Comitato Nazionale Energia Nucleare

V. Cotecchia - E. Tongiorgi

Natural Tracing by Seasonal Variation of $^{18}O/^{16}O$ Ratio in a Ground Water Research

Symposium on the application of Radioisotopes in Hydrology
Tokio, march 5th - 9th 1963

RT/GEO (63) 25
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In order to examine the practical possibilities of application to a large area of the isotope method based on the natural tracing of ground waters, an Italian region, particularly suited for this purpose, has been considered: the Salentina Peninsula (fig. 1).

The information we possess on the aquifer in this area is such as to allow us to consider the ground water pattern very close to an ideal one.

Cretaceous limestone, reaching remarkable depth below sea level, is the main rock in the region. The limestone is strongly fissured and allow a remarkable infiltration of rain water on almost all the surface, so that rivers are completely absent. The limestone maintains a Karst character down to a level of more than 100 m below the present sea level. Evidently, this has been made possible by the eustatic decrease of the sea level, which took place during the Pleistocene glacial periods.

The part of the total volume of the rock, filled by water, can be evaluated to 5 - 10%. In such conditions, we can assume an aquifer consistent both horizontally and vertically - a large reservoir of fresh water superimposed on sea water. In the deep fissured limestone, the latter determines an underground link between the Adriatic and Ionian seas. Throughout the Peninsula, which has an average width of about 40 km, sea water is found at a depth which is a function of the height above sea level of the water table (or of the piezometric level).[1]

Sea water depth can be generally determined in advance on the basis of the Ghyben - Herzberg relation, which, due to the almost schematic characteristics of this region's aquifer, has been developed in such a way as to reach an almost perfect correspondence to the data observed. In practice, a value of 32 times the level of the water table above sea level allows to determine

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[1] COTECCHIA V. - *Influenza dell'acqua marina sulle falde acquifere in zone costiere, con particolare riferimento alle ricerche di acqua sotterranea in Puglia.* Geotecnica, n. 3, 1955.

the depth at which a salt containt of 4-5 gr/l is found. This marks the beginning of a zone where salinity increases quickly, to equal that of a pure sea water; this is generally observed at a depth equal to 40 times the height of the water table above sea level.

As a result of the hydrostatic equilibrium between fresh water and sea water, most of the former participates in the downflow, though requiring low piezometric slopes. In fact, the piezometric surface has an extremely flat shape, with a height on the sea which is of only about 3 m at the center of the peninsula. Thus, there are springs of remarkable flow, but disposed only along the coast, at sea level. Since the position of the aquifer's lower surface - the fresh - sea water interface - is variable a deepening of the interface follows, although with some delay, the aquifer's supplying. Thus, only low increases of the piezometric slope are possible, due to outside water flowing into the aquifer; consequently, there are no remarkable periodic fluctuations of the output in coastal springs.

The rainfalls absorbed by the soil in the zone considered can replace, according to an approximative calculation, 1/50 of the ground water volume, This figure also gives an idea of the flow which interests all the aquifer's volume. This flow is sufficent to maintain the individuality of the fresh water stratum floating on the encroaching sea water. However the two different kinds of water are separated by a zone where there is a quick variation of salinity. This zone is commonly known as *diffusion zone* even though actually, in a few cases, this phenomenon is connected to turbolent movements causing the intrusion - and later the dispersion - of bodies of salt water into the fresh water[2]. Outside the area we are considering (as, e. g., in the inland of Barletta), particularly slow flows have been observed: as a consequence high values of salinity were found at a remarkable distance from the interface. Generally, however, relatively high salinity is observed in the higher section of the aquifer only in few sites near the coast, where the fresh water grows thinner and thinner, until it finally fades.

As for the upper section, the aquifer's recharge from the surface causes it to be strictly dependent on the supply due to seasonal rainfalls. In such conditions the stratification of water in the aquifer can best be investigated. This is made possible by a few hundreds of wells existing in the area considerated. Some are stations for the measurement of the water table levels and allow sampling of water from wells out of exercise.

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2) COTECCHIA V. - *Geohydrological aspects of the Cretaceous limestone aquifer in Apulia and their bearing on the practical avoidance of sea water contamination in extraction from well and springs.* ONU, Special Fund, Technical Meeting on Karst Hydrogeology, Athens, March 1963.

