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A HYDROGEOLOGICAL STUDY IN THE BASIN OF THE GULP CREEK – A RECONNAISSANCE IN A SMALL CATCHMENT AREA

2. Fissured rocks and their anisotropic behaviour in catchment studies

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Summary

Catchment studies are carried out to obtain a good understanding about the interrelationship between input, storage and output elements in a drainage basin.

The occurrence of zones with increased fissure density in such areas is very important in that they produce significant deviations from flow systems expected for homogeneous media. The presence of preferential zones of groundwater movement is characteristic as is shown by a comparison of hydrographs for three wells not far apart. Groundwater capture and interbasin flow may become major factors and the definition of the water table also needs special attention.

Introduction

Within the framework of a hydrogeological training project for students of the Agricultural University of Wageningen (the Netherlands) field studies have been undertaken in the valley of the Gulp creek in the S.E. part of the Netherlands (cf Figure 1). The Gulp Basin forms part of a dissected plateau landscape, that is

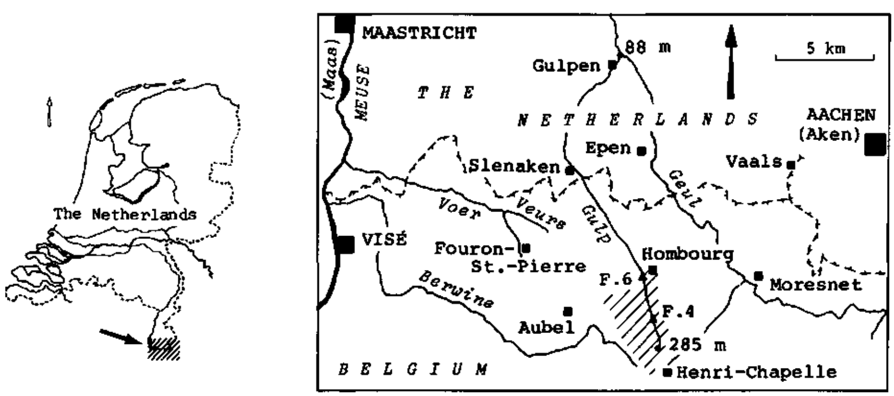

FIG. 1. Location of the study area; F_4 and F_6 are stream gauging stations.

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situated near the northern margin of the Ardennen uplands, where the Hercynian fold belt meets the low plateaus which have a subhorizontal cover of Mesozoic and Cenozoic formations.

Stratigraphy, structure and surface extent of the various lithologic units have been mapped, with particular attention given to their water bearing properties. Precipitation is measured with the aid of a pluviograph and samples of surface and samples of groundwater are regularly collected for chemical analysis at key locations (cf NOTA and BAKKER, in preparation). Continuous records of surface water discharge and groundwater level fluctuations are gathered at selected sites. The period of record for these data is three years.

According to Köppen's classification the climate in the region can be described as temperate rainy, moist in all seasons. The average annual precipitation amounts to 890 mm. Rainfall intensity is highest during the summer; during a thunder storm 19.5 mm per hour has been measured. Precipitation intensities during the winter are lower and average between 1 and 3 mm per hour. Figure 2 presents precipitation and temperature data from our hydrogeological field station at Hombourg (in Belgium). Comparative measurements have shown that the pluviograph readings may be up to 12 per cent lower than the values obtained with standard rain gauges.

The total length of the valley (cf Figure 1) is approximately 18 km, the maximum width between the topographic divides is about 4 km, while the total surface area of the basin is about 4,600 ha. The stream originates at an elevation of approximately 285 metres above sea level and discharges at about 85 metres, into the Geul river. The average discharge is about 350 litres per sec. Approximate separations of discharge hydrographs indicate that baseflow comprises some 70 per cent of the total discharge. The southernmost part of the basin, just across the Belgian-Dutch border, was selected to start with a reconnaissance survey. The area comprises the upper reaches of the basin and includes a total surface area of about 730 ha. The objective was to determine the major hydrogeological characteristics and transfer the results to the remainder of the basin.

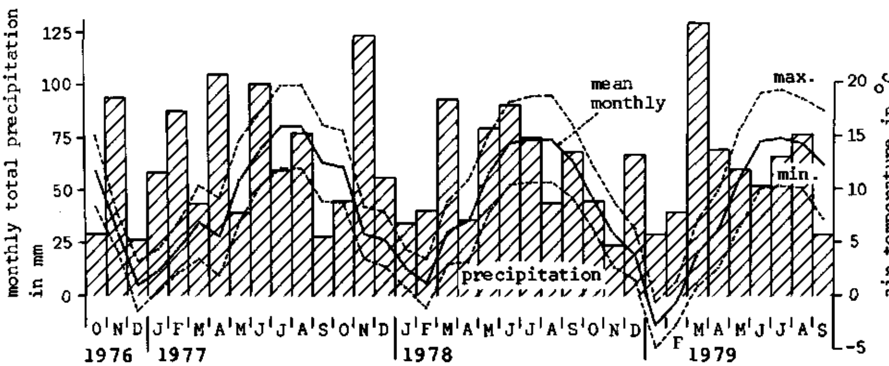

FIG. 2. Monthly total precipitation and air temperature data for the hydrogeologic field station at Hombourg (Austen).

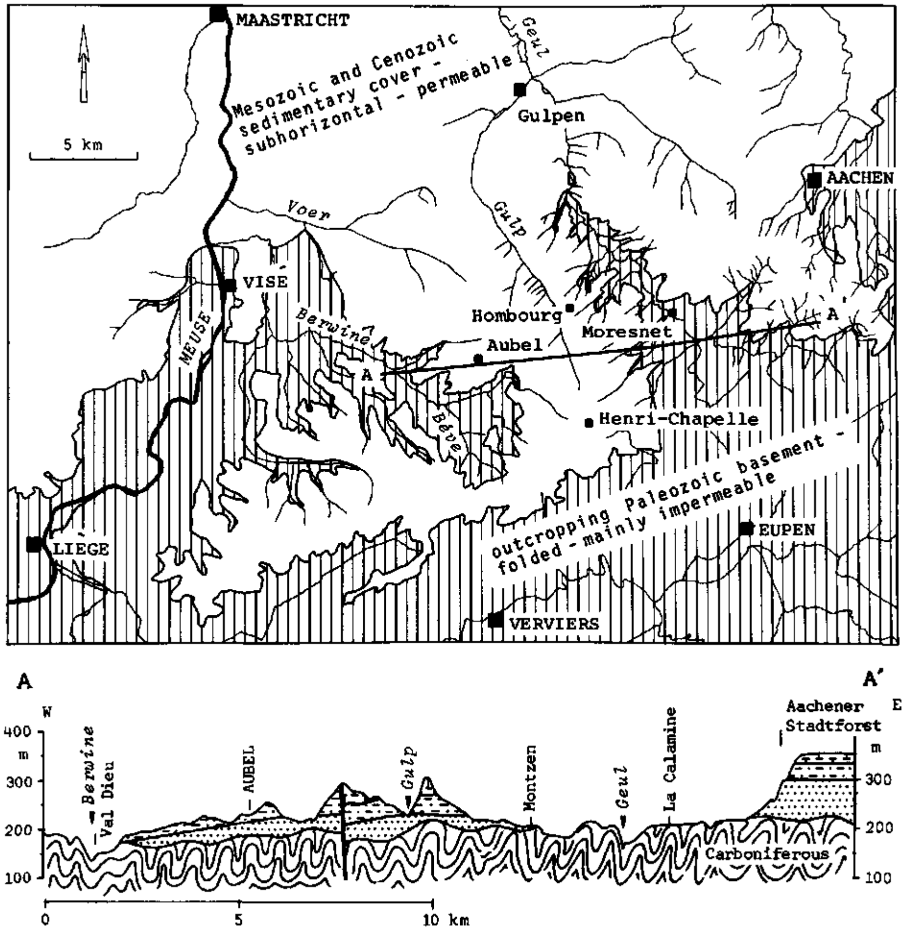

FIG. 3. Geological framework of the Gulp Basin and surroundings. For stratigraphic legend cf fig. 4.

GEOLOGICAL FRAMEWORK

The geological framework of the Gulp Basin and surroundings is depicted in Figure 3 (cf NOTA and VAN DE WEERD, 1978). Folded sedimentary rocks of Paleozoic age underlie the basin; generally these formations consists of interbedded fine grained sandstones and shales. The Paleozoic bedrock is considered to form the base level of the flow system.

The Mesozoic formations that cover the Paleozoic bedrock are of Upper-Cretaceous age. The Aken, Vaals and Gulpen Formations respectively are of marine Upper-Senonian origin.

Lithologically the *Aken Formation* consists of non-indurated silty clays in the lower part of the series and light coloured fine grained well sorted quartz sands

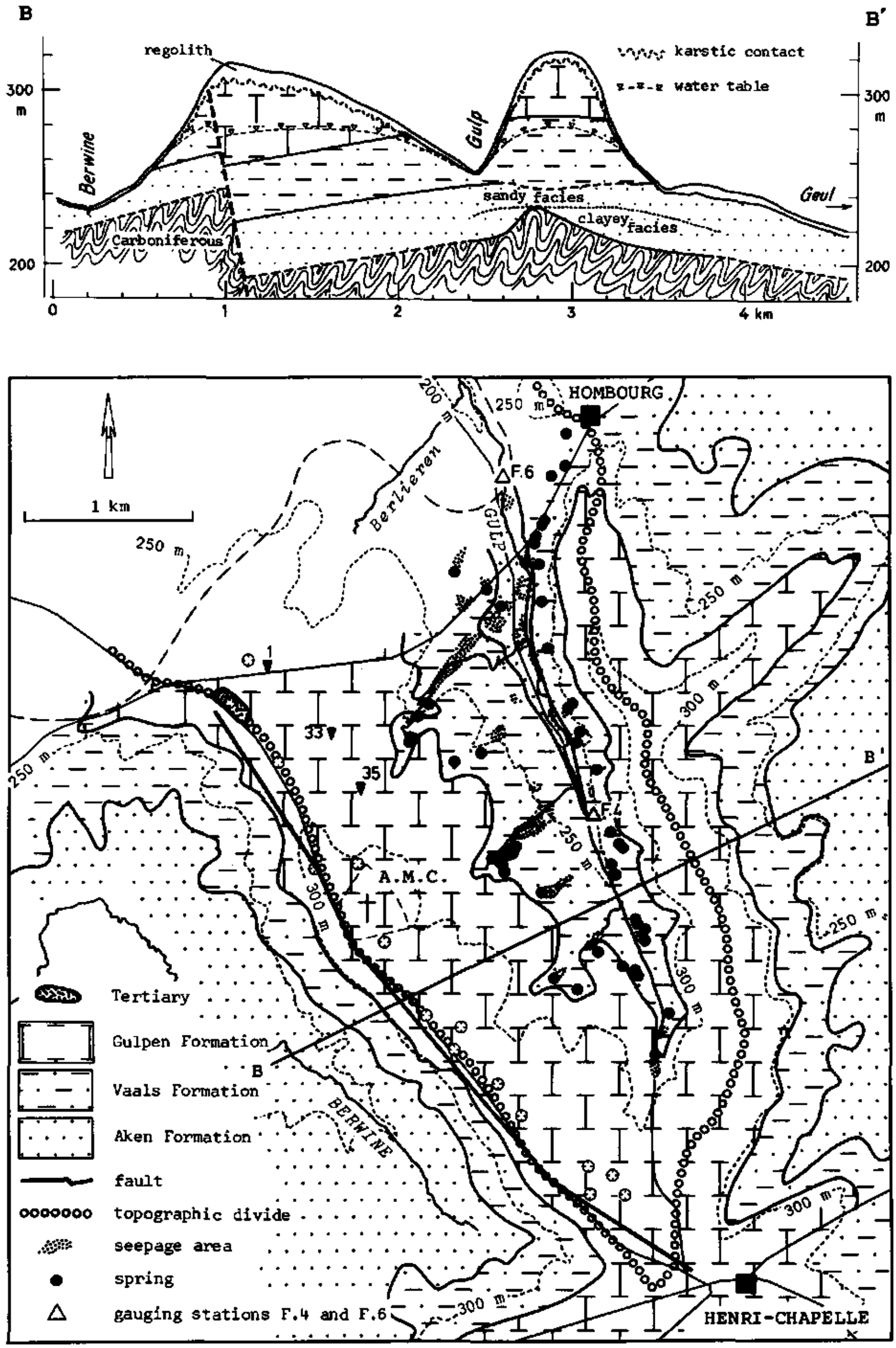

FIG. 4. Map and cross section to show the general hydrogeological conditions in the southernmost part of the Gulp Basin. For legend see also Figure 6.

(Md values between 150–200 microns) in the upper part; in the basin the thickness of the formation is about 35 m (cf Figure 4).

The *Vaals Formation* overlying the Aken Formation is about 40 metres thick. Generally it consists of silty clays and clayey silts, with abundant glauconite and interbedded with consolidated sandstone layers (10–20 cm), that are fractured.

The *Gulpen Formation* is a light coloured, fine grained fairly homogeneous chalk with joints and fissures in places; its thickness measures approximately 40 metres. The carbonate content is over 80%, silicifications are rare and most of the limestone is soft and poorly bedded.

As a result of regional uplift most of the *Tertiary deposits* have been removed by erosion. The differential uplift is expressed by the presence of a fault along the western edge of the catchment (cf Figure 4) and by a general 1–2 degree northwestern dip of the Mesozoic and Cenozoic cover. The fault offsets the relatively permeable chalk of the Gulpen Formation against the generally low permeable silty clays of the Vaals Formation; the fault block is tilted towards the fault.

The composition of the *regolith* varies greatly from place to place; generally it is composed of an admixture of chert nodules, clay size material and loess. Permanent pasture covers 90 per cent of the area. Measurements have shown that the regolith is sufficiently permeable to permit infiltration. The saturated vertical permeability for the upper 50 cm was determined to range between approximately 0.50 and 4.00 m/day, being dependent to a large degree upon the frequency of bioturbations. Hence, overland flow will be very unusual in the study area.

Effects of fissure density on movement of groundwater

The behaviour of the hydrogeologic system is controlled by the properties of the lithologic units, by their structural arrangement, by the topographic relief and by its geological history. Stream incision, tilting and faulting as a result of regional uplift since Late-Tertiary have been of vital importance for the surface and groundwater regime in the study area. The uneven uplift caused tectonic deformation, the regional tilting is reflected in the general direction of the drainage to the northwest and the stream incision created favourable conditions for groundwater discharge in the valley. The groundwater flow system in the Mesozoic-Cenozoic sequence is considered as a multiple layer aquifer in which a number of preferential zones of groundwater flow exists (cf Nota and van de Weerd, 1978).

Many workers in karstic terrains have emphasized the importance of the tectonic deformation of carbonate rocks (cf Burger and Dubertret, 1976). The occurrence of a series of more or less linearly arranged dolines and related features in the vicinity of the fault along the western edge of the catchment is striking. It is considered that the development of the dolines in the chalk is associated with the increased fracture and fissure density in the fault zone. It can be expected that circulation of water through these fissures has enlarged the

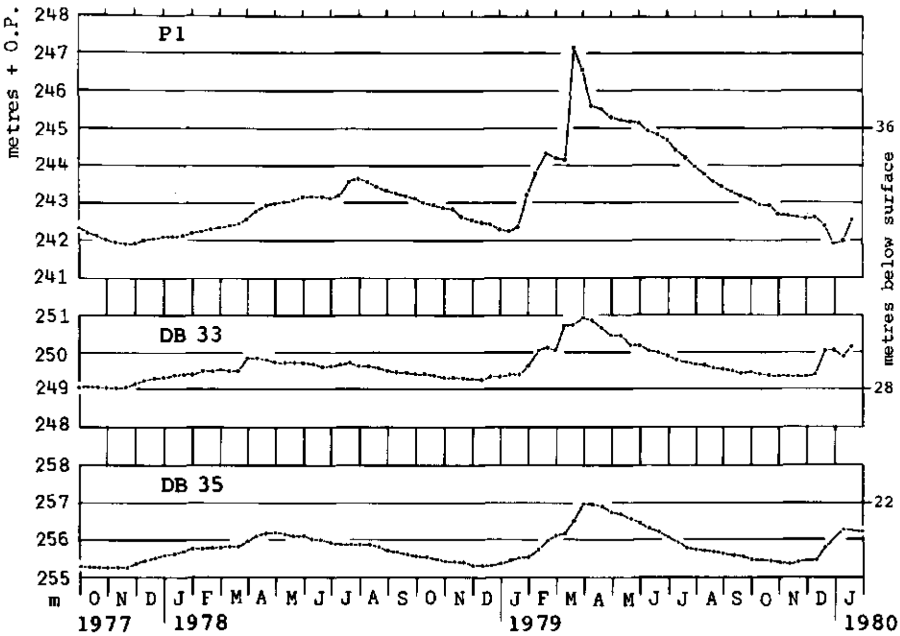

FIG. 5. Groundwater table fluctuations for three observation wells that are not far apart. For locations cf figures 4, 6 and 7.

passage-ways by the solvent action of the water and that also under present conditions the fissures and fractures serve as selected avenues, through which water moves downward, particularly after intense rainfall or snow-melts. However, the secondary permeability thus developed is unevenly distributed. A comparison of hydrographs from three wells within the limestone (cf Figures 4 and 5), that are located not far apart (not more than about 500 metres respectively), indicates that the groundwater table fluctuations are different from place to place. Well Pl is very typical, showing the characteristics of a well near a doline. Particularly the rapid rise during the period February-April 1979 is very striking. Obviously the water-table level of Pl is very local, anomalous and not representative for the area. Clearly, the dominant mechanism of flow is connected with fissures and fissure flow behaves anisotropic and erratic. Pl also shows the influence of the thickness and condition of the unsaturated zone on the rise and decline of the groundwater. At the end of the summer 1977 the unsaturated zone was practically dry whereas in February-March 1979 it was already practically saturated; an equivalent amount of recharge as in November 1977 was in early 1979 enough to rise the water table rapidly. It further appears that during periods of low water levels the fluctuations are more smooth as compared to the periods of higher water tables; it might indicate that fissure density decreases with depth. Similar hydrographs have been obtained in other parts of the basin, near dolines. Under certain conditions, the shape of the water

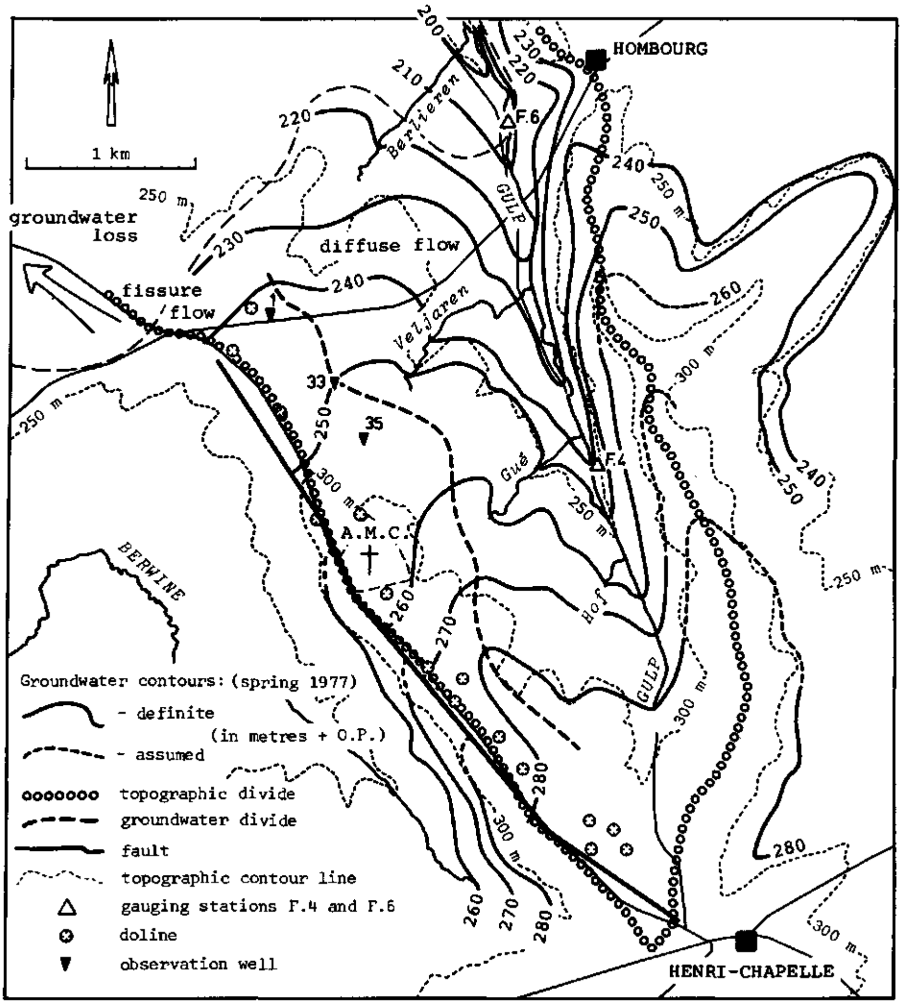

FIG. 6. Simplified contour map of the groundwater table. See also figure 4.

table apparently is complex, varying from place to place, particularly and most extremely when the unsaturated zone is already largely filled. The study of the interrelationship between water table fluctuations and groundwater storage is thus complicated. The contour map of the water table (cf Figure 6) indicates that on the whole the fault zone acts as a drain, a zone of preferential groundwater flow, along which a substantial water loss occurs for the Gulp catchment. Because the fault offsets rocks of different permeabilities the chalk side behaves as a preferential zone, while the other side in the silty clays of the Vaals formation will have been plastered and more or less sealed off and thus acts as a barrier (cf Fig. 4). The tilting of the fault block towards the fault and the regional northwestern dip of the geological formations in the study area cause a discharge in a

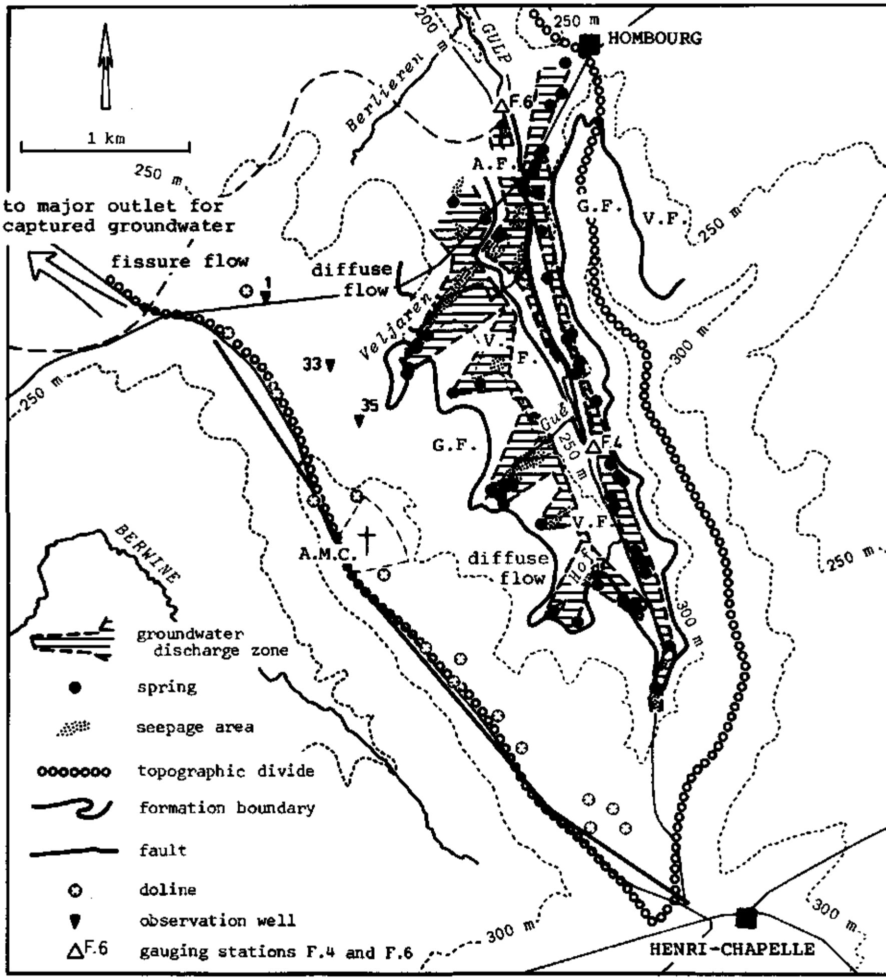

FIG. 7. Simplified map to show distribution of types of groundwater flow and groundwater discharge zones in the study area. G.F. = Gulpen Formation; V.F. = Vaals Formation; A.F. = Aken Formation.

northwestern direction. Approximate calculations of the hydrologic budget indicate that between 30–50 per cent of the recharge is lost by subterranean capture. As a result, surface and subsurface catchment areas do not coincide and thus only part of the catchment will contribute to the base flow of the Gulp creek. A large limestone spring (in the adjacent Voer basin) is a major point of discharge for the captured groundwater. Thus, interbasin flow is a major factor to be considered.

The average discharge measured for the above mentioned major spring was 80 litres/sec for the period between August 1st, 1977 and October 1st, 1978. The differences between minimum and maximum discharge comprise not more than

1:6. This indicates that the fault zone behaves not as a marked conduit flow according to the definition given bij WHITE (1977); it is intermediate, combined intergranular and fissure flow, but definitely acting as a preferential zone of groundwater discharge.

On the contrary, the occurrence and general distribution of a large number of steady seepages and small springs in the area of groundwater discharge (cf Figure 7) indicates that within the chalk the groundwater movement is mainly diffuse, generally intergranular with a more uniform permeability.

Summarizing, the differences in fissure density have led to the anisotropic behaviour of the catchment in terms of input, storage and output relationships. The uneven distribution of fissures in the rocks of the study area thus accounts for differences in groundwater regime in different parts of the catchment, for interbasin flow and for a complex water table pattern, particularly during the wet season of high water levels.

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