SEISMIC ZONATION OF THE SOUTH-WESTERN PART OF KANTO PLAIN, JAPAN, BASED ON GEOMORPHOLOGICAL ANALYSIS

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SUMMARY

Based on geomorphological expertise, we present a seismic microzonation of the South-Western part of the Kanto Plain, Japan, which contains such densely populated areas as Kawasaki and Yokohama cities. Preliminary zonation, based on morphotectonical analysis, independently depicts the subsurface structure of the territory and can serve as a framework for further geotechnical surveys. By applying this technique on a few tens of kilometres wide area, we go "from relief to structure" and reconstruct possible (likely) geological structure. We carry out consequent operations for morphotectonical reconstruction and verify the ongoing geomorphological hypothesis about geological composition and tectonics of the analyzed territory. Such a cost-effective analysis can be performed for poorly studied areas with integrity and accuracy unattainable by other methods, even without access to mining and drilling information. Resulting resolution exceeds by at least one order of magnitude that of earlier reported seismic zonation attempts on a comparable scale. In this study, the Earth's surface was divided into a number of simplest morphologic structures – blocks – naturally defined polygons of various shape and dimension. To verify the proposed microzonation scheme, we superimposed the recorded earthquakes' epicentres on the map, representing a blocks structure. For the first time, excellent correlation between earthquakes prone locations – especially those of near-field zone – and the suggested seismic microzonation scheme was achieved, thus showing the appropriateness of our methodology. We believe that development of this technique for the needs of earthquake engineering may lead to a tremendous advance in seismicity studies, as morphotectonical analysis can provide invaluable information on three-dimensional subsurface geological structure, crucial in a wide array of applications ranging from infrastructure planning and disasters prevention. In addition it effectively addresses the fundamental issues of Earth's surface evolution.

INTRODUCTION

The last few decades have seen a continuous effort by researchers worldwide towards mitigating hazards. Pursuing a proper seismic zonation for the specified areas has became a topical issue. Gradually, the natural role of geomorphology, a discipline dealing with forming and developing of the Earth relief as a result of endogenous (internal) and exogenous forces acting on its surface, has largely been superseded by geophysical methods. Use of air photos and satellite images to seek for oil and minerals, which used to be an interesting geomorphic activity, has been dropped in favour of direct drilling and making use of mining information.

On the other hand, the rapid development of information technology brought about the Geographic Information System (GIS), remote sensing and workstations capable of 3-D modelling has made the gap between the abandoned enthusiasm of geomorphologists during the 1960's and the current technology driven state of the things become more and more apparent. Geomorphic studies, not numerically constraining landform evolution processes, are currently seen as out-dated, or at least not looked upon favourably. Meanwhile, employing even such advanced tools as Global Positioning System (GPS) geodesy does not solve centuries old fundamental problems of Earth's

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surface evolution, especially concerning tectonic processes operating in plate interiors and associated landforms. The currently dominant model of plate tectonics fails to describe about 15% of Earth's surface covered with deforming lithosphere (for reference , see for example [Gordon and Stein, 1992]). In recent years, high-precision measurements of GPS geodesy has triggered the emergence of various multiple-microplate models for regions – considered to be within wide plate boundaries – in an attempt to compensate this existing gap in Geosciences fundamentals.

Active faults, being under intense study in Japan for a long time, are considered to restrict the border of plains and basins, tending to be in accordance with large-scale geomorphological boundaries between mountains and basins, mountains and plains, and hills and planes [Yamazaki, 1996]. Such an interrelationship is generally accepted worldwide, and the subject was exhaustively covered in the literature by distinguished authors [Summerfield, 1991]. Our particular interest lays in further delineation of the morphostructures beyond that associated with active faults, which resembles the above-mentioned multiple-microplate modelling attempts. The approach reported here is primarily based on geomorphological expertise.

During the last 50 years, extensive material, exposing various relations between geomorphological forms and tectonical structures, has already being accumulated, especially by research groups in Russia and Eastern Europe. There are various methodologies to reveal such interdependencies. One of them, that of MorphotectonicalAnalysis, was employed in the present study, where we present factual material to demonstrate the correlation between the densely occurring earthquakes in tectonically active region, located on the junction of three tectonic plates, and suggested seismic microzonation scheme. Unique availability of the earthquakes hypocentres data, commercially available from Japan Meteorological Agency, enabled us to verify a proposed microzonation scheme, by superimposing the recorded earthquakes' epicentres with the map, representing a block structure of a region.

PRINCIPLE

The technique of Morphotectonical Analysis, of particular importance to this study, is rooted on the investigations of various schools of geomorphology in the former USSR. It was notably in the laboratory of mathematical modelling of Moscow State University Geographical Faculty, that this technique was in the focus. With well-known strength in mathematical sciences in Russia, the procedures of creating relevant morphometrical maps of the block structure were thoroughly analyzed by employing mathematical statistics and probabilities theory, linear algebra, analytical geometry, as well as other disciplines of advanced mathematics along with heavy calculations [Simonov, 1998]. Nonetheless, the procedure of morphotectonical blocks delineation itself, remains very much artwork, and can be performed only by the expert-geomorphologist with a sound background in Geosciences and adequate training in graphoanalytic techniques, cartography, etc.