The application of the isotope method to the study of such a large region, where problems of general interest can be tackled, shall stretch over considerable time and shall require the analysis of a large number of samples. The results which we are presenting are those of the initial stage of this work, which have been applied in order to draw a program for the further development of research. However, we felt it useful to present them, as they show what can be obtained from a survey based on a single sampling.

The sampling in Salentina Peninsula was carried out from November 12th to 17th, 1962, drawing water samples from springs, working wells, and wells out of exercise. In the latter, samples were drawn from different dephts in all cases in which this was possible, and as long as such sampling could be considered significant with regard to the stratification of the water in the aquifer.

As far as interpretation of results is concerned, some isotopic ratio values of water must be determined. They are: *(a)* the isotopic composition of the sea water; *(b)* the average isotopic composition of the rain water wich supplies the aquifer; *(c)* the size of the isotopic composition variations in the water supplying the aquifer, in connection with the seasonal variations of the isotopic composition in the rainfalls.

The isotopic composition of the various types of water is expressed as deviation (δ) in parts per mill of the $^{18}O/^{16}O$ ratio in the sample as compared to a standard. The figures which will follow, are referred to the Standard Mean Ocean Water (SMOW). It must be pointed out they cannot be assumed as deviation from the isotopic ratio in the sea water of the Mediterranean, as the water of the sea - due to its high evaporation - is enriched in ^{18}O with regard to the mean ocean water. In fact, a sample of sea water taken 4 km off Bari at a depth of 70 m, gave a value $\delta = +1.3$, which we shall use in this paper from now on. Samples taken along the coast would not be significant in this case, on account of the strong continuous downflow of fresh ground water towards the sea. In various cases, underseas springs can be recognized from their high output. The low-flow veins, instead, are generally missed. Thus, e. g., in a sample from the sea North of Gallipoli a Cl^- conteint of only 10 gr/1 was found.

As far as the isotopic composition of the aquifer's fresh water is concerned, it could be thought of drawing it from the average of the figures regarding all precipitations throughout the year. Aside from the difficulty of obtaining such informations, which would require a large number of analyses on samples taken regularly through space and time over many years - it is uncertain that it may be considered wholly significant. In fact, even in a zone such as the one we are considering where the infiltration is very pronounced, the amount of water which can penetrate in depth in the different seasons depends on various factors which cannot be evaluated quantitatively. It is more convenient to deduce the average value of the isotopic ratio of rain water reaching the aquifer from the isotopic ratio of the water contained therein. We have already seen that the fresh water in the aquifer due to its slow substitution, to the diffusion from the underlying sea water and possibly to the partial mixing to the latter, has a salt containt variable but not indifferent. In practice it is convenient to refer to the Cl^- containt, which represents better than any other piece of data the sea water contribution.

The δ values of the samples taken at various depths in the aquifer are plotted in fig. 2 versus their Cl^- containt. Almost all points marked in the diagram fall within a narrow triangular band, having as its basis ($Cl = 0$) the interval between $\delta = -5.6$ and $\delta = -6.5$, and as its vertix the point with coordinates $\delta = +1.3$ and $Cl = 22$ gr/l (average Cl^- containt of the Adriatic and Ionian seas). A figure ($\delta = -6$) sufficiently close to the mean value of the above mentioned interval can be assumed as the average value of the meteoric waters which supply the aquifer.

Any deviation from this figure, not justified by a mixing with sea water, shall correspond to a major or minor contribution of rains, which have condensed at temperatures different from the average one of the clouds originating the precipitations. With connection to this fact, summer rainfalls are enriched in heavy isotopes more than winter ones.

Regardless of the time of the year in which the precipitation took place, we shall consider as *summer* ones all waters whose δ value is more positive than the upper limit of the above-mentioned interval ($\delta > -5.6$), and *winter* ones all those with δ lower than -6.5. Such kinds of water can be considered as traced as compared to the average fresh water in the aquifer. It is clear that, with this criterion, the aquifer's recharge must take place in equal amount in both isotopic seasons.

The distribution of rainfalls through the year is shown in fig. 3. Considering it, one may suppose that the separation of the two isotopic seasons must fall in the months of April and November. In any case, between October and December a quick variation from summer-to winter-precipitations must take place. This corresponds also to the climatic character of the region, where a real intermediate season does not exist between summer and winter.

