Wave-Power and the Djursland Coast

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Wave-Power and the Djursland Coast

By Sofus Christiansen

Abstract

For some localities of the Djursland coast an essay is made to estimate the influence of the fetch on wave-power. Variations of fetch and coastal material seem to be of major importance for the configuration of the coast, while vertical movements seem to be quite insignificant. For geomorphological description of the Djursland Coast, see Axel Schou: The Coastline of Djursland. Geografisk Tidsskrift, vol. 59, 1960.

The coastline of the peninsula Djursland in the eastern part of Jutland shows a diversity of morphology, which is unusual in so small a region. It is for that reason difficult to establish a standard of reference from which the coast can be morphologically analysed. In this article an essay of using numerical expressions of total wave-work fit for specially selected localities is shown. The method by which the expressions used is derived was published earlier (*S. Christiansen*, 1958), and is based on a formula for effect of wave-work $E = W^4 x HxF$. In the formula E means total wave-energy from a given direction, W is windforce after the Beaufort-scale, H the frequency of wind from the direction considered, and F the fetch given in km. The formula was worked out by *Per Bruun* (1955) and is based on both practical experience and theoretical calculations. From the named formula a vector for every compass-direction is determined; these are later geometrically added forming a direction-resultant. Use of geometrical addition of vectors based on other calculations was earlier made by *M. Musset* (1923), *A. Schou* (1945), *S. Y. Landsberg* (1956) and others.

The wind-observations on which the statistics used in this work are based, were made 1879-1925 from the Fornæs Lighthouse. Of course the wind varies somewhat in the region dealt with, but errors introduced in calculations on behalf of this are considered insignificant, especially as maximum-error in observations of wind-direction is as much as 22½°. The advantage of using the calculations shown below is therefore not the exactness of the expression of wave-work, but the fact that the calculations involve an estimation of the influence of the fetch. As stated already by many workers in coastal matters, variations of fetch at least in closed waters are significant.

The southern part of Djursland, the morphology of which is mainly glacial, is characterized by the three glacial-depression-bays: Kalvö Vig, Begtrup Vig and Æbeltoft Vig (fig. 1).

For *Kalvö,* the direction-resultant of wave-work (DR) is shown in illustration. The dimension given in arbitrary units amounts to »1.2«. The direction of the DR means, that the beach-drifting of the bay has a net-movement towards the inner part — as is usually the case for bays. It must therefore be expected, that an accretion of material can be found round the small island of Kalvö. It must be noticed however, that the marine foreland of the region partly is due to the postglacial upheaval of land.

The coastline south of *Strands* has a DR which is larger than that of Kalvö and a direction more to the south. This is caused by the somewhat larger areas of water, which magnify the work of waves. The accumulation of material is for that reason larger than for Kalvö Vig. As a sign of accumulation, a very nice complex recurved-spit is seen. It is of some use as a natural break-water for fishing-dinghies.

Measured in the same units, the wave-power of *Örby* is still a little larger. The resistance against wave-attack of this landscape has been so small, that the glacial forms of the initial coastline are hardly recognizable. In fact, the coastline is almost linear, and it will most likely maintain its form. The wave-power of this coast will show but slight variation, and the recession of the coastline will consequently be almost constant per unit of length. Not much doubt can be raised about the perception that the coast by this locality has developed one of the plane-equilibrium-forms described by *Per Bruun* (1946). It can be noticed, that in accordance with the more violent movement of coast-material, the average grain-size of it is larger than that of the localities previously mentioned. Some of the pebbles are indicator-boulders revealing a glacial drift from the bottom of the Baltic between Sweden and Estonia (quartz-porphyries).

