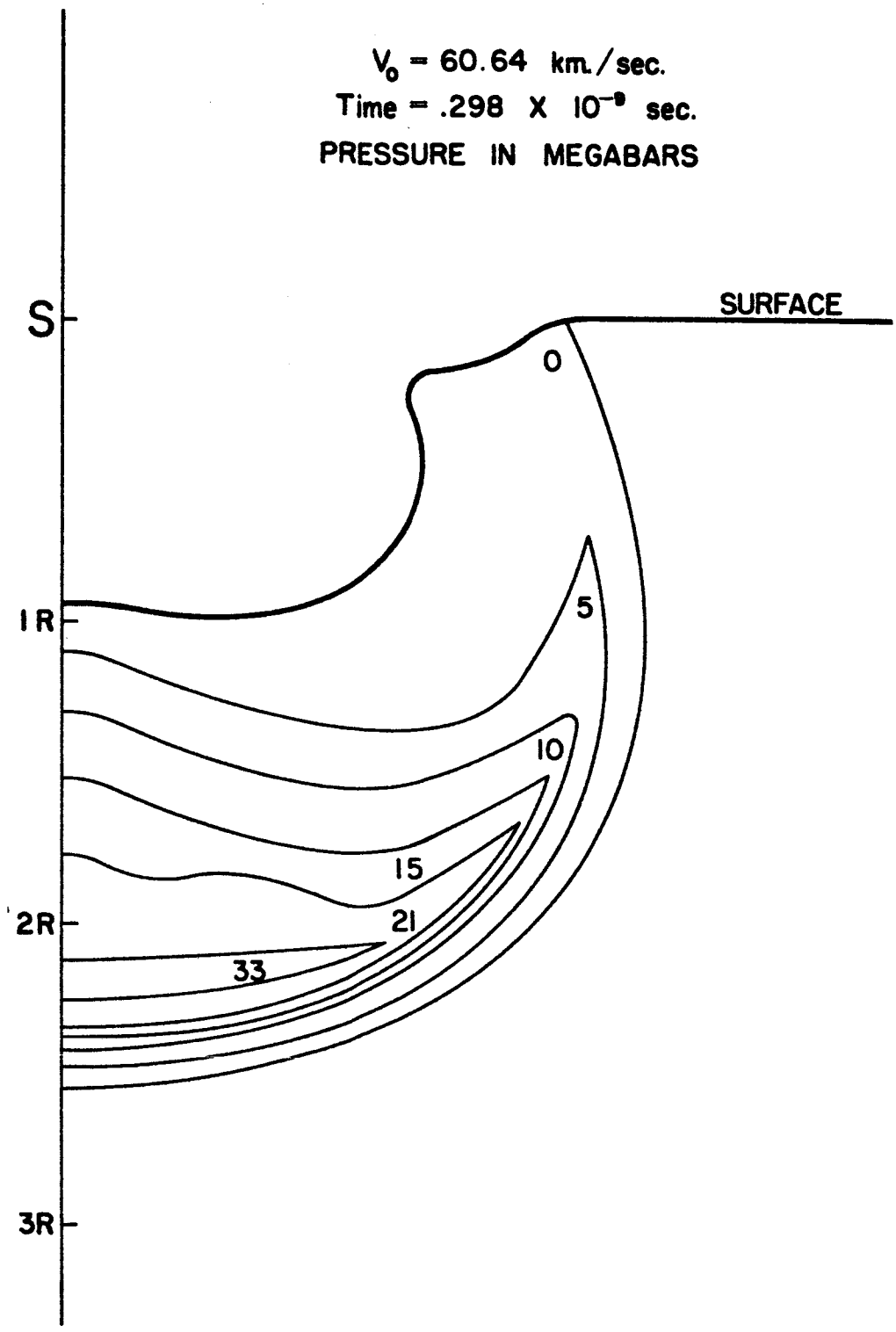

Figure 253. Pressure Map (t = .298 x 10^{-9} sec) VI

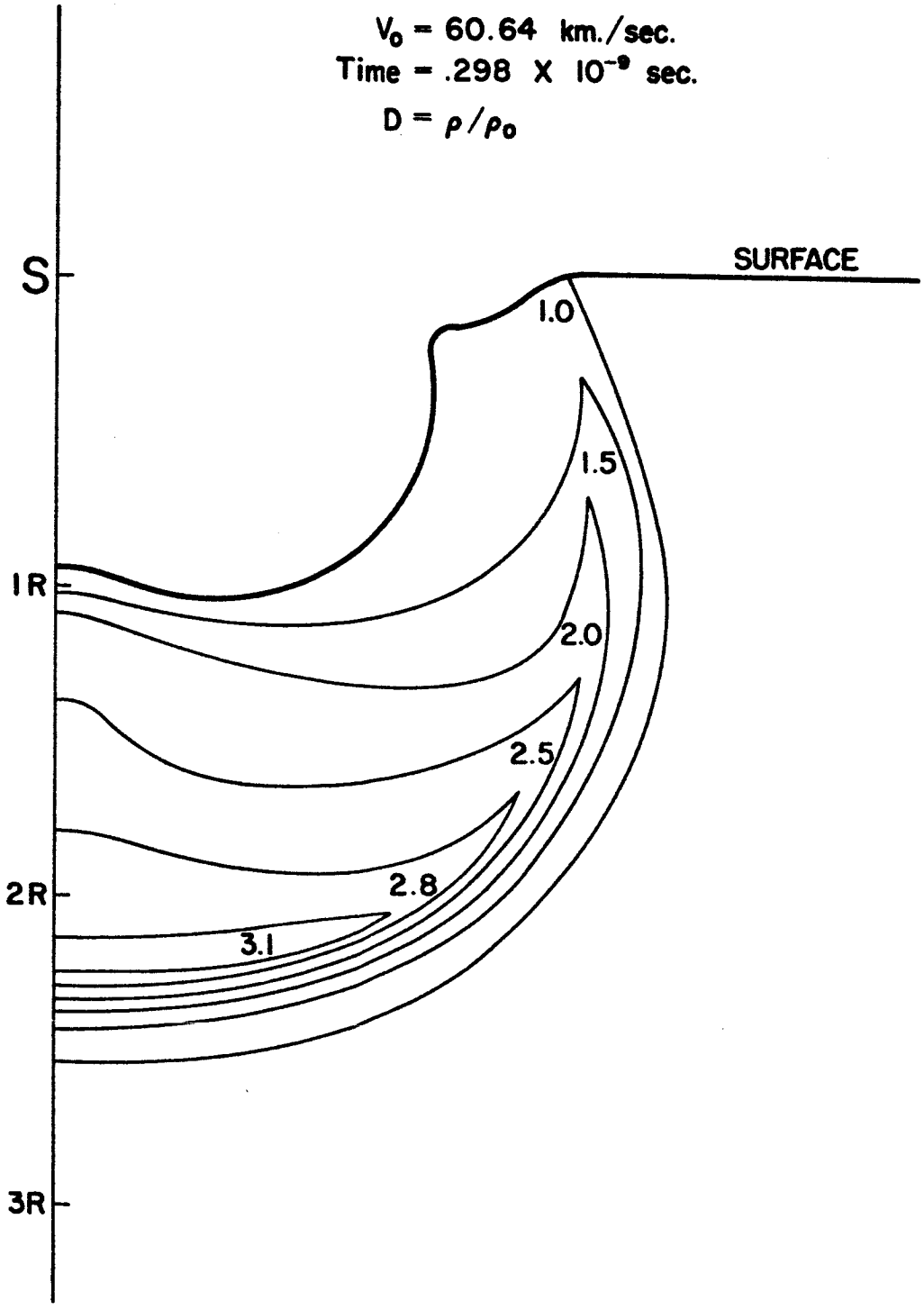

Figure 254. Density Map (t = .298 x 10^{-9} sec) VI

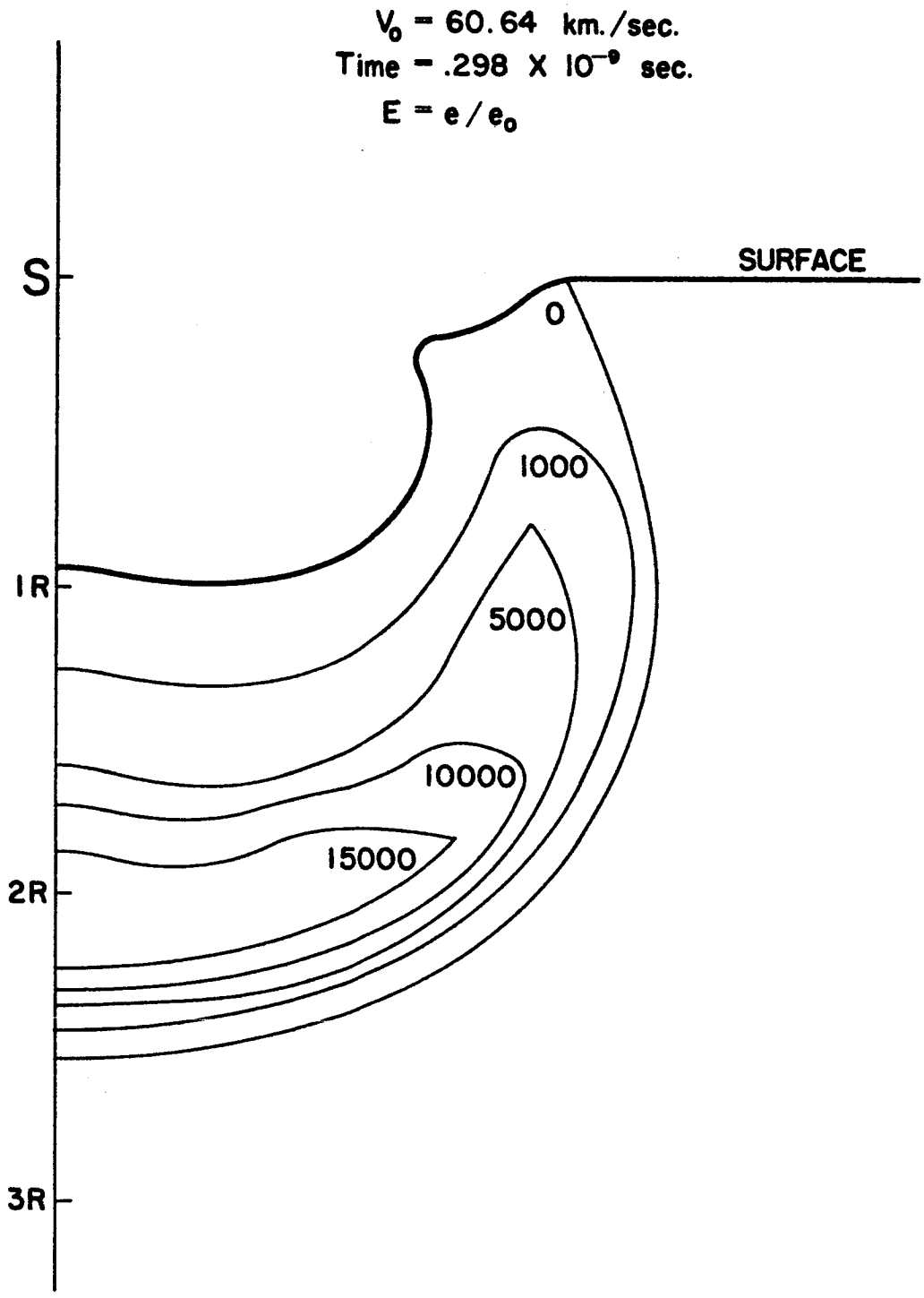

Figure 255. Energy Map (t = .298 x 10^{-9} sec) VI

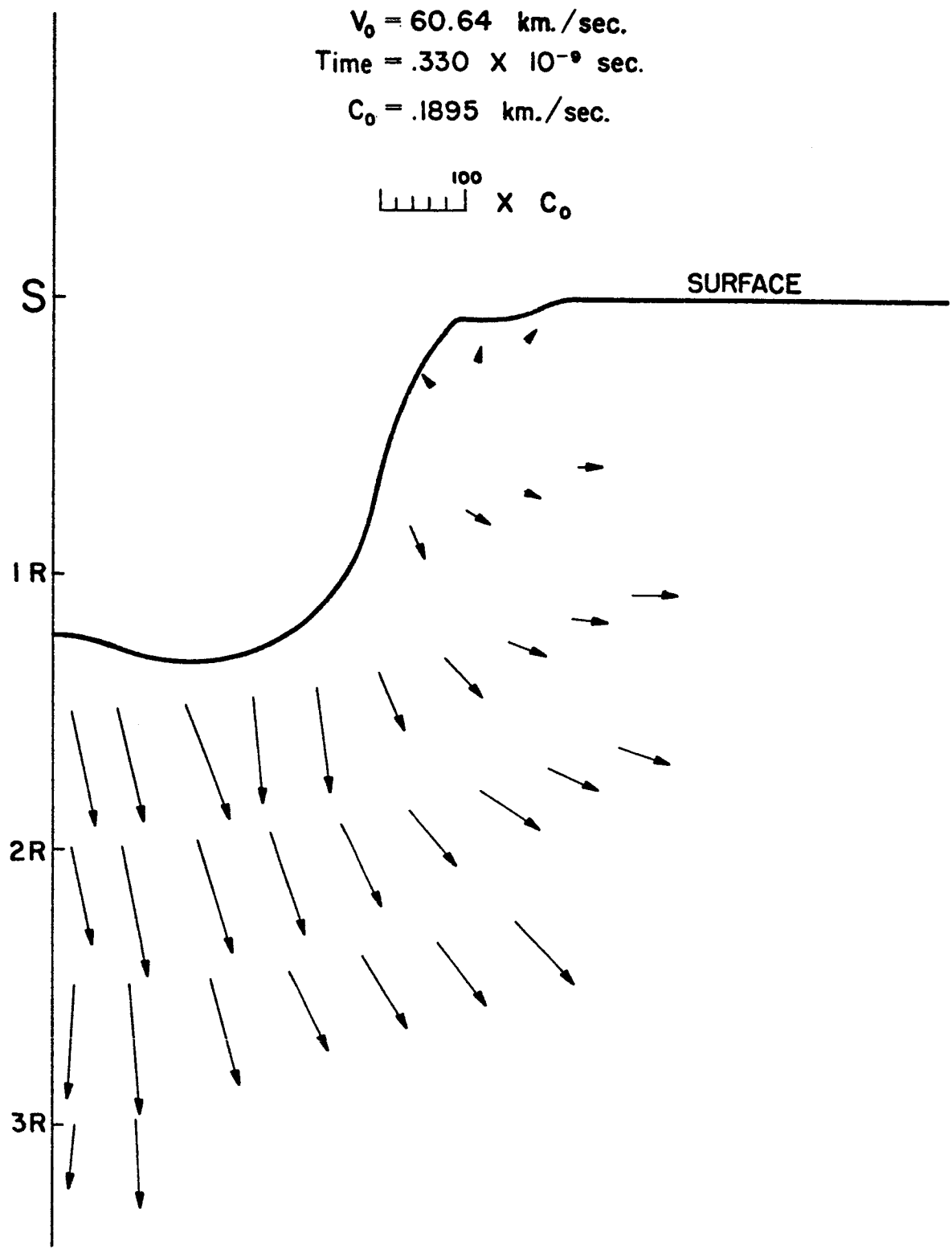

Figure 256. Velocity Map (t = .330 x 10^{-9} sec) VI

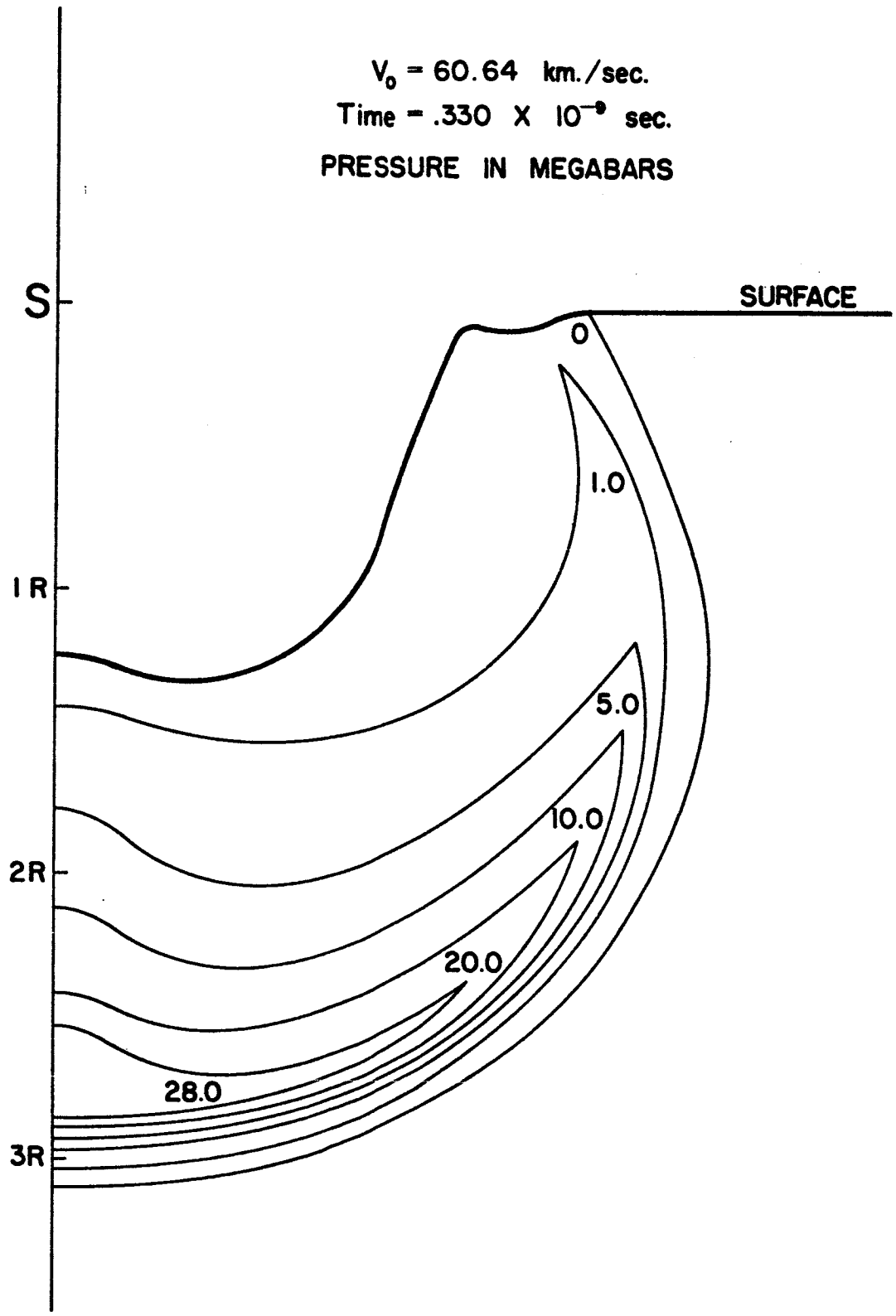