As the samples here studied had been taken between November 12th and 17th, it must be inferred that they were collected at the beginning of the isotopic winter season. Therefore, the existence of samples reflecting the isotope ratio of summer water, which can be present in the aquifer with a certain delay, as well as that of other samples reflecting the composition of winter water, is to be expected. Actually, in the area we have been considering, only cases of summer water have been found. This fact, however, is certainly due to the delay in the aquifer's recharge. In fact, from a well filled with mud and from whose mouth surface water can enter, a completely saltess sample was obtained, with $\delta = -8.3$. This must correspond to a rainfall of winter type in the days immediately before the sampling. Contemporary to the sampling of the wells in the Salentina Peninsula, other samples were taken in a zone 70-100 km North.

Letter A) in fig. 2 indicates the results regarding two coastal springs and a well a few km upstream, near the town of Trani. The spring and the well lie at the margin nearest to the sea of a large outcropping of cretaceous limestone, which, especially at the lowest levels - where it is intensely fractured - allows a quick flow of vadose waters toward the aquifer. This quick flow is to be accounted for the presence of very negative values of δ, due to winter-type precipitations, as the other cause which might justify them - that is, water coming from high mountains - can be excluded, since the inland relief reaches very few peaks in the range of 300-500 m. As in all coastal springs and well, the salt containt is rather high.

Letter B) in fig. 2 indicates the results regarding wells which attain a superficial aquifer in the Tavoliere di Foggia, having Pliocene clay as its basis. Also in this case, therefore, we are faced with a ground water supply from winter rains fallen in the same areas at levels below 100-150 m. a. s. l. The scarce quantities of salt found in this ground water are derived mostly from the Pliocene clay, as it lies completely outside the scope of influence of sea water. The contour lines of the area B in fig. 2 indicate the sense of the variation found when samples were taken at different depths in the same well. As depth increases, there is always a trend toward the same value of δ. This indicates the presence in the aquifer of a stratification which can be recognized by means of seasonal tracing.

The existence of strata of water seasonally traced in the upper section of the aquifer appears even more evident when considering the samples with a summer isotopic composition, as shown in fig. 2. All these samples were collected in the area indicated in fig. 4. It is difficult, on the basis of information available to-date, to establish which are the conditions that make this area so peculiar for the remarkable thickness of summer water observed in them during the month of November. This fact, however, is not so surprising if one considers, for instance, that anisotropy in the permeability of limestone may easily allow concentrations and deviations of waters very close to the surface of the aquifer. From this fact, the seasonal stratification can be extolled.

The existence of a large reservoir of summer water results evident in the case of a pit 18 km from Brindisi, having a draining gallery in correspondence of the water table which, with a dynamic depression of 1 m, supplies continuously 40 l/sec.

A special case is that of the well near Nardò from which the samples C in fig. 2 were drawn. In spite of a distance of over 6 km from the sea, the elevation of the water table above sea level is here less than 1 m. The very low piezometric gradient (0.15 per thousand as compared to the 0.4-0.5 in the whole region) depends probably on a very advanced Karst stage. The water's downflow in such conditions may take place in a turbolent form, and this is probably the reason of the fact that, although the sea water level may be evaluated as -40 m, the samples taken at -5 and -13 m turned out to have Cl^- containts respectively of 2.3 and 3.3 If we admit the possibility of extrapolating the variations observed between the samples C. towards conditions of higher and lower salinity, we may assume that water having zero salinity and $\delta = -3.6$ must have mixed with water containing 4.5 g/l of Cl^-; the last resulting of the mixing of sea water with fresh water having $\delta = -6$.

The variation observed between the samples taken at various depths in the wells where the upper layers are seasonally traced indicates in all cases a mixing with depth with increasing amounts of water without seasonal tracing. This agrees with the recharge of the aquifer from the surface, and indicates that the zone above the superficial one is formed by water in which an average value of δ has been obtained as a result of continuous superimposition of strata of water seasonally traced; these, in time, lose their individuality, thus determining a strong layer of water having uniform isotopic composition. This has been evidenced in a well drilled by the Geomining Division of the National Committee for Nuclear Energy for research purposes, near Copertino. Samples were taken here as the drilling went on. fig. 5 shows in upper levels the inflow of waters which are assuming the winter composition, while a layer of water influenced by summer rainfalls was observed at a depth of 55 m. Below these layers, δ and salinity values are constant down to a level where, as predicted by the theory, the beginning of the diffusion zone was found.