The form of *Æbeltoft Vig* is probably a constant one too, but in this case recurved. *Per Bruun* postulated (1946) a special recurved plane-equilibrium-form. The postulate was met with strong criticism. If lines indicating the dominant fetch are drawn from points along the beach, the lines are most often orthogonal to the coast. This means that such points of beach (often) can be regarded as,

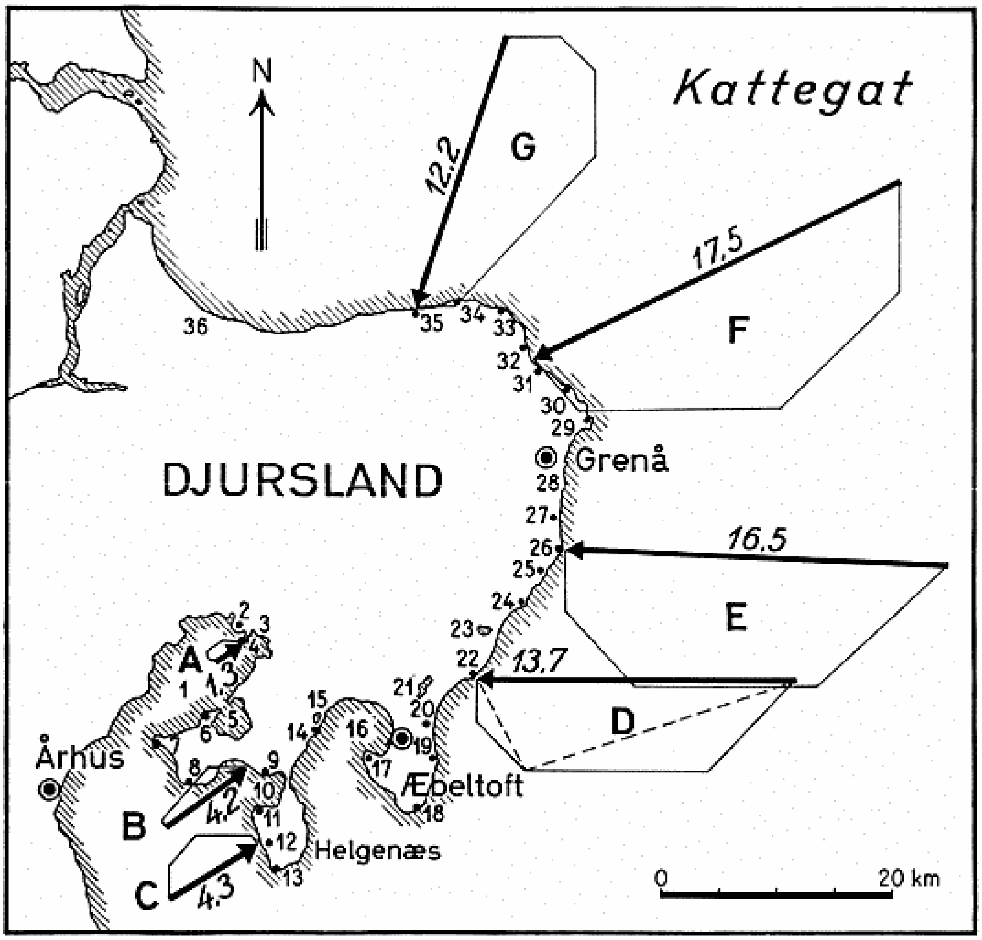

Fig. 1. *Direction resultants of wave work (DR) along the Djursland coastline.* A. Kalvö. B. Strands. C. Örby. D. Jærnhatten. E. Katholm. F. Gerrild. G. Bönnerupstrand. 1. Kalvö Vig. 2. Hestehave. 3. Kalvö. 4. Egens Vig. 5. Knebel Vig. 6. Dejred Öhoved. 7. Sködshoved. 8. Mols Hoved. 9. Strands Gunger. 10. Begtrup Vig. 11. Stavsöre. 12. Örby. 13. Sletterhage. 14. Bogens Hoved. 15. Bogens Sö. 16. Æbeltoft Vig. 17. Ahl Hage. 18. Hasenöre. 19. Brokhöj. 20. Gungerne, Boeslum. 21. Draaby Sö. 22. Jærnhatten. 23. Nörresö, Rugaard. 24. Glatved-Limbjerg. 25. Katholm Skov. 26. Havknude. 27. Katholm. 28. Hessel Hede. 29. Fornæs. 30. Sangstrup Klint. 31. Karleby Klint. 32. Gerrild Klint. 33. Knudshoved. 34. Stavnshoved. 35. Bönnerupstrand. 36. Hevring Hede.