Figure 257. Pressure Map (t = .330 x 10^{-9} sec) VI

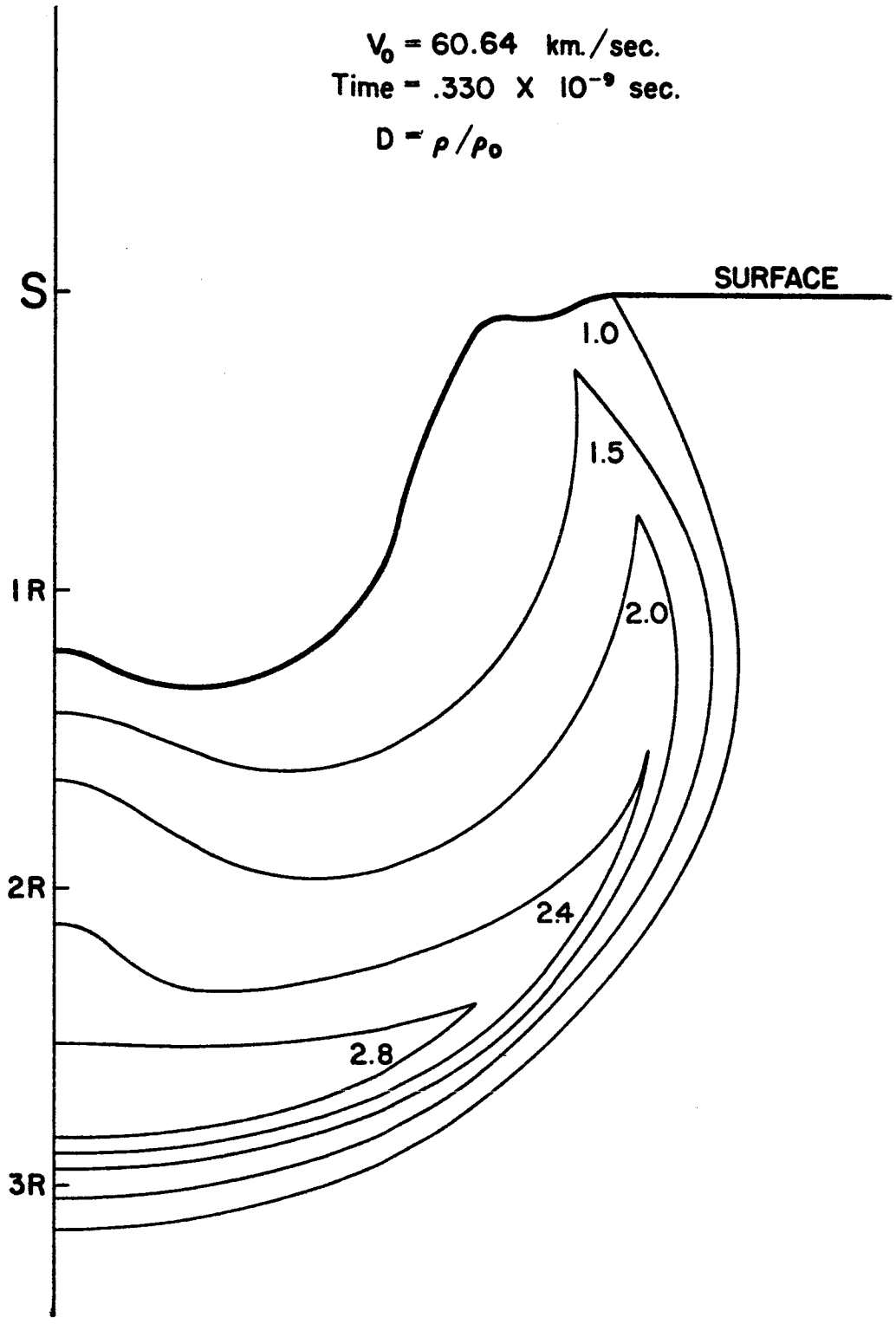

Figure 258. Density Map (t = .330 x 10^{-9} sec) VI

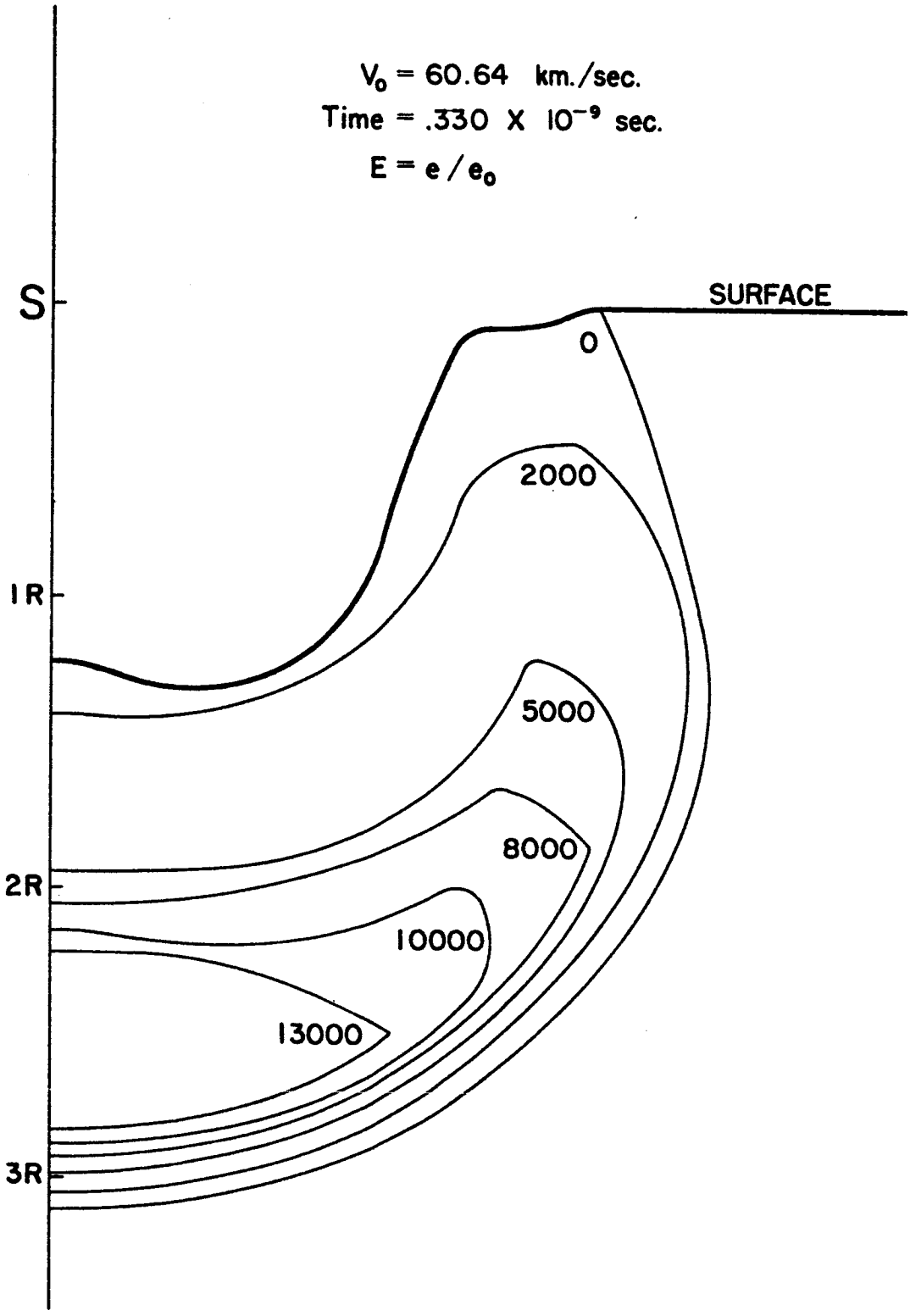

Figure 259. Energy Map (t = .330 x 10^{-9} sec) VI

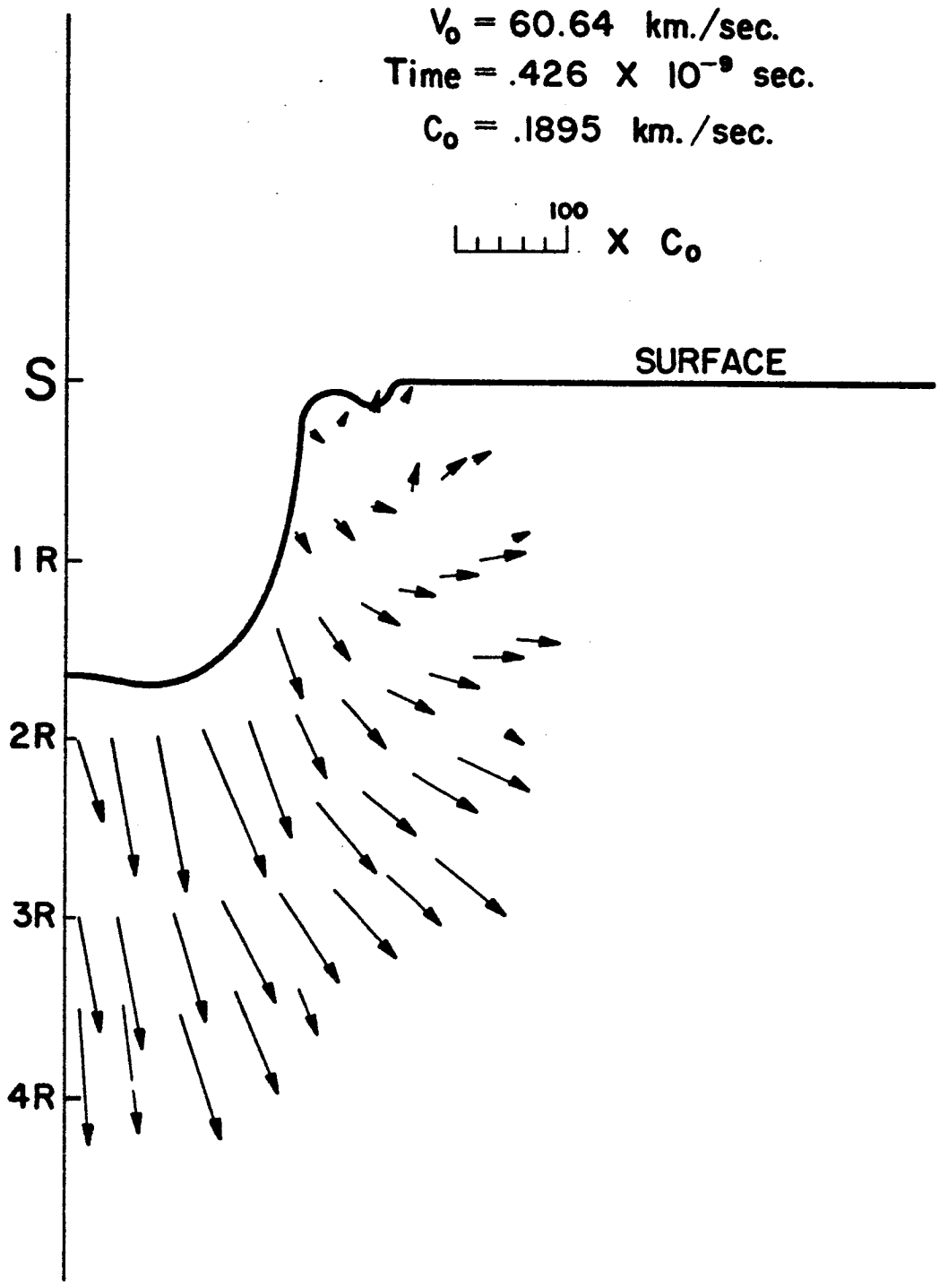

Figure 260. Velocity Map (t = .426 x 10^{-9} sec) VI

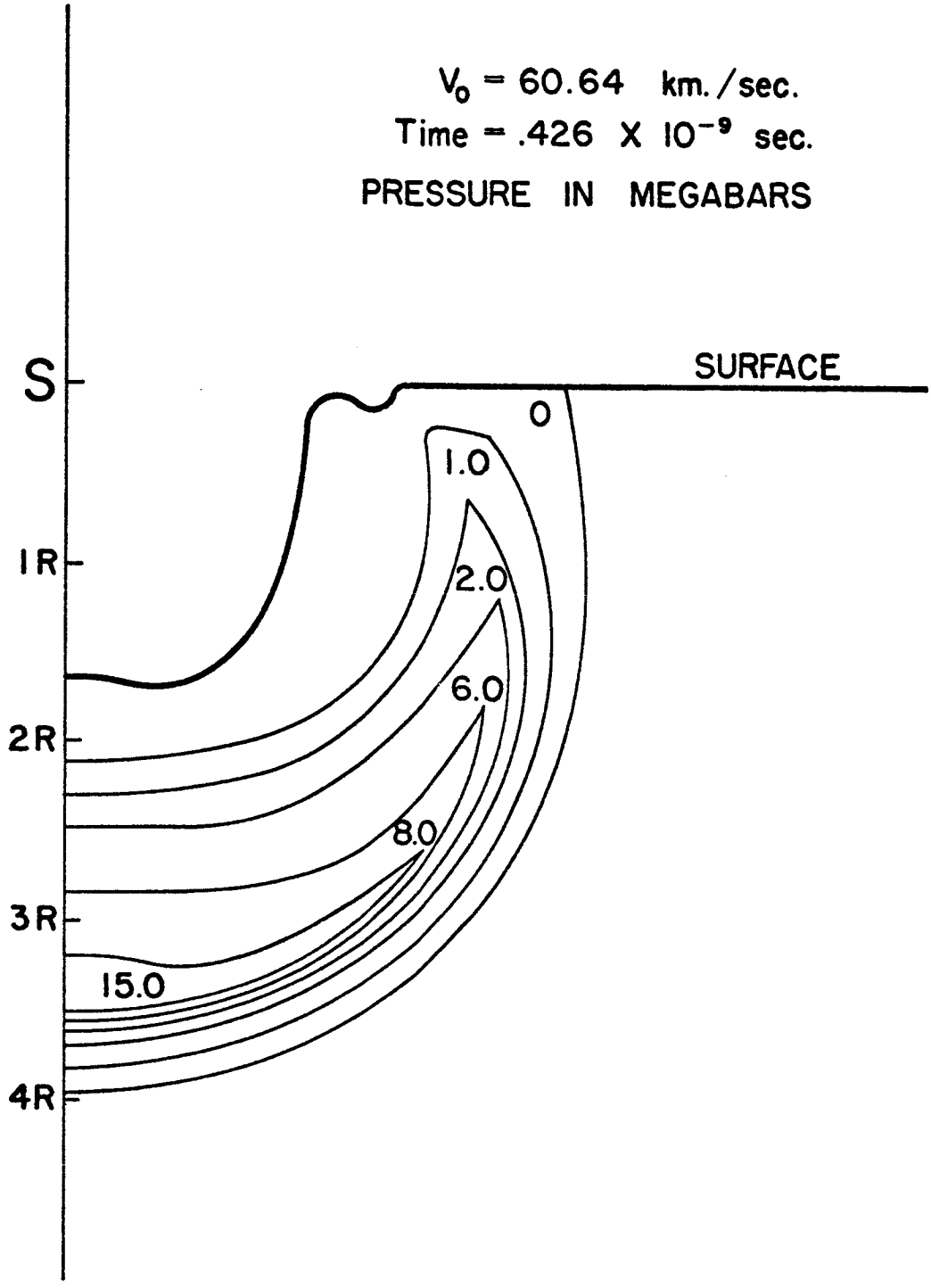

Figure 261. Pressure Map (t = .426 x 10^{-9} sec) VI

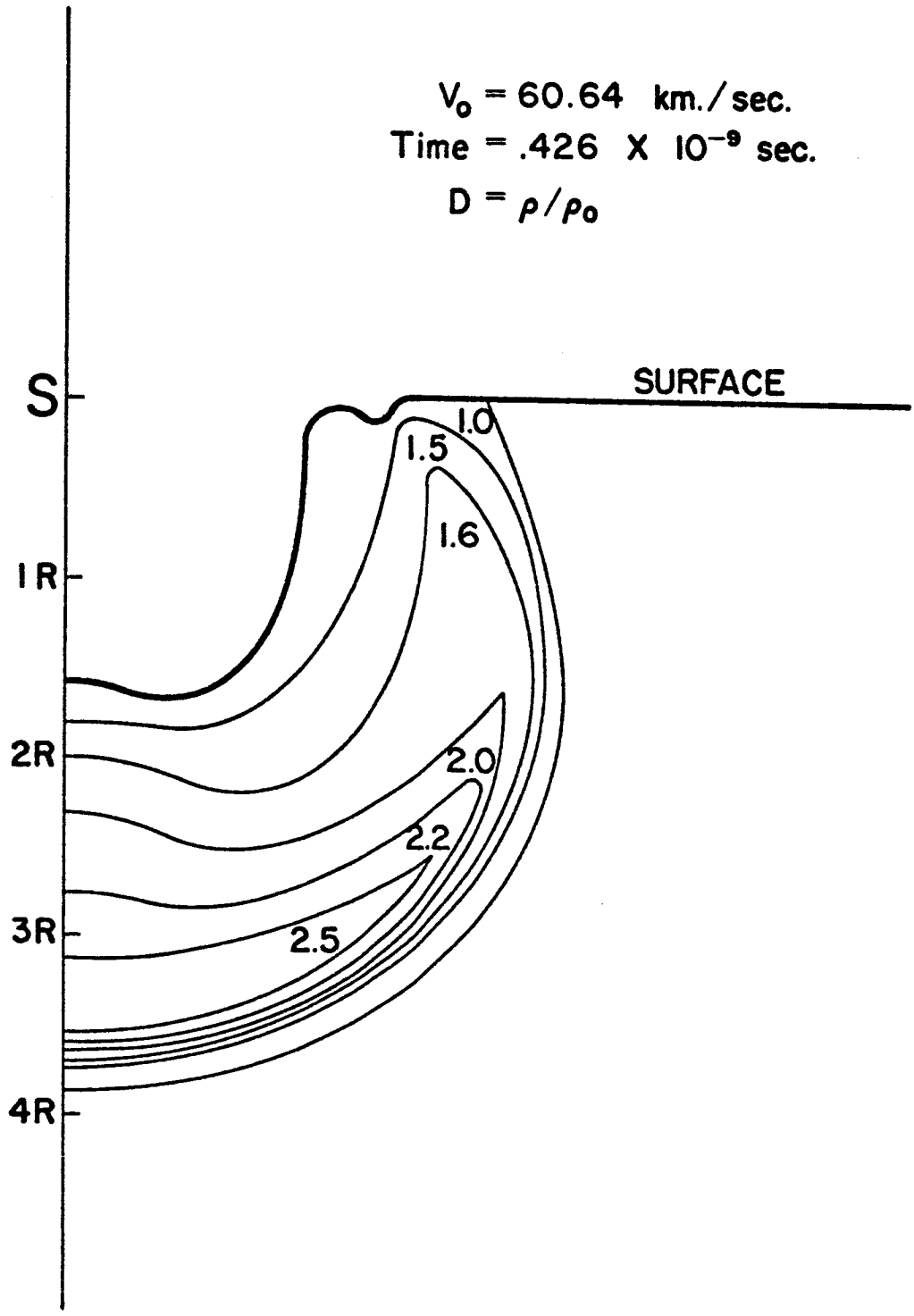

Figure 262. Density Map (t = .426 x 10^{-9} sec) VI

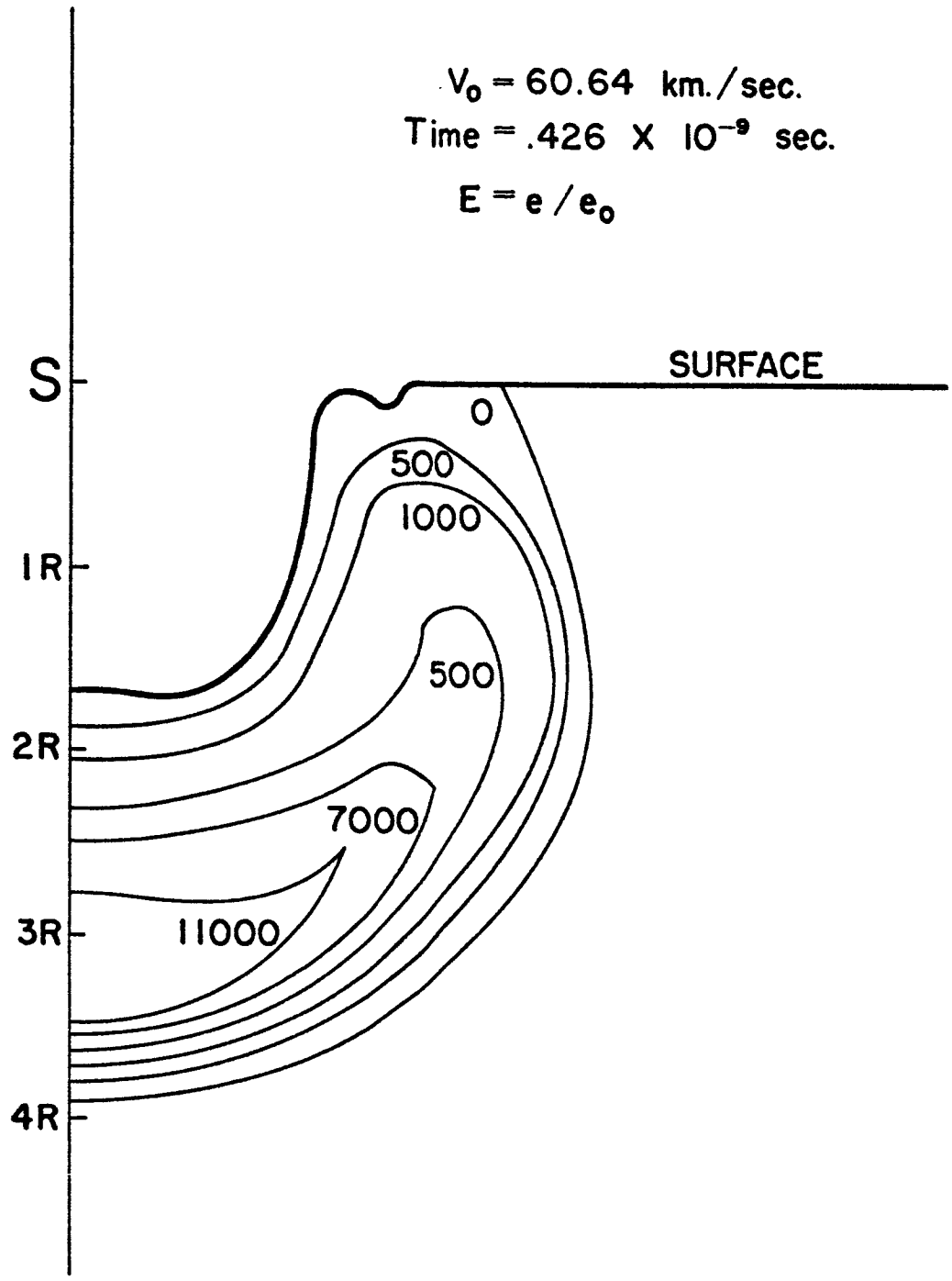

Figure 263. Energy Map (t = .426 x 10^{-9} sec) VI

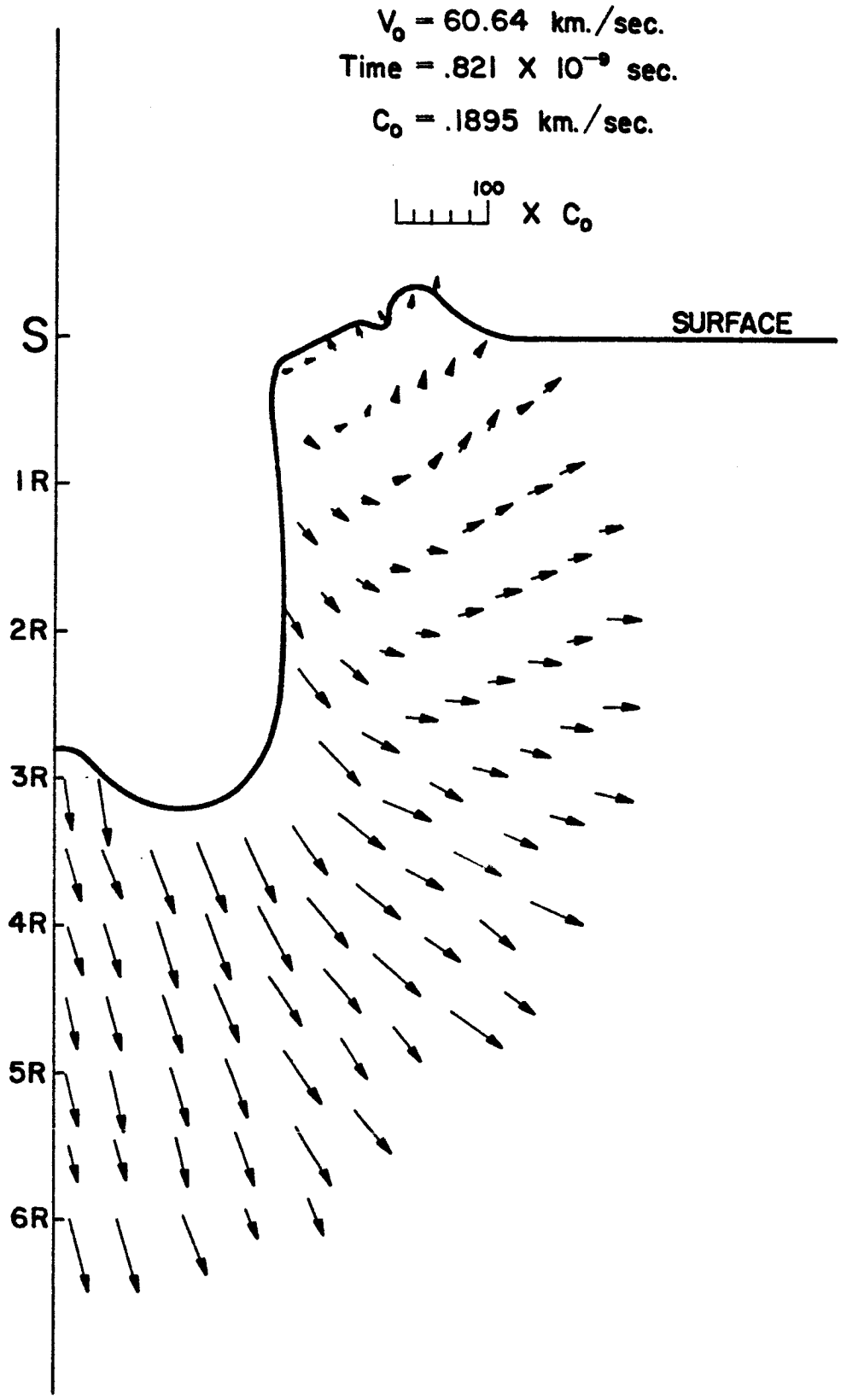

Figure 264. Velocity Map (t = .821 x 10^{-9} sec) VI

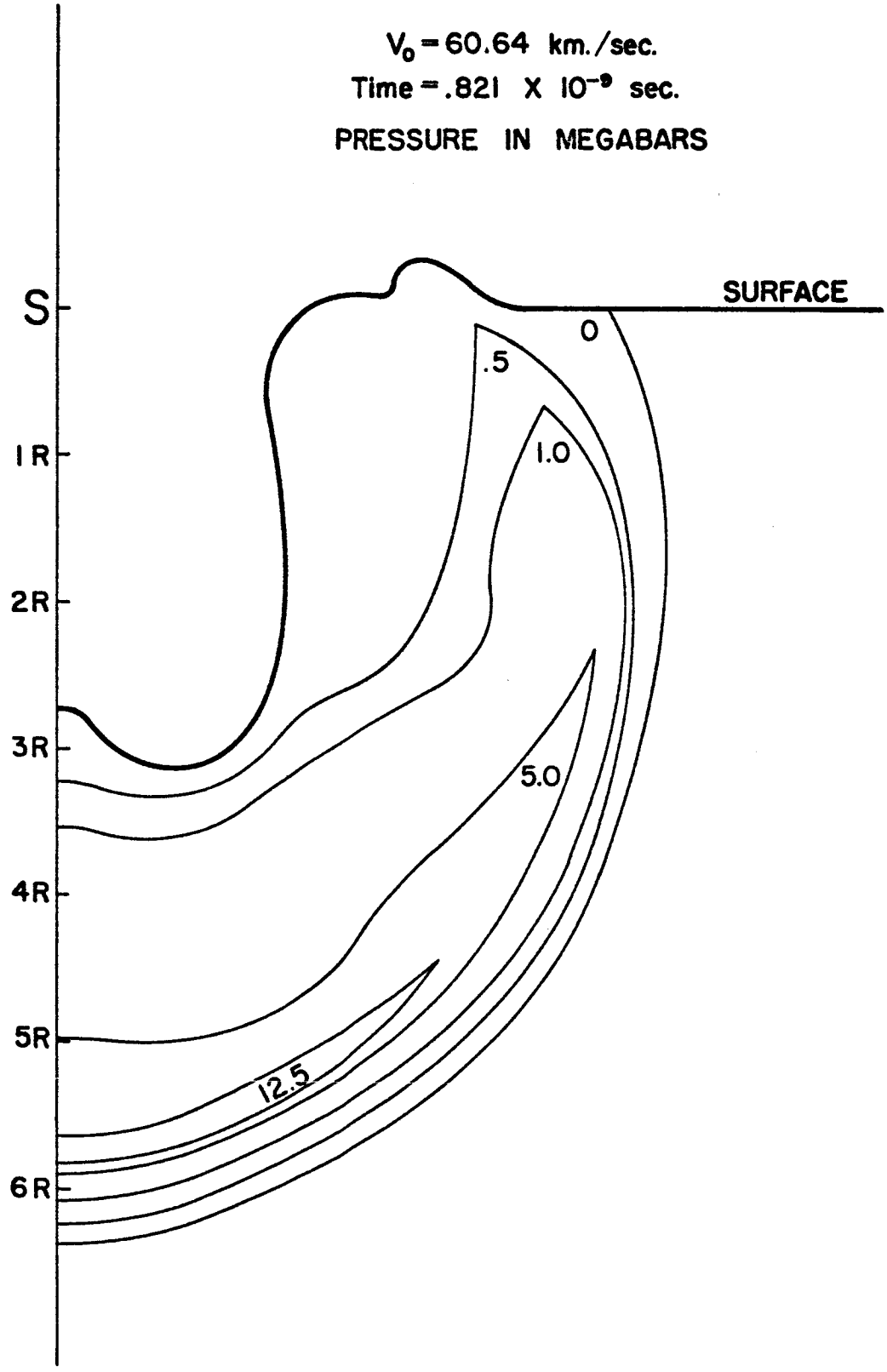

Figure 265. Pressure Map (t = .821 x 10^{-9} sec) VI

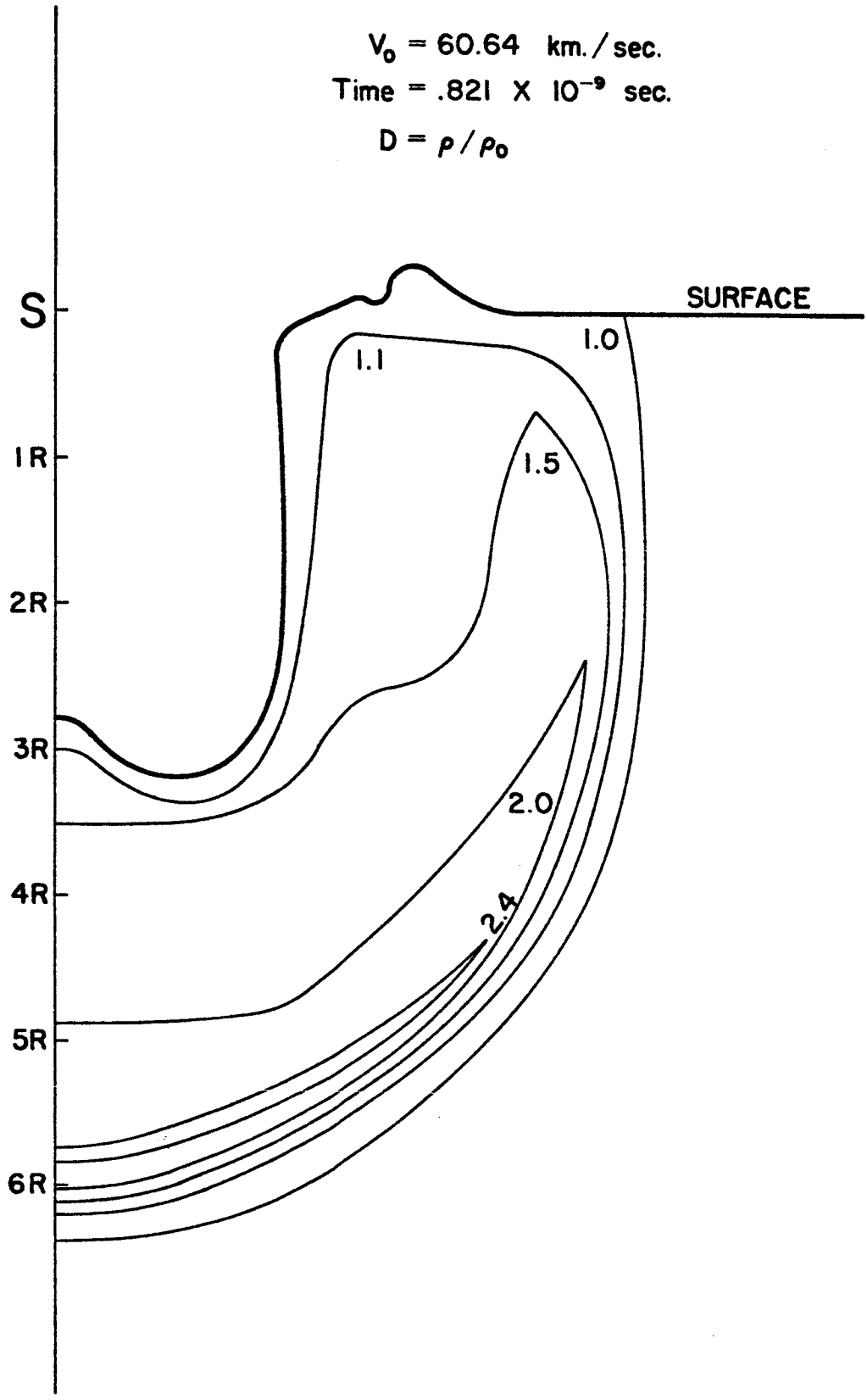

Figure 266. Density Map (t = .821 x 10^{-9} sec) VI

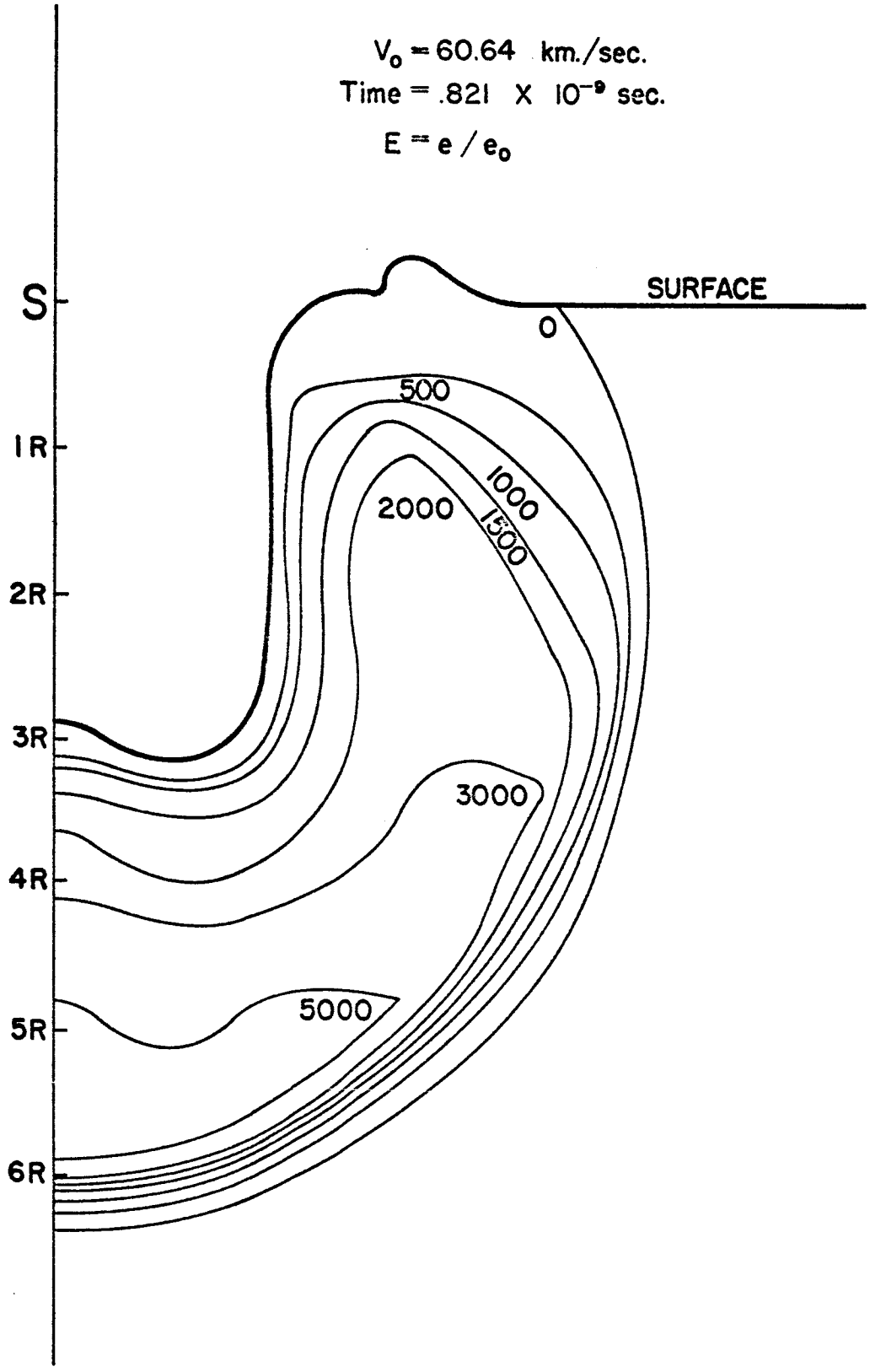

Figure 267. Energy Map (t = .821 x 10^{-9} sec) VI

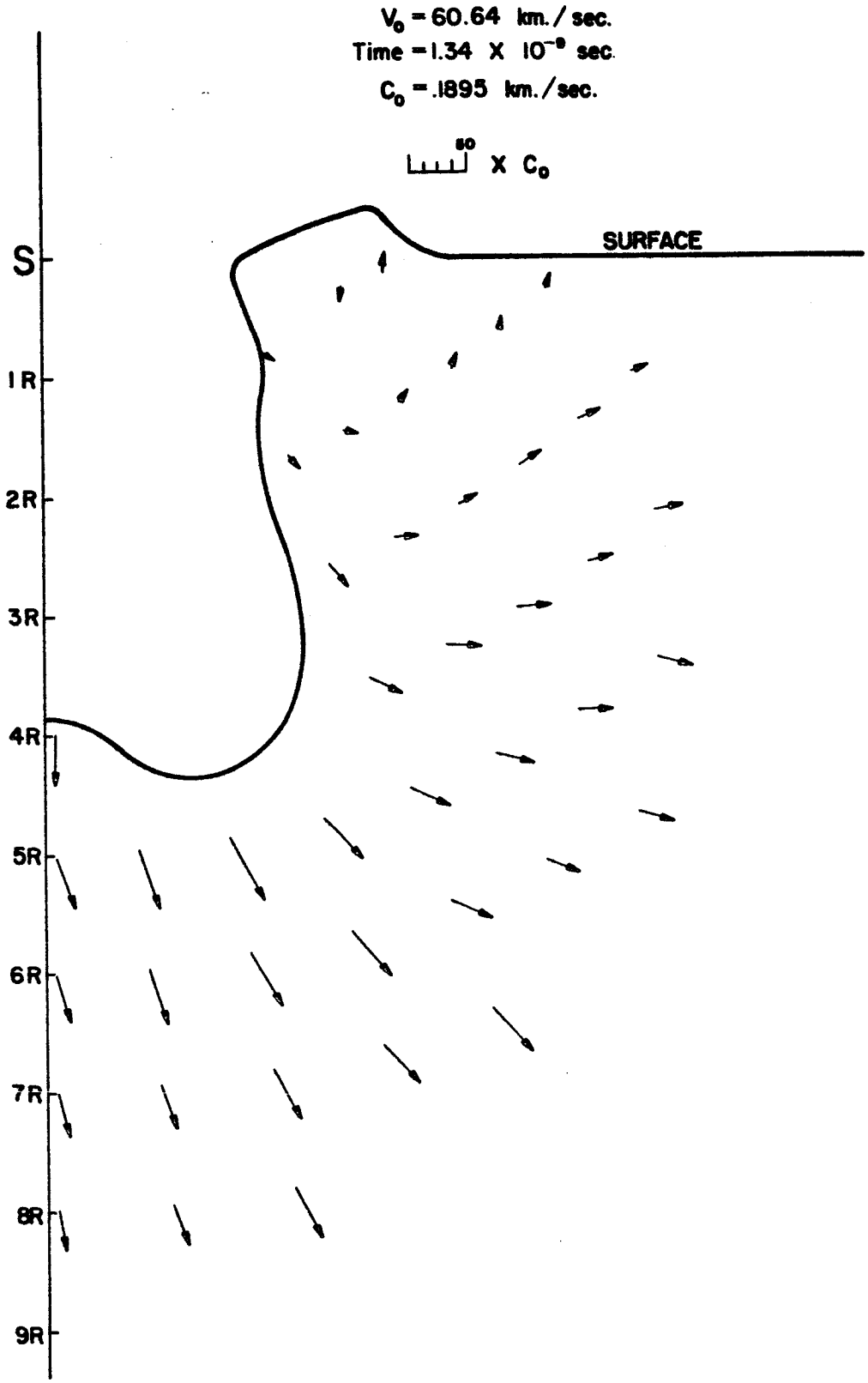

Figure 268. Velocity Map (t = 1.34 x 10^{-9} sec) VI

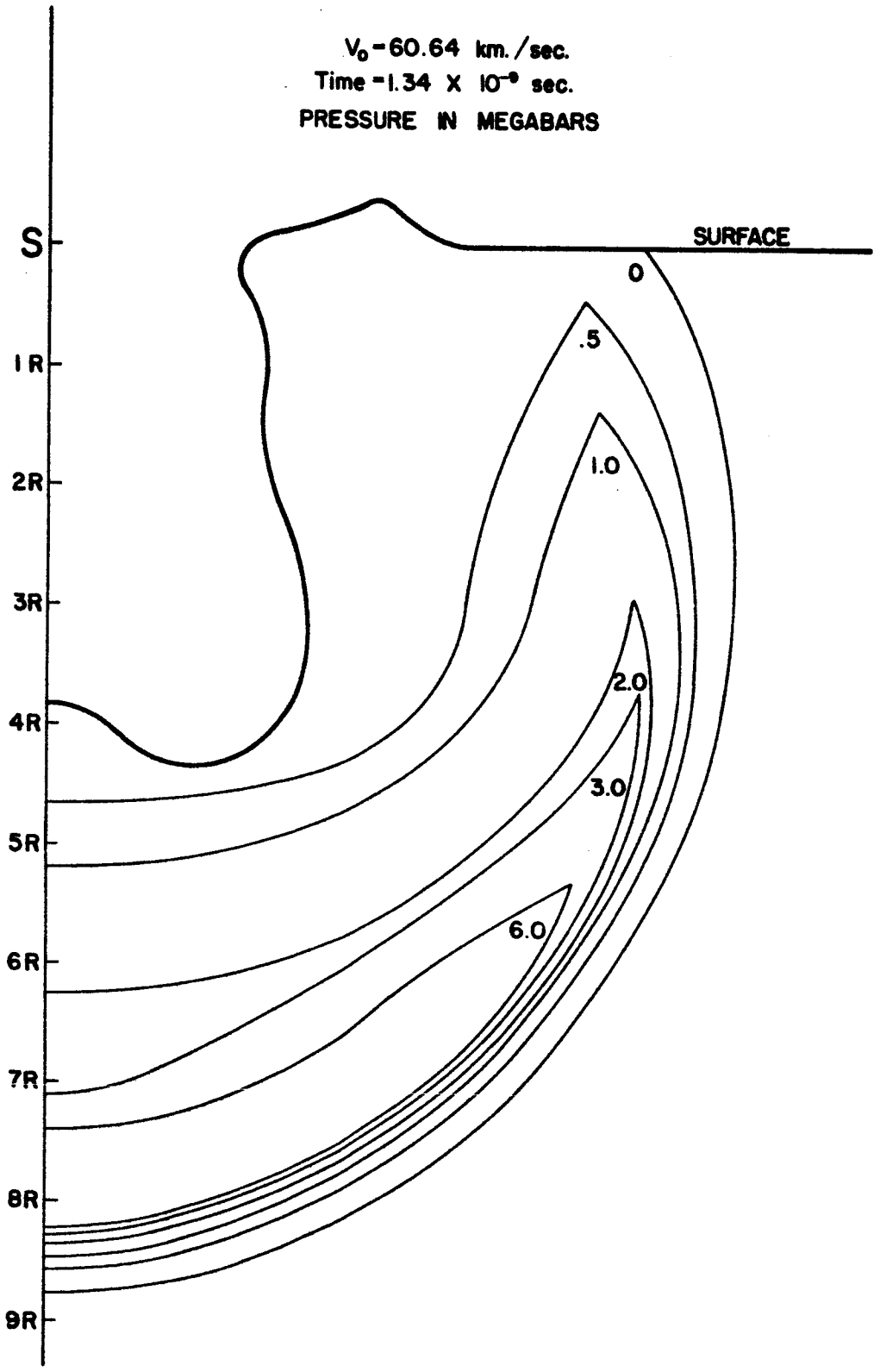

Figure 269. Pressure Map (t = 1.34 x 10^{-9} sec) VI