Once the sketch of the block structure is completed, algorithms dealing with the outlined objects can be employed to further process the geomorphological hypothesis. Step by step, various factors such as hipsometry, drainage network, slope angles, erosion processes, rocks denudation and so on are included, depending on the input data available. Generally speaking, such analysis can be performed having only high resolution maps and aerial photographs. However, field checks are highly desirable before the final conclusions can be made. Additional data can be very helpful but is not crucial.

By applying morphotectonical analysis on a tectonically inhomogeneous region, one goes "from relief to structure" and reconstructs possible (likely) geological structure. We carry out consequent operations for morphotectonical reconstruction and verify the ongoing geomorphological hypothesis about geological structure and tectonics of the analyzed territory. Compared to conventional procedures of microzonation [ISSMFEE(TC4), 1993] - where region is divided into small size square segments - Morphotectonical Analysis allows such subdivision to be naturally predetermined by the subsurface structure. Taking into consideration various input layers as topography and drainage patterns, the inspected area is subdivided on morphotectonic blocks - the simplest morphologic structures. These elementary units are separated amongst themselves by fracture planes or zones - surfaces across which the material has lost cohesion. When a fracture is associated with faulting, the blocks may exhibit relative motion: i.e. they may undergo uplifting, subsidence and bending over. Simultaneous horizontal movements may occur too. The block limiting fracture zone may have different depths, as can be predicted after peculiar analysis of block's morphometry is completed. A number of blocks may form mesoblocks, with the dimensions comparable to those of the "microplates" in recently appearing multiple-microplate models mentioned above. Again, we would like to emphasis that our modelling is based on naturally predetermined elements, in comparison to those tailored through heavy computations.

PROPOSED MICROZONATION SCHEME

We applied this new geomorphic approach to provide a first step seismic microzonation, which independently depicts the neotectonical structure of the territory and can be used as a basis for further geotechnical surveys, isotope tracing, GPS interferometry for monitoring crustal movements, and so on.

Numerous attempts of subsurface structure modelling have been reported to tackle the problems associated with earthquake-resistant design and infrastructure planning. These require a clear picture of ground motion distribution in different locations. Site effects within sedimentary basins present one of the major obstacles in a seismic risk assessment as they seriously affect experimental determination of seismic waves propagation. Instrumental solutions target increasing site specific signal to noise ratio with further spectra analysis. Numerical simulation models tailor seismic wave propagation to the varying soil properties of the area in order to solve the differential equation matching vibrational characteristics for the specified area. As a rule, adequate accuracy in such investigations requires computational time far beyond the capacity of modern workstations. Therefore new approaches are needed to significantly reduce computational time by making search spaces narrower. Besides targeting detailed microzonation, the proposed study aims to shorten the existing gap between the numerical simulations of the ground motion and measured seismograms in the presence of three-dimensional irregularities of a region with deep sediments.

Assuming that our naturally defined mosaic zonation scheme represents the blocks – possessing certain degrees of freedom and relatively loosely moving in relation to each other – one can expect that seismic wave propagation is strongly affected by the block positioning and geometry. Namely, the blocks' boundaries should exhibit the path similar to that of conducting electrodes for electricity. As a result, ground motion, induced by earthquakes in the proximity of well identified plate junctions, should preserve a high devastating energy considerably far from the sites along the known active faults. It would eventually explain the fact that several destructive earthquakes, occured at shallow locations on land, not corresponding to known active faults. Moreover, high-magnitude earthquakes sometimes occur even outside the active fault zone (for reference , see for example, [Earthquake Research Committee, Government of Japan, 1998]). (It should be noted in passing that there has been an earlier attempt to employ GPS Interferometry and tide gauge station data for evaluation of the coastal movements in the specific sites, considering the proposed block structure of the territory [Polonska *et. al.*, 1997]. Observed movements of the upper layers of the Earth's crust did not coincide with those estimated earlier employing plate tectonics model. Measurements have shown that the vertical movement between the relevant morphotectonic blocks is superior to the expected displacement caused by tectonic plates movement.)

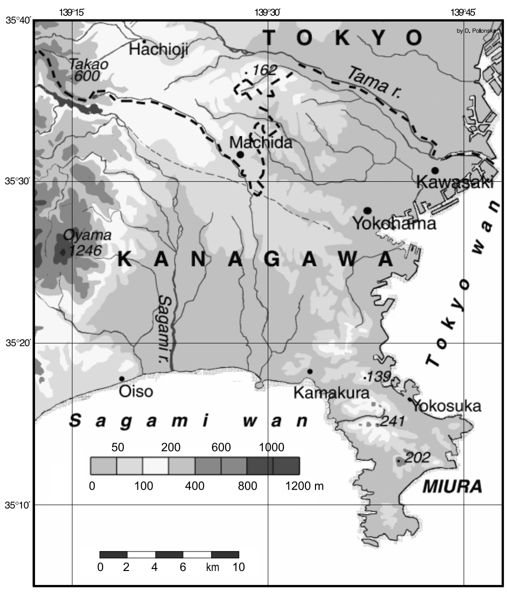

Figure 1: Hipsometric map of a chosen for investigations area. The South-Western part of the Kanto plane (mainly Kanagawa prefecture) contains many densely populated locations, such as Kawasaki