Hede = moor. Hoved = cape, point. Klint = cliff. Skov = wood. Sö = lake. Vig. = bay. ö = island.

forming a curve of equilibrium. Supposed the inlet of the bay is narrow, there is a tendency for the bay to develop a half-circled coastline. Probably this is the case of Lulworth Cove, Dorset, and of Æbeltoft Vig too. The inlet of the latter seems to be too wide to make the explanation valid; however it is in fact greatly narrowed by the presence of a low-water area, which excludes all waves of larger magnitude.

The east coast of Djursland differs in total from the coasts already treated. *Jærnhatten* (i. e. the »Iron-hat«, an old fashioned helmet) is a morainic cliff developed by strong wave-power. The large fetch from east results in a DR from that direction. A small truncated foreland is situated in front of the cliff (fig. 2). Eventually the form of this can be explained by splitting the DR in two composants. These will be orthogonals to each of the two sides of the foreland. The sides of the foreland can then be regarded as equilibrium coasts. Of course the splitting is only allowable if the two sides are individual coasts; this can be the case if the bottom really indicates a diversion in this place. In fact the problem of cuspate forelands is still not definitely solved (the »Dungenessproblem«).

The magnitude of DR by *Havknude* and especially by the cliffs of *Sangstrup* and *Gerrild* shows a maximum for the region treated in this work. In spite of this the coastline around the points mentioned is far from the straightline-form developed by Örby. The cause of this is a resistance against abrasion of the east coast which by far exeeds that of the average moraine-coast. In the case of Jærnhatten the resistance was conditioned by the large amount of wave-work required to move the masses of material concentrated in the cliff and in the bottom before it. Farther to the north, the cliffs are not solely consisting of glacial deposits, but are fundamented on »limsten« (a limestone belonging to the Cretacious system). Because of the varying resistance against erosion, the east coast of Djursland has developed the characteristic »festoon«-form.

The north coast has no reinforcements of limestone and is for the larger part built up by accumulation of beach-material. This is why the coastline by *Bönnerup* in spite of its smaller DR-values is made far more straight-lined than was the east coast. On account of the beach-drifting — as indicated by the DR from the east — a small harbour by Bönnerup is built according to the »island«-principle.

Calculations of wave-power of the north coast are impeded by the distribution of the fetch. Fetch of significance are found in only few directions, but in those cases they are far larger (300 km.) than is usually seen in inner waters. The difficulty by so large fetches is, that the material of observations does not show if an observed windforce is accompanied by the correlated maximum height of waves (or of wave-energy). With a small fetch the problem is not overwhelming, because of the observation-frequency, which is 4 hours. In 4 hours lesser windforces will over a small fetch be able to raise maximum wave-height. Evidently, this can not be expected, when the fetch is 300 km. Wave-power must therefore by Bönnerup by a conservative estimate be about 1200-1500 »units«. Incidentally one is from the wind-observation tables mystified by the relatively frequent winds of force 10. The explanation of their abundance must be the human tendency to prefer »easy numbers«.

Four factors seem to determine the development of coasts: 1) the initial form, 2) the structure of the coast (mass of material, kind of material and grain-size), 3) wave-power and 4) vertical movements of coast.

The importance of the initial form is clearly seen by comparing the coastline of Strands by that of Örby. Though identical in regard of most things their initial forms make them so different, that the former is a young coast, while the other has reached maturity.

Effect of difference in structure is easily seen from the fact, that the eastern coasts of Djursland have not yet reached maturity as has the Örby coast. Limestone seems to exert a resistance against abrasion at least 3-4 times as great as boulder-clay. By comparing the two coasts it must however be noticed, that they differ in length. The length of a mature coast can under certain conditions be regarded as an expression of stage in development — or in many cases being almost the same, an expression of the available wave-power.

Vertical movements seem to be of no importance in the region concerned. From measurements the north coast is seen to rise, the south coast to be sinking. When differences in initial forms are considered, this statement cannot be drawn from the morphology. Effects of the very slow vertical movements are at Danish coasts at least by no means dominating the fast work of waves on the loose deposits. By this reason systematics of Danish coasts cannot be based on the Davis-Johnson system. Generally the principle of Gulliver seems to be more fit.

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