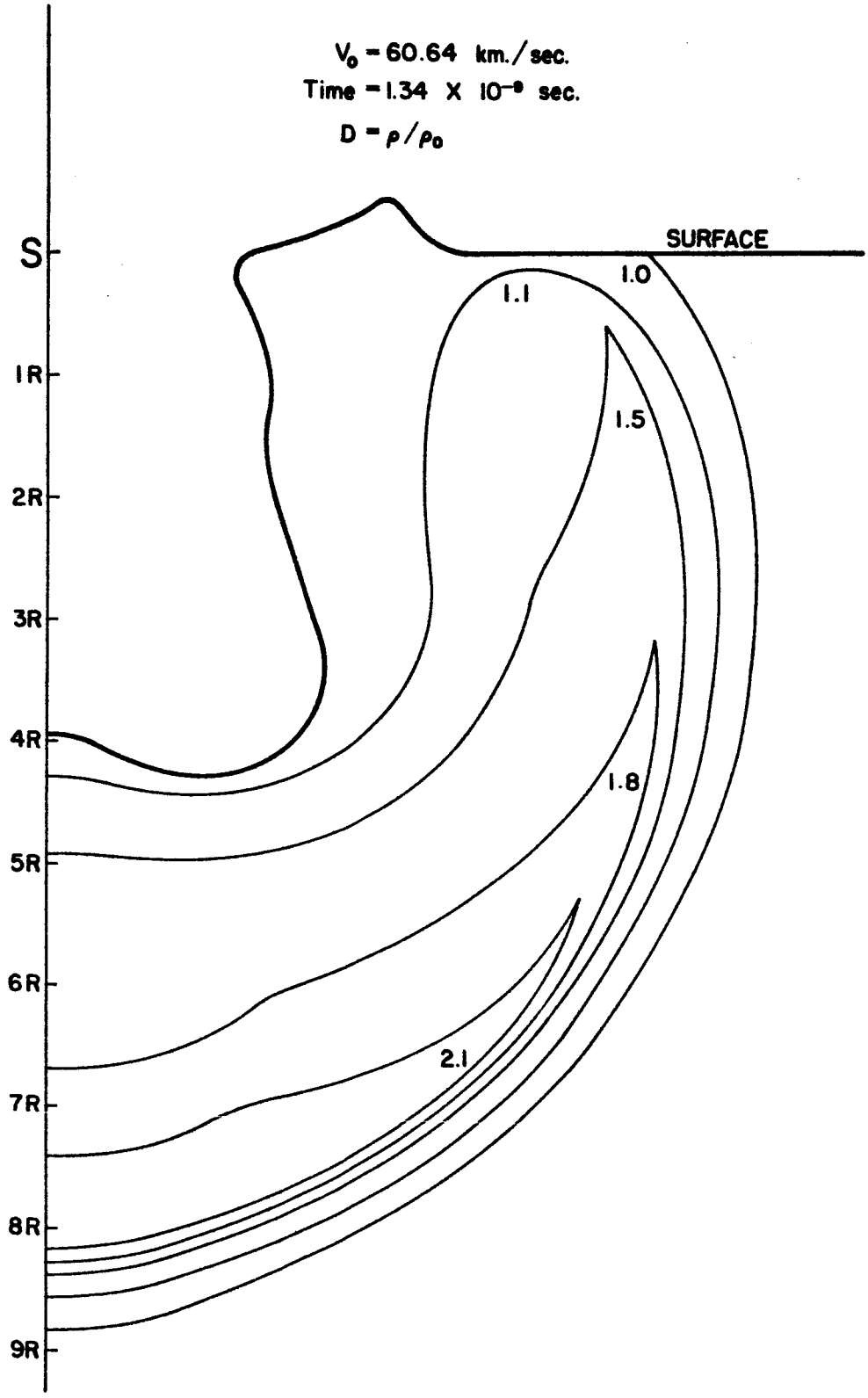

Figure 270. Density Map (t = 1.34 x 10^{-9} sec) VI

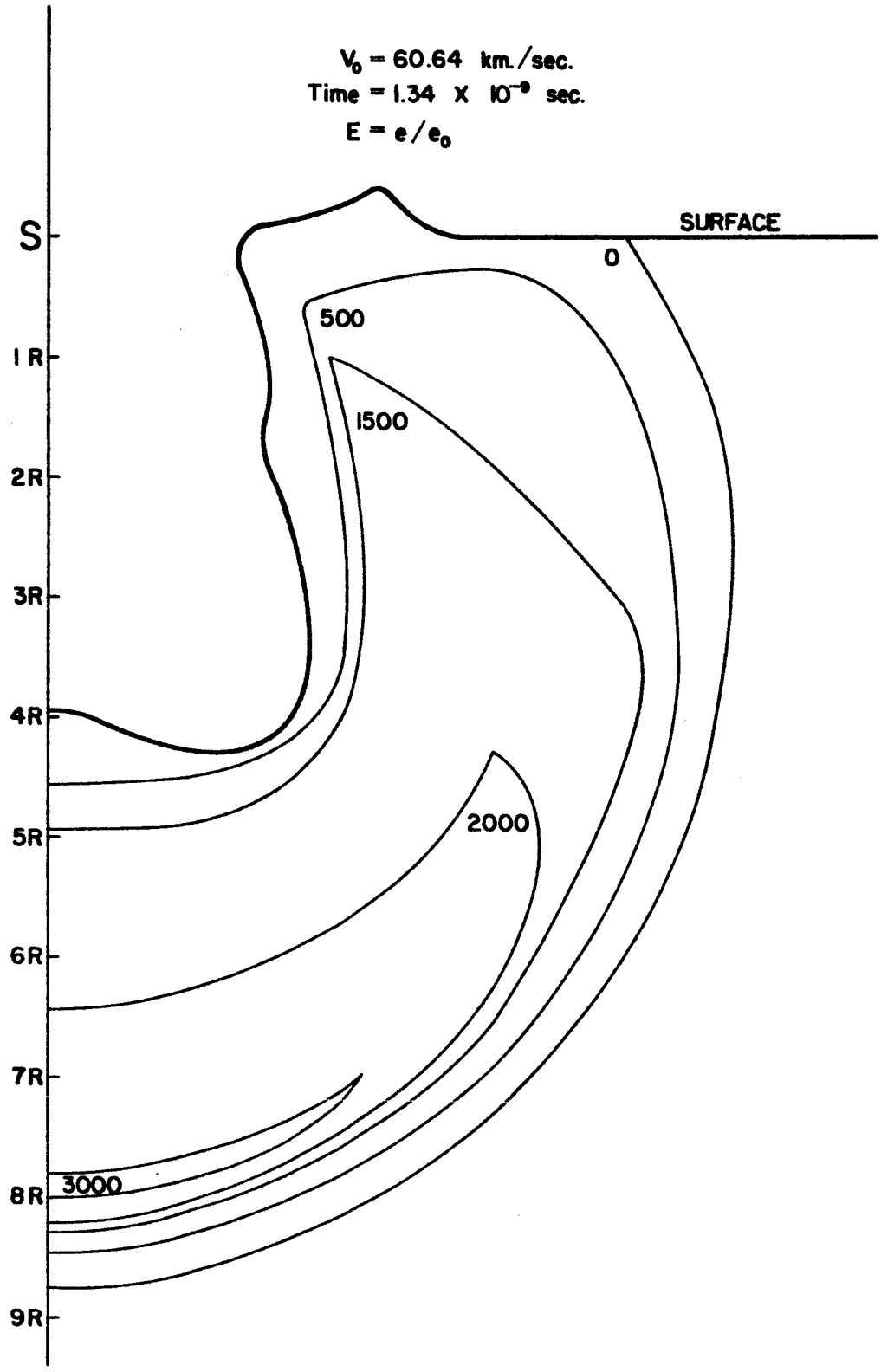

Figure 271. Energy Map (t = 1.34 x 10^{-9} sec) VI

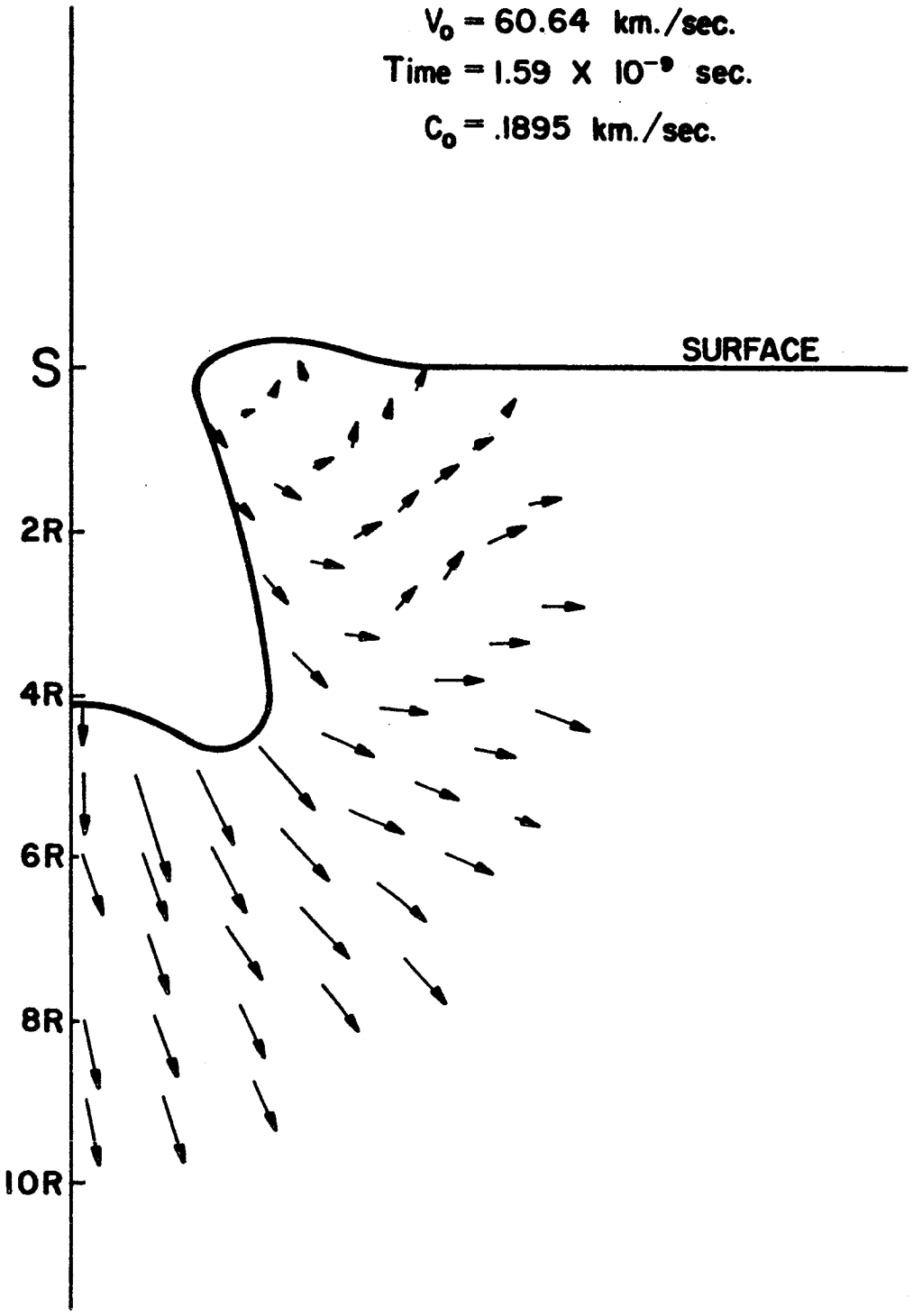

Figure 272. Velocity Map (t = 1.59 x 10^{-9} sec) VI

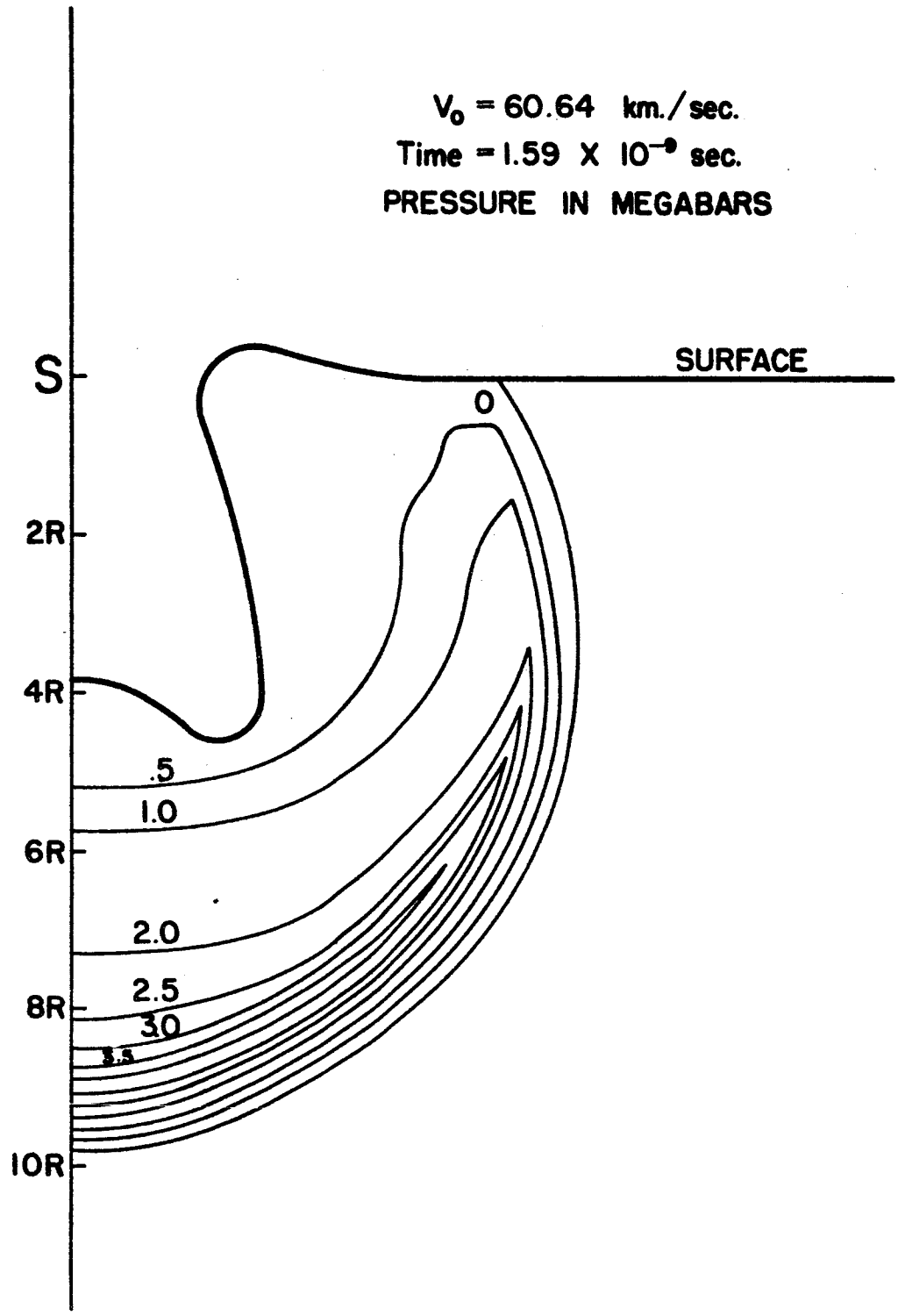

Figure 273. Pressure Map (t = 1.59 x 10^{-9} sec) VI

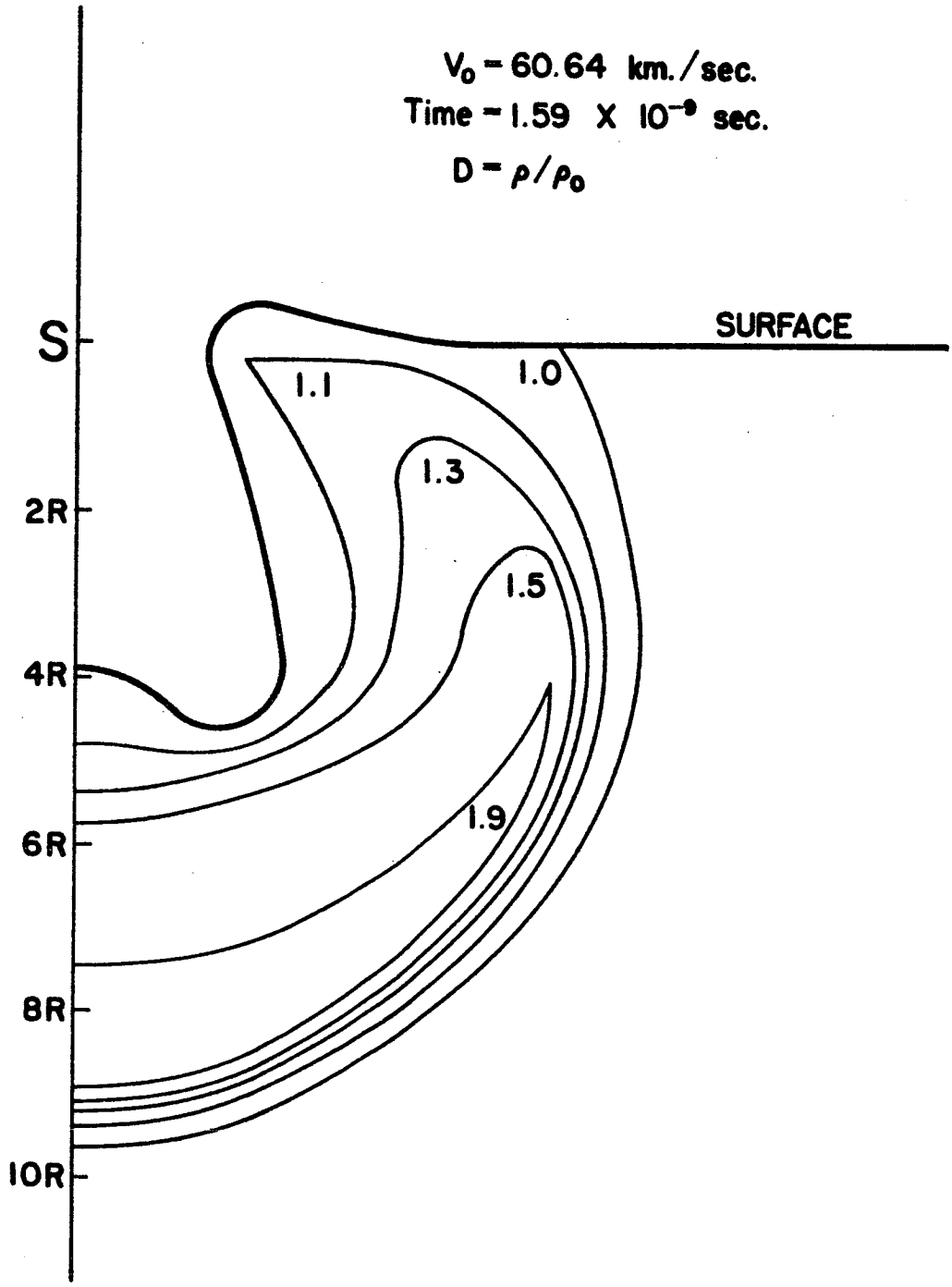

Figure 274. Density Map (t = 1.59 x 10^{-9} sec) VI

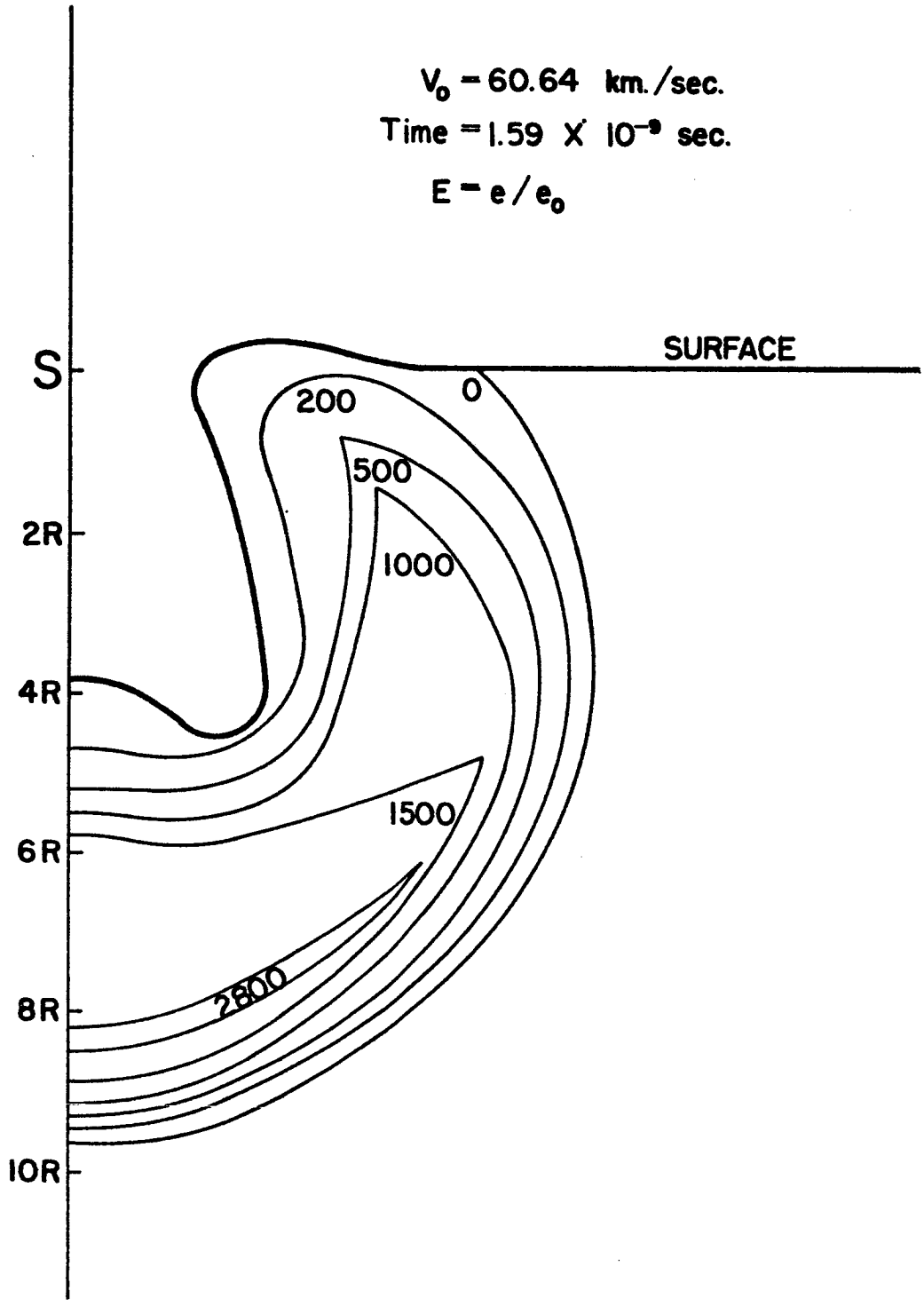

Figure 275. Energy Map (t = 1.59 x 10^{-9} sec) VI

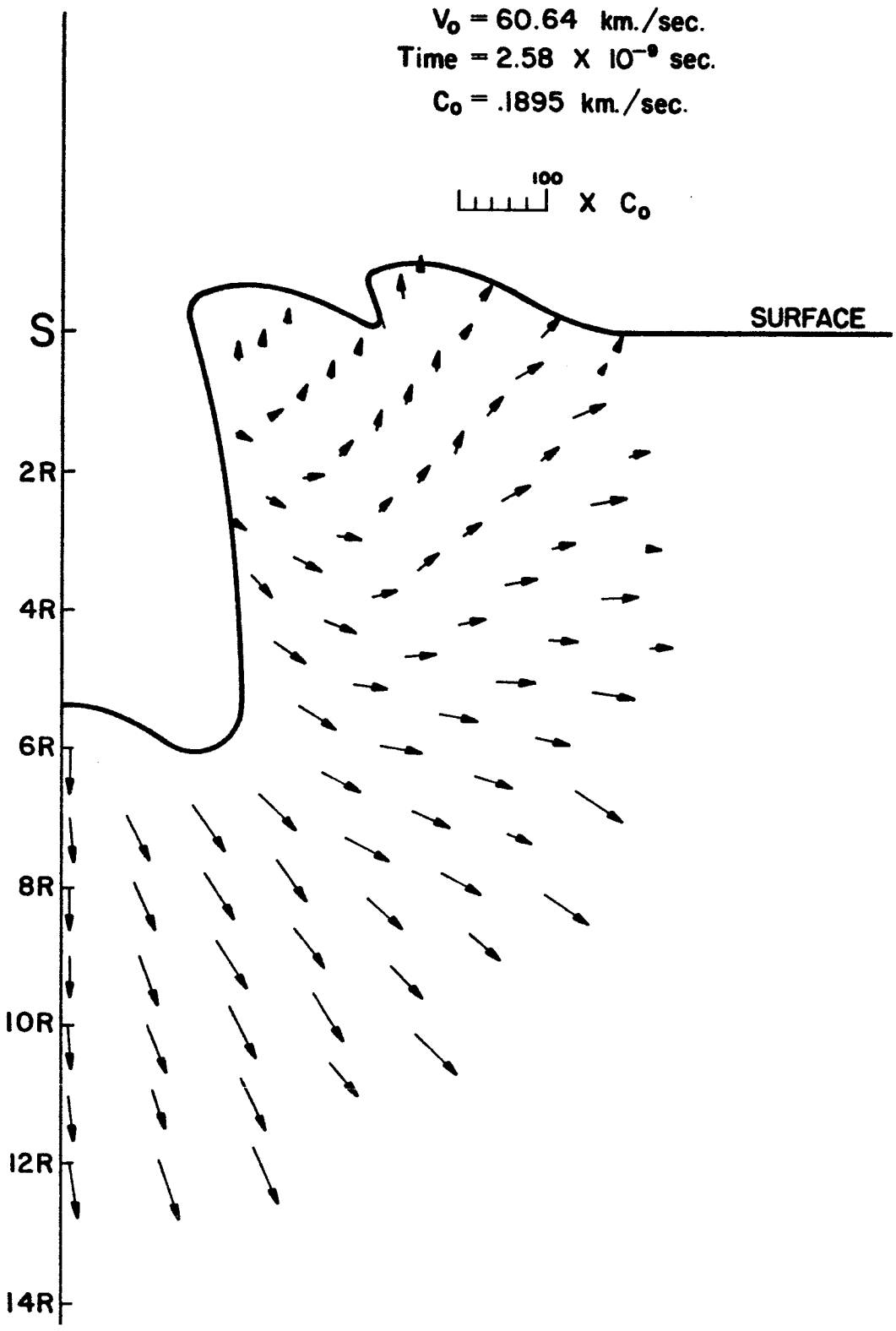

Figure 276. Velocity Map (t = 2.58 x 10^{-9} sec) VI

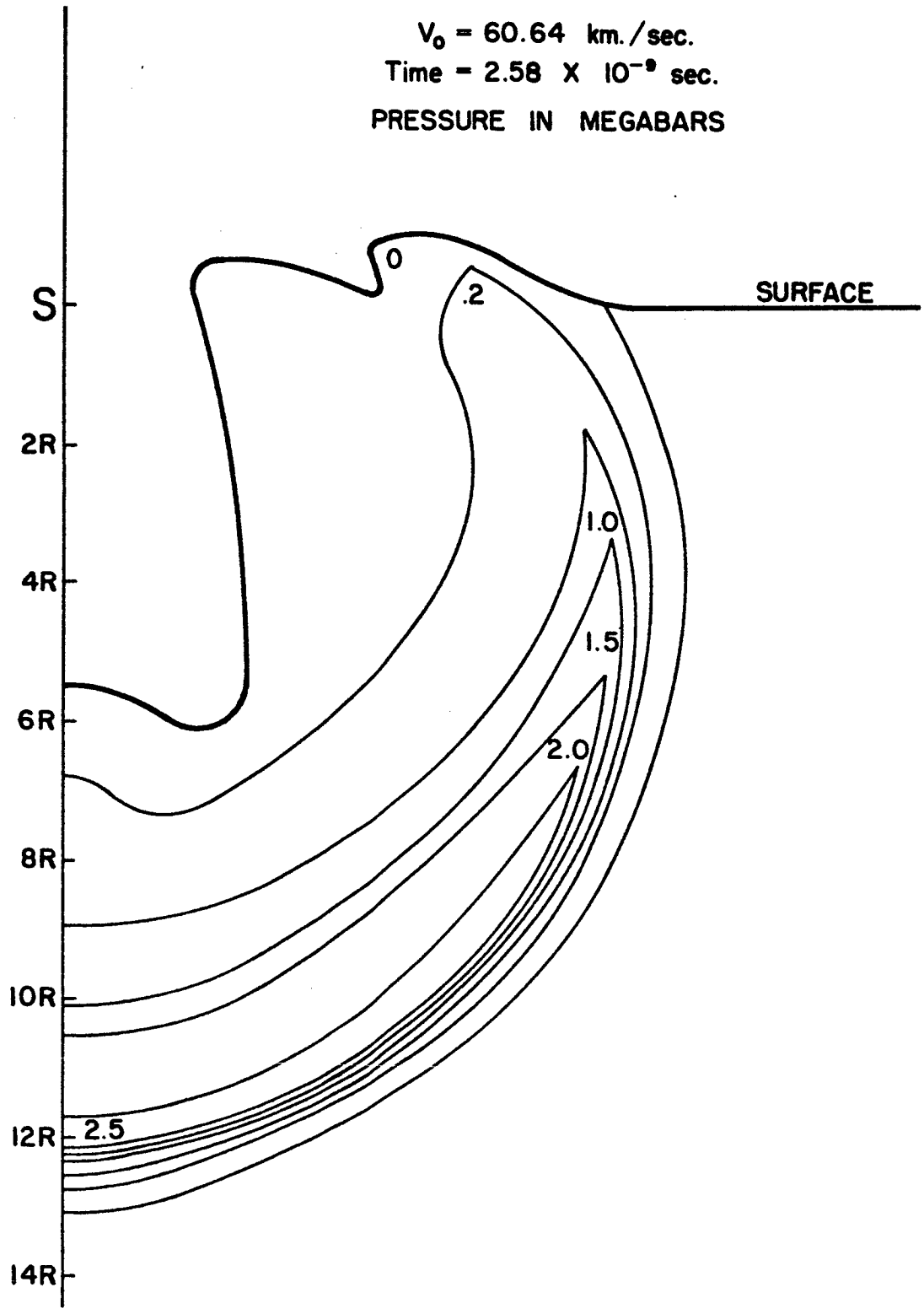

Figure 277. Pressure Map (t = 2.58 x 10^{-9} sec) VI

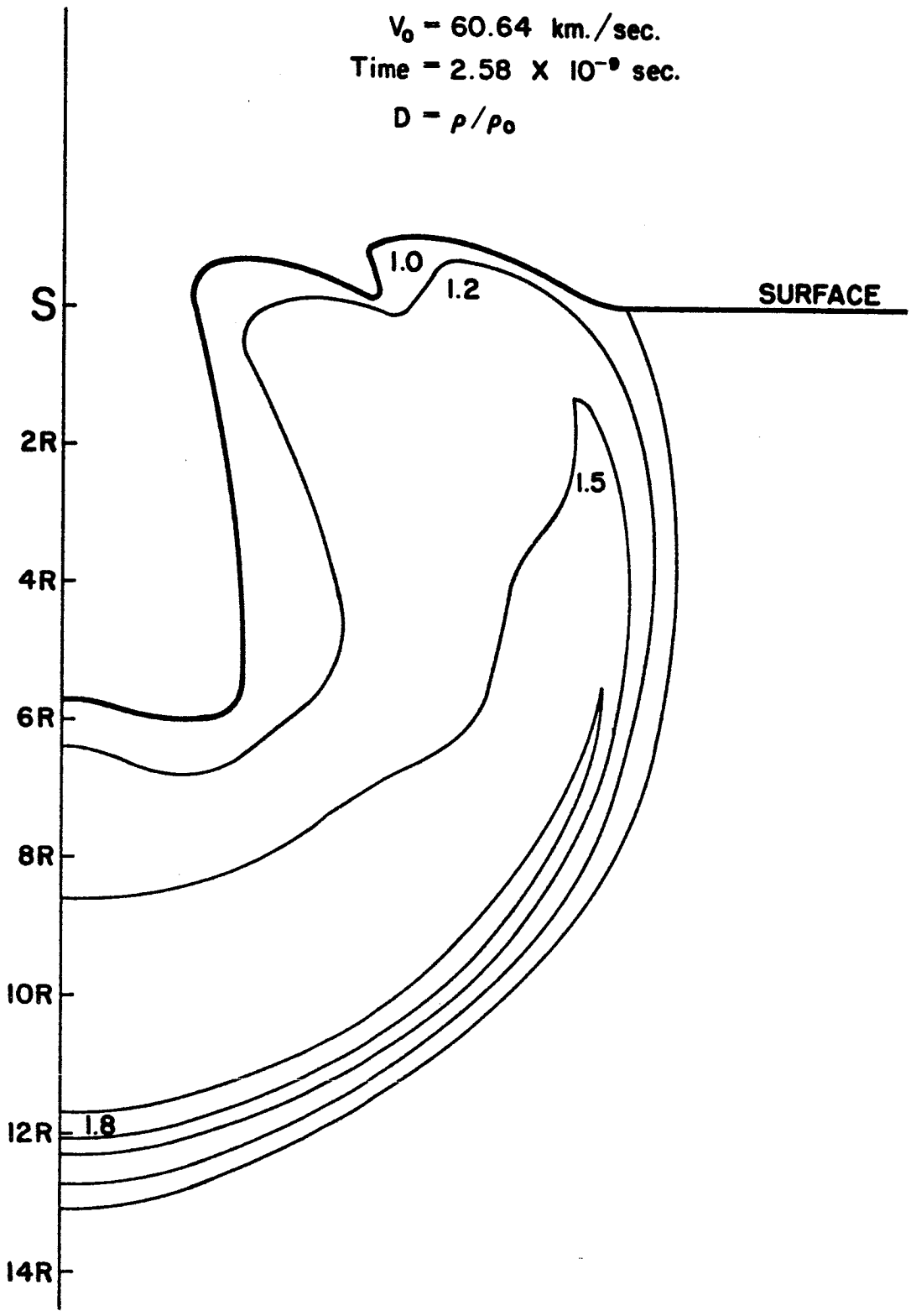

Figure 278. Density Map (t = 2.58 x 10^{-9} sec) VI

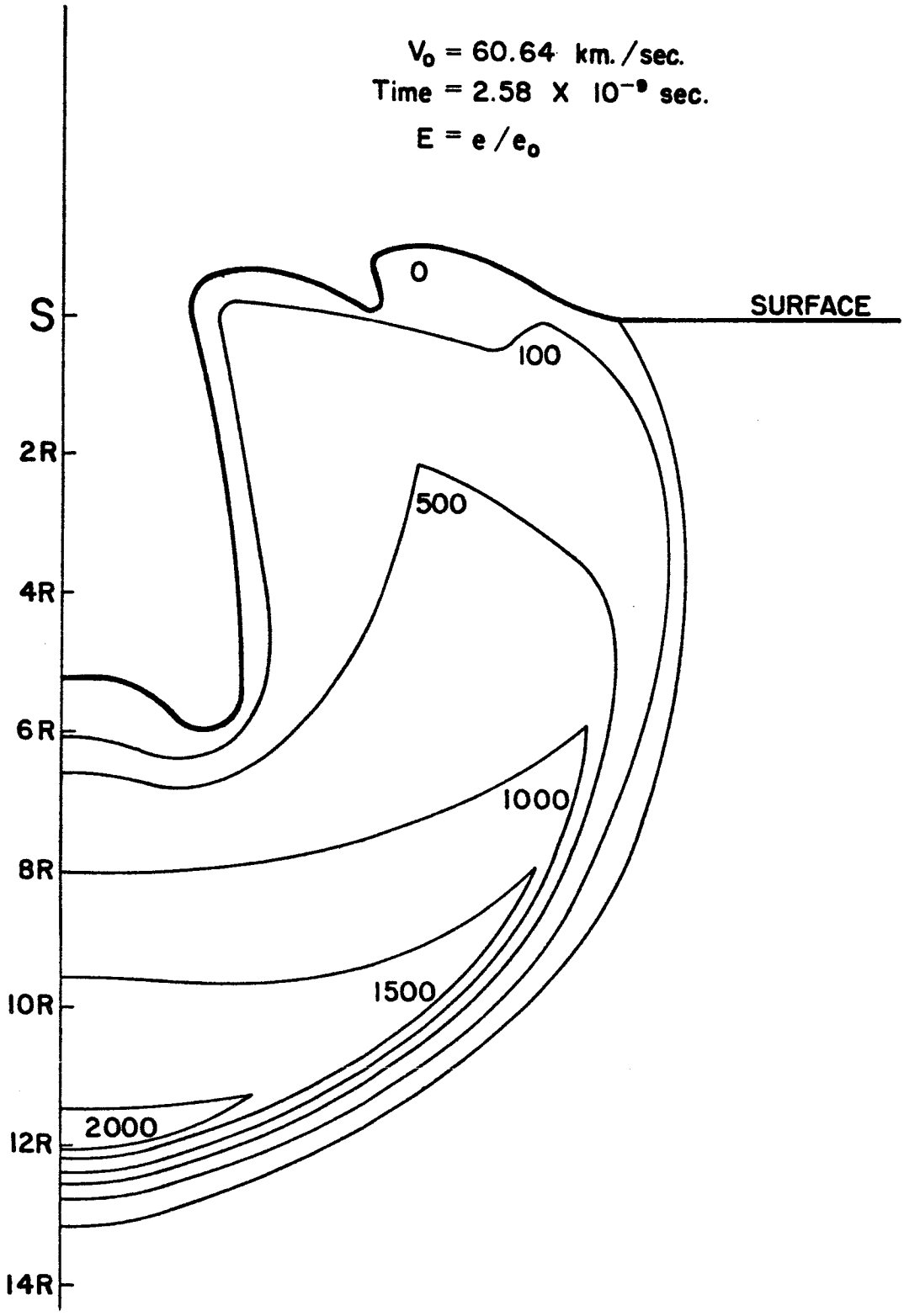

Figure 279. Energy Map (t = 2.58 x 10^{-9} sec) VI

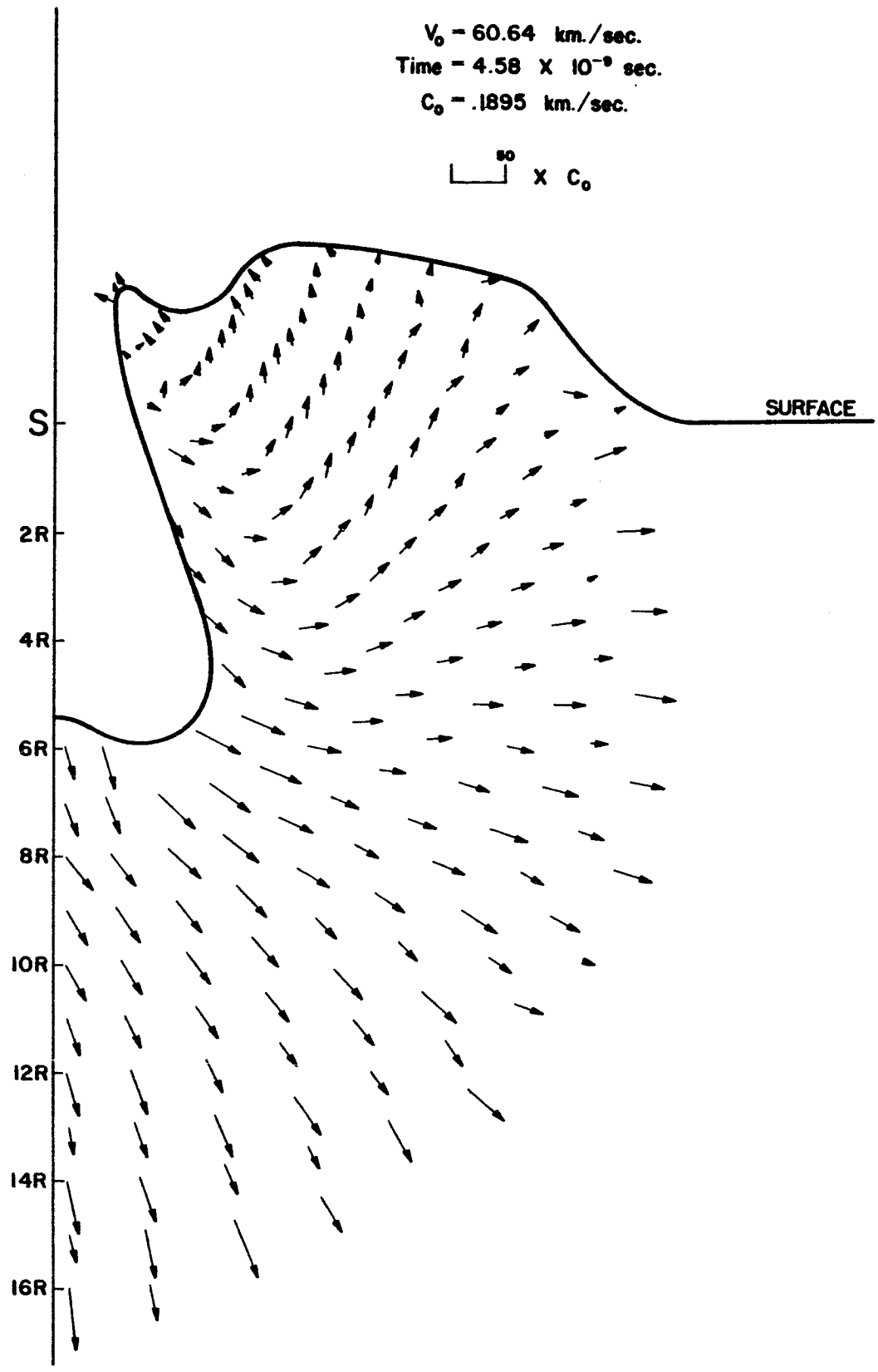

Figure 280. Velocity Map (t = 4.58 x 10^{-9} sec) VI

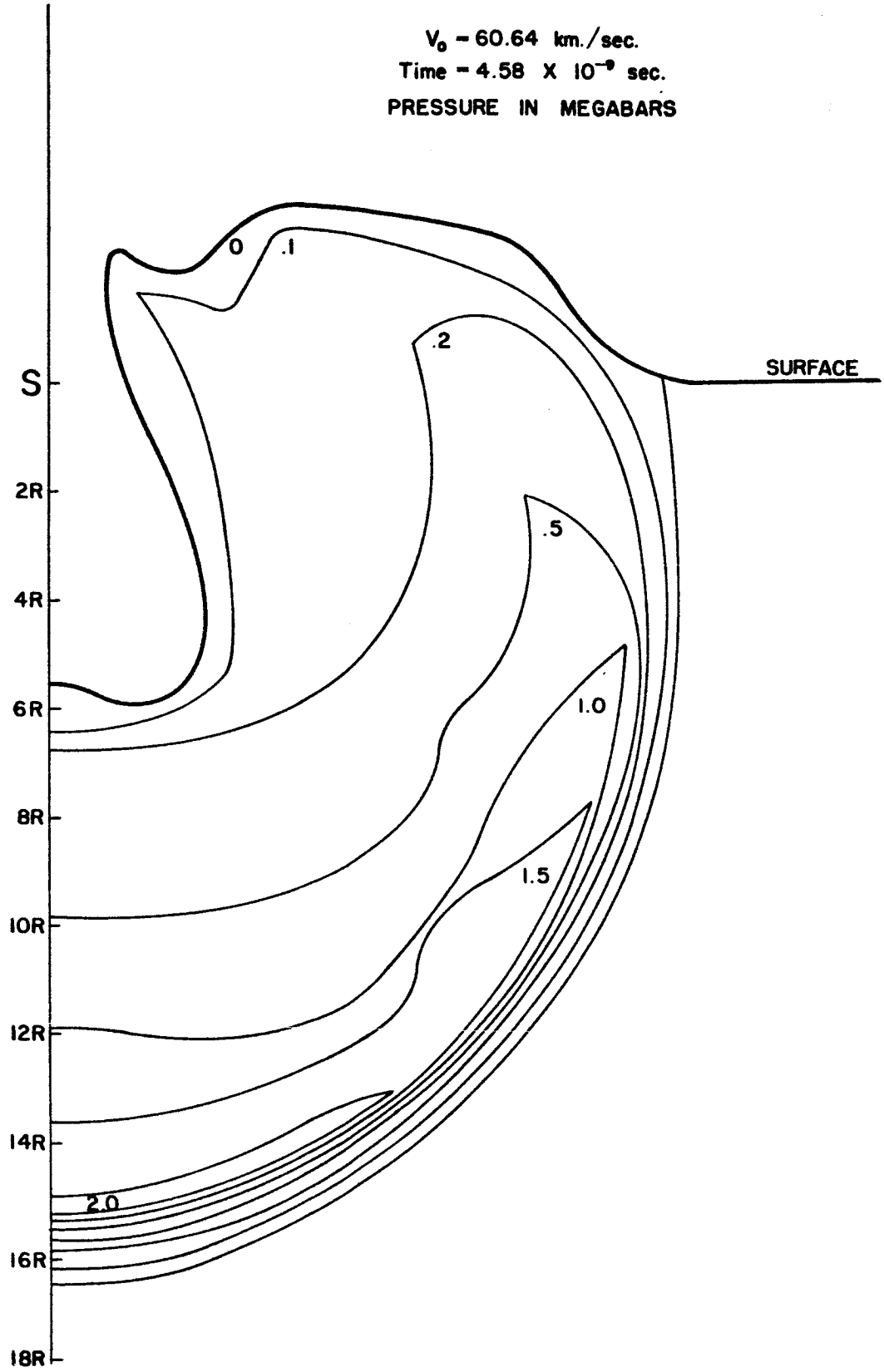

Figure 281. Pressure Map (t = 4.58 x 10^{-9} sec) VI

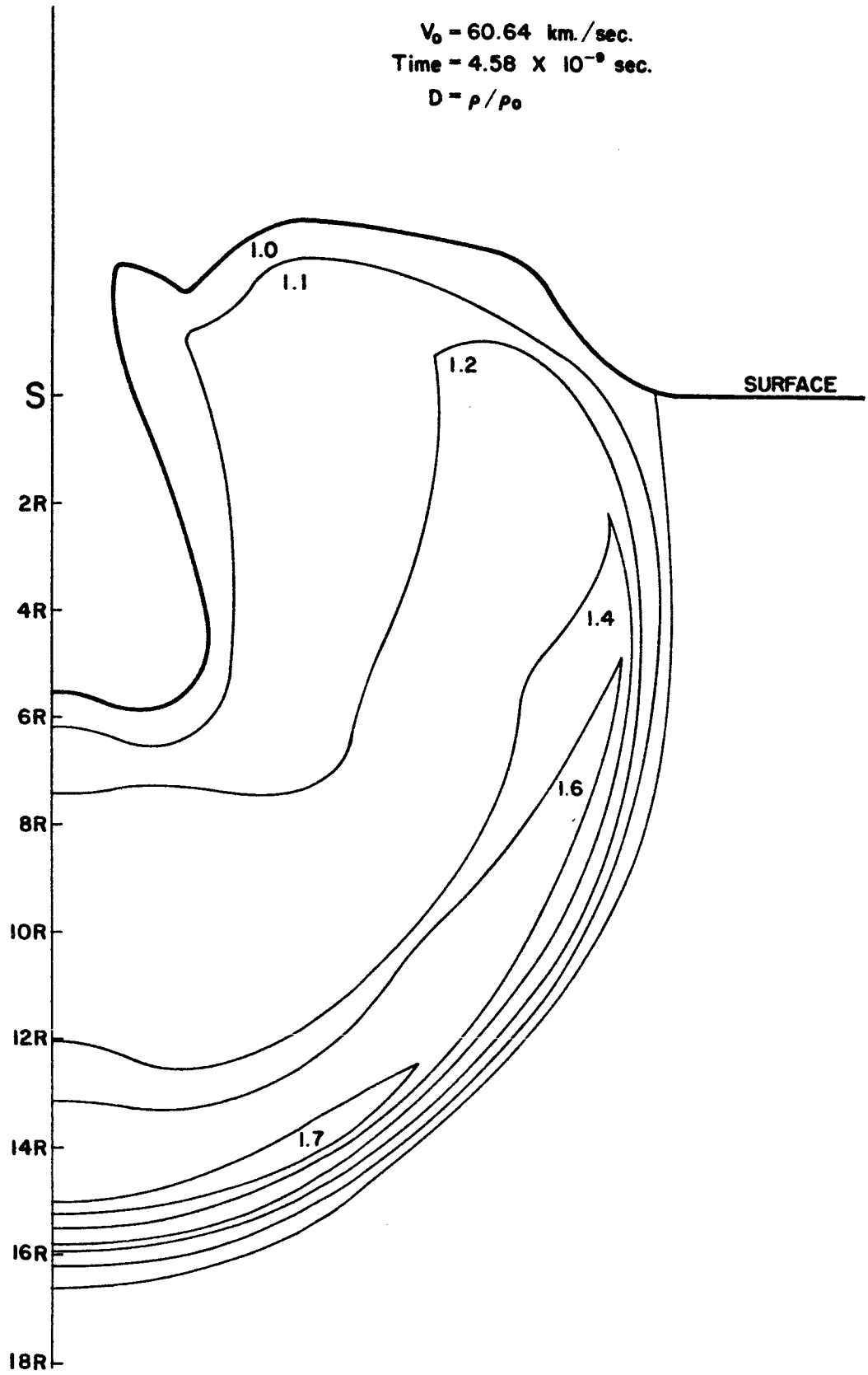

Figure 282. Density Map (t = 4.58 x 10^{-9} sec) VI

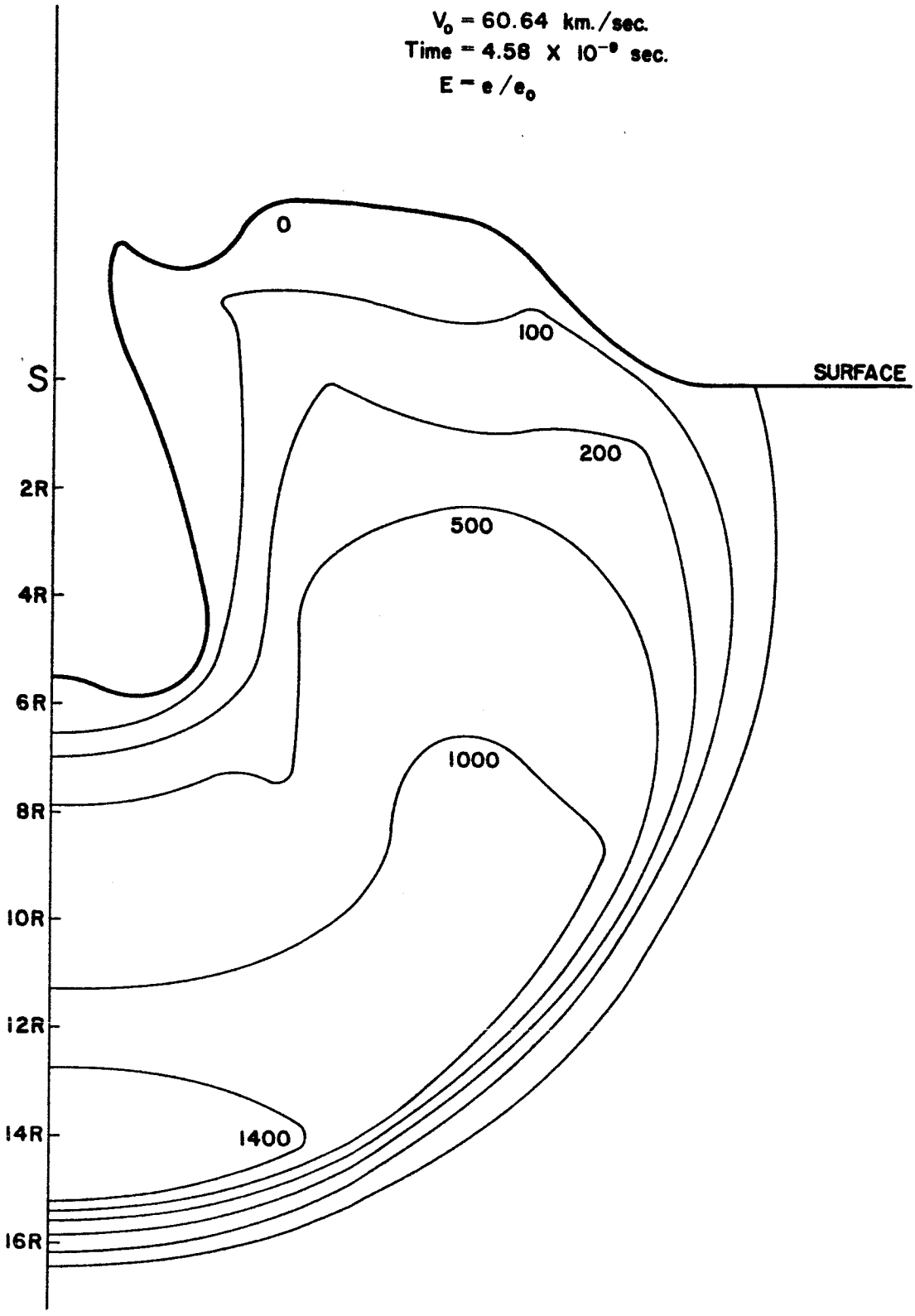

Figure 283. Energy Map (t = 4.58 x 10^{-9} sec) VI

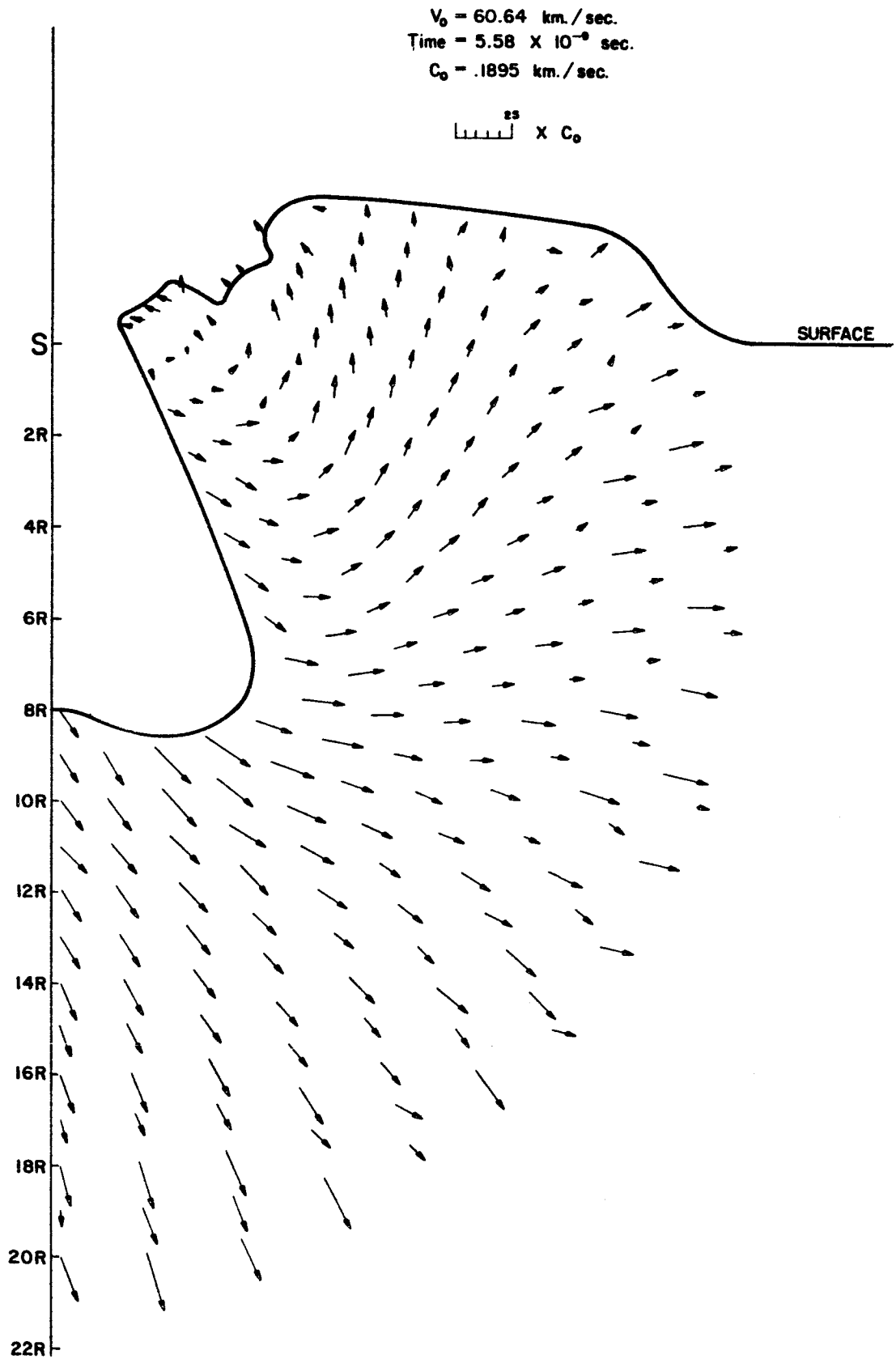

Figure 284. Velocity Map ($t = 5.58 \times 10^{-9}$ sec) VI

Figure 285. Pressure Map (t = 5.58 x 10^{-9} sec) VI

Figure 286. Density Map (t = 5.58 x 10^{-9} sec) VI

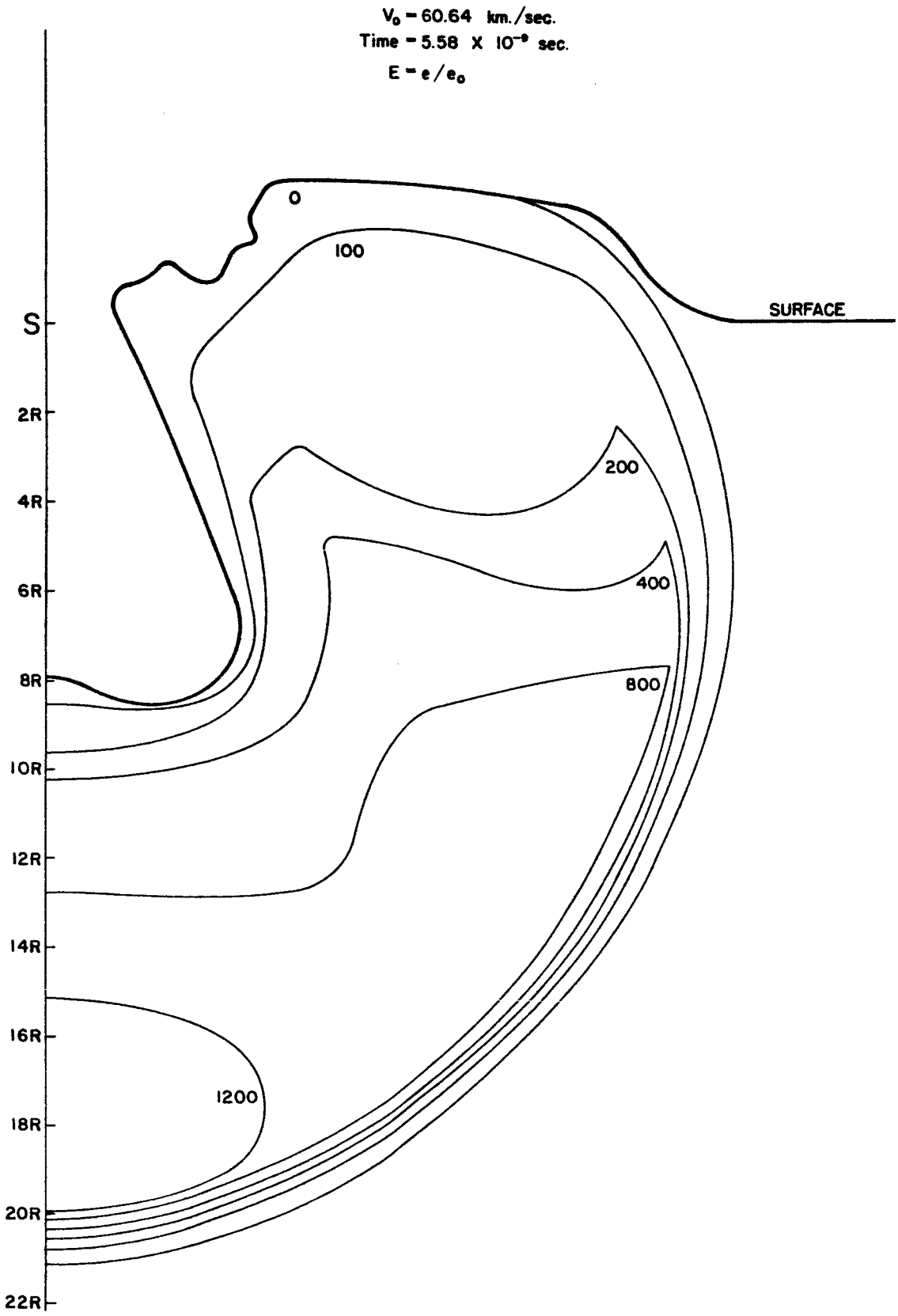

Figure 287. Energy Map (t = 5.58 x 10^{-9} sec) VI