Considering all the situations exposed above, we see how a single sampling, carried out during the transition period, allows to remark in certain cases the presence of summer waters, and in others that of winter ones. This cannot give an exact idea of the isotopic composition of these two kinds of water; however, it can give us the lower limits we must allow, as it is very probable that summer waters with δ more positive than the maximum value observed and winter waters with δ more negative than the lower one, may reach the aquifer. However, the figures like δ = −3.6 and δ = −8.3 found in November is itself sufficient for practical applications of the seasonal tracing. This tracing also allows us, as we already saw, to identify various hydrogeological situations, differing in the thickness and in the individuality of the various layers. It is evident it must be possible to follow the evolution in time of the various situations, thus obtaining information suitable for the solution of problems which it has not been possible to tackle yet, such as the quantitative study of recharge and flow of the ground water.

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COMITATO NAZIONALE ENERGIA NUCLEARE
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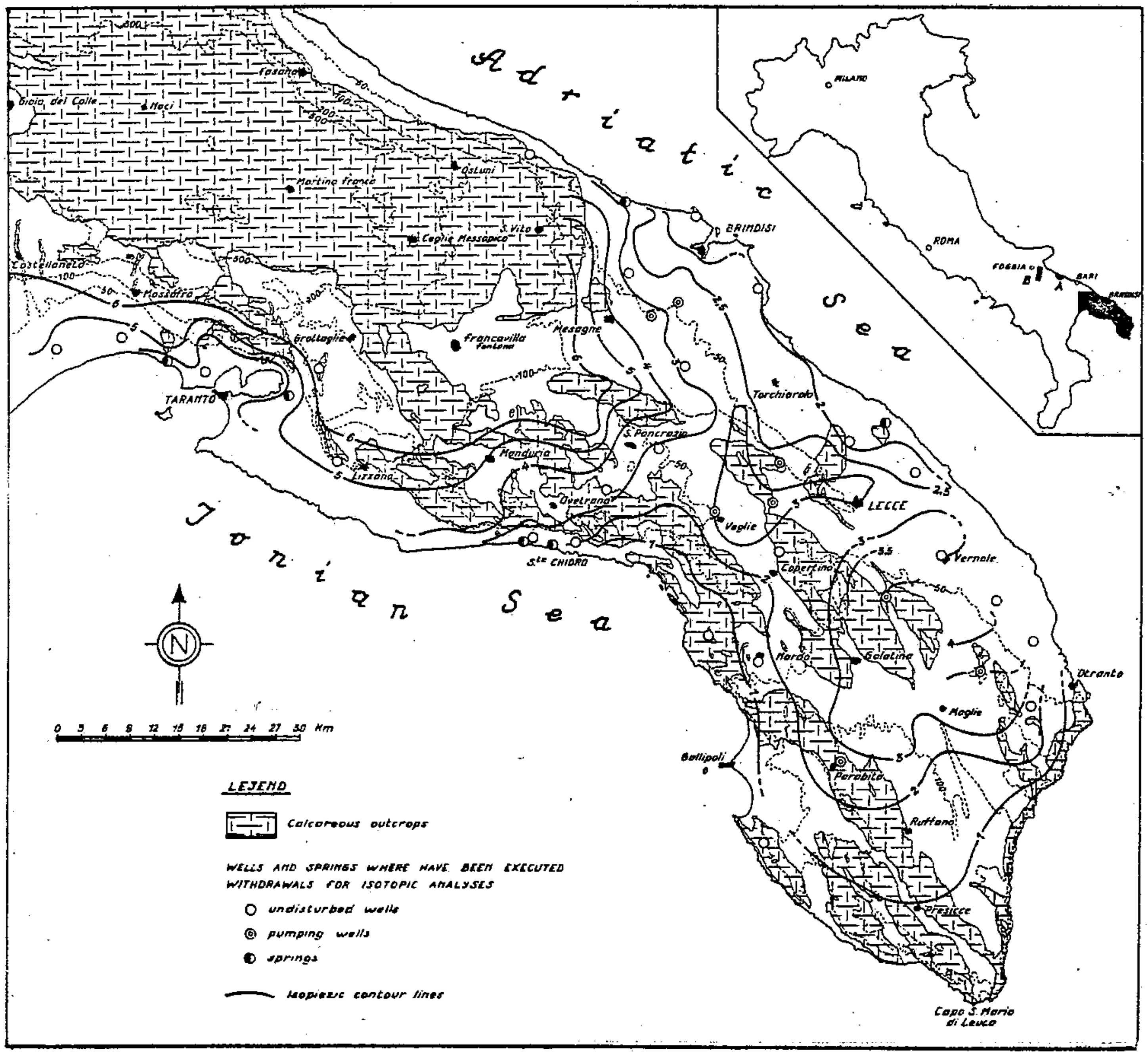

Fig.1 - Map of area concerned by the limestone aquifer studied

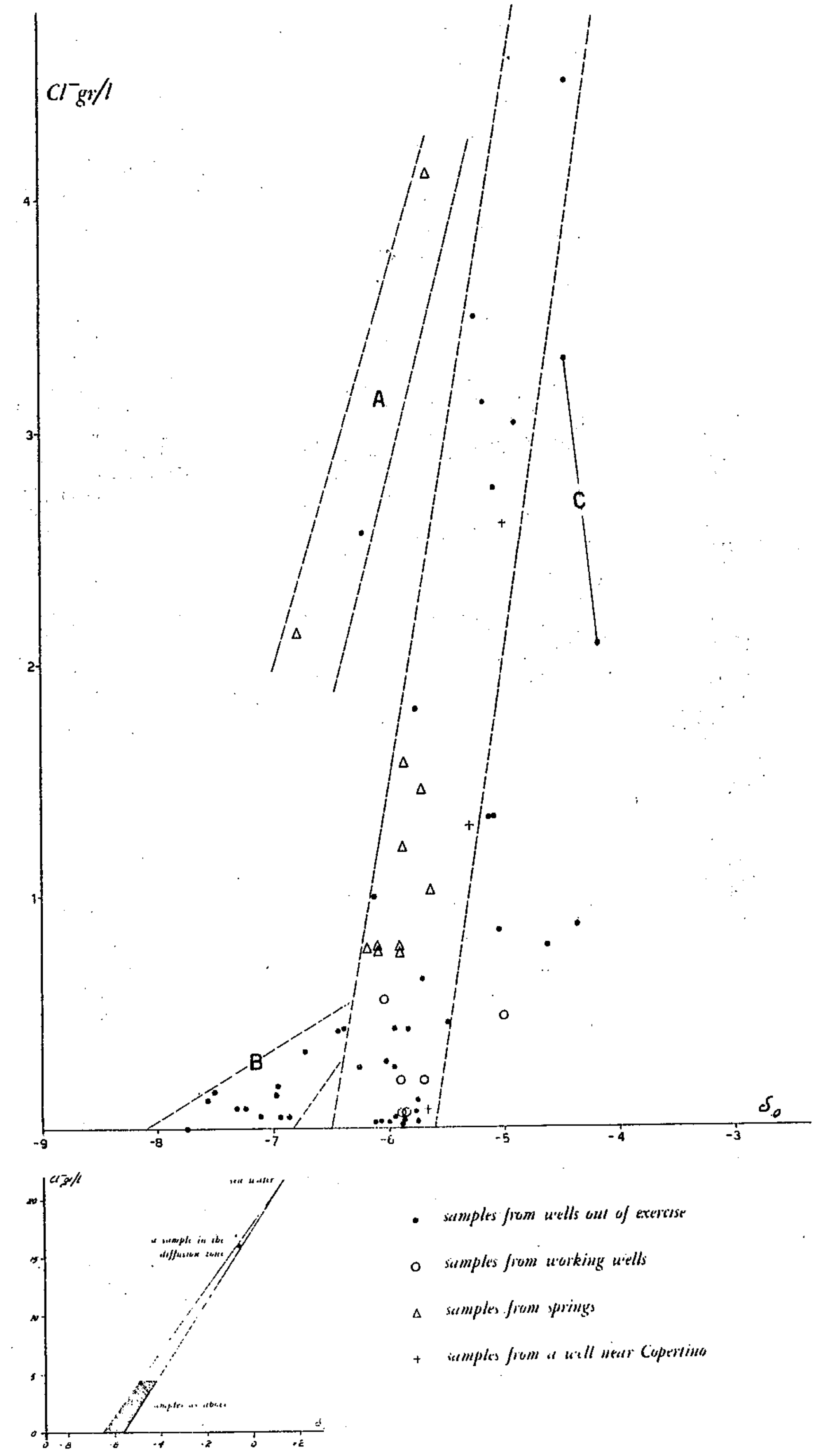

Fig. 2 — Cl$^-$ containt and δ values in samples collected in Salentina Peninsula and A) near Trani, B) in Tavoliere di Foggia, C) in a well near Nardò

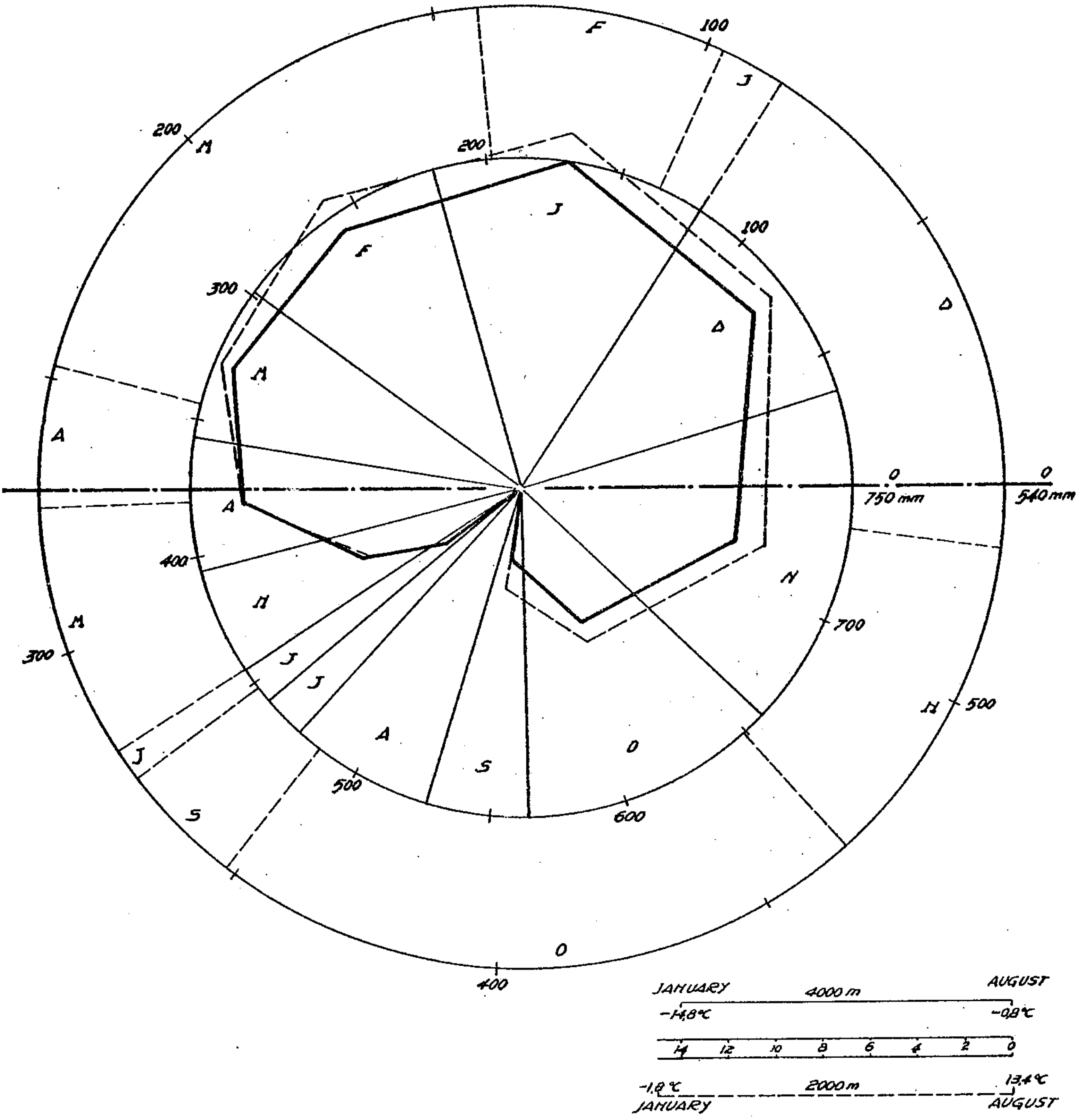

Fig. 3 - Monthly distribution of rainfalls at Brindisi - Average data for 1953-1962 (inner circle) and for 1962 only (outer circle).
Average monthly temperatures at 4·000 meters a.s.l. (continuous line) and at 2·000 meters a.s.l. (short dashes line).

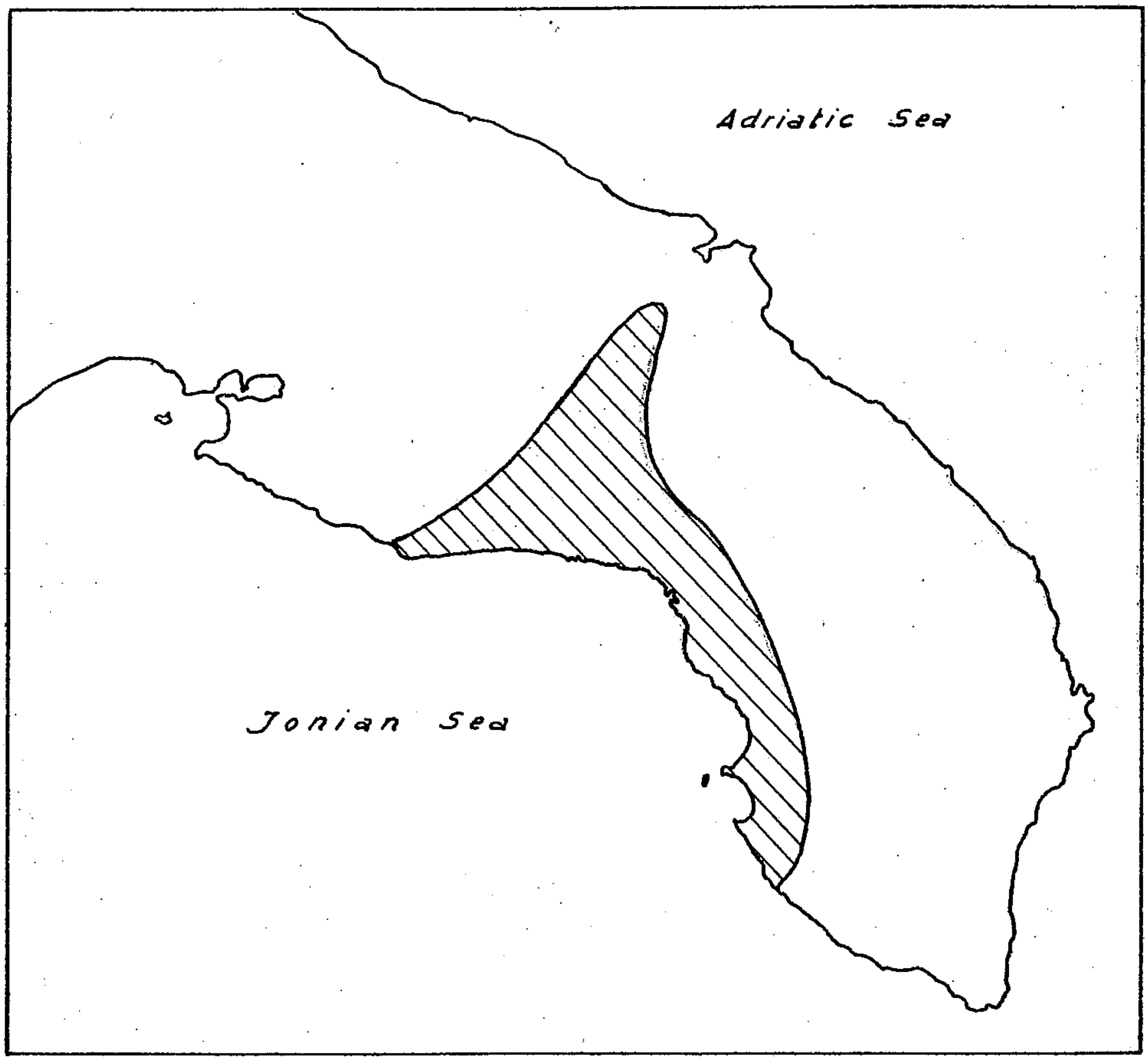

Fig. 4 - Area in which upper layers of ground water show a summer tracing.

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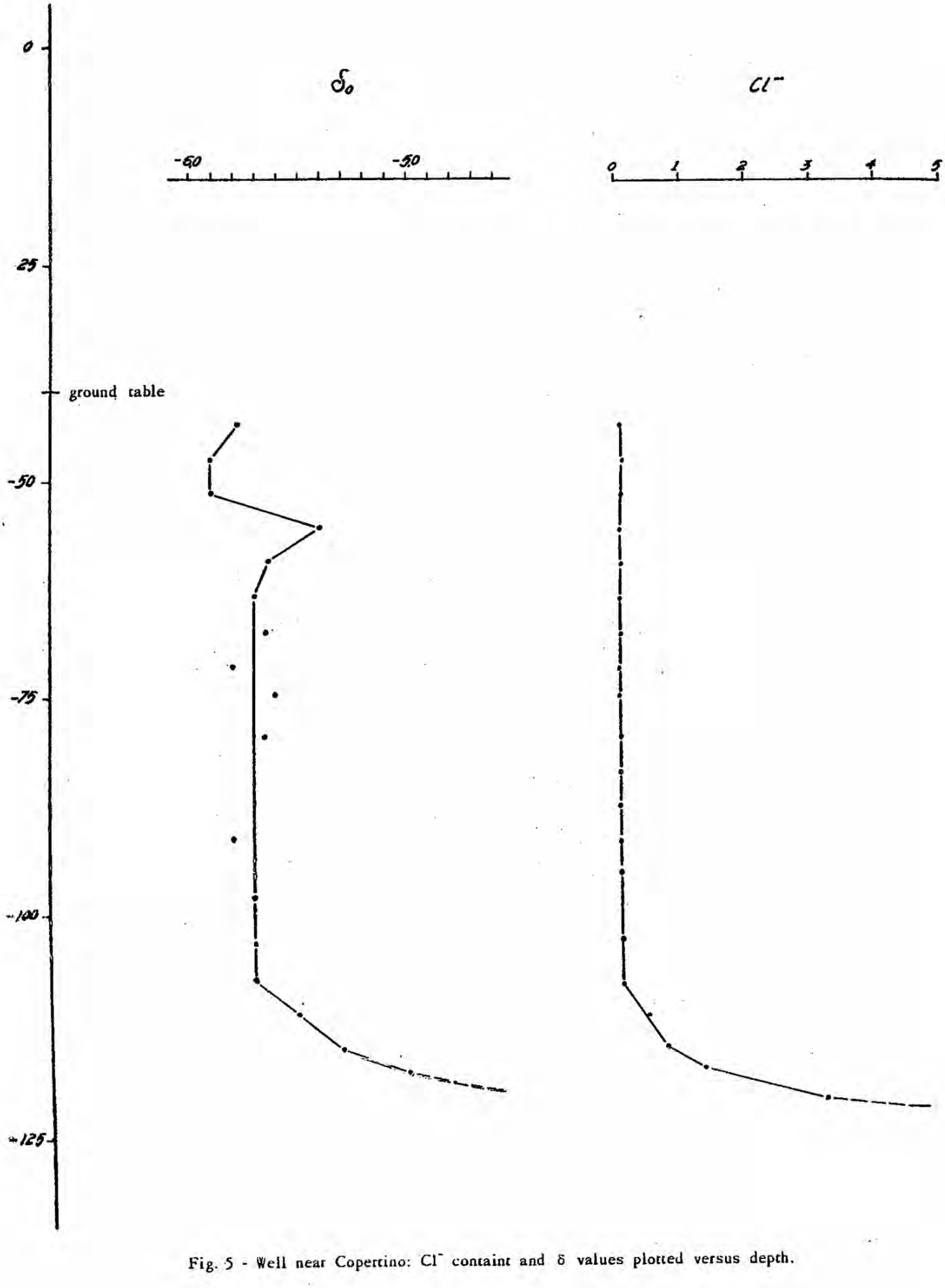

Fig. 5 - Well near Copertino: Cl⁻ containt and δ values plotted versus depth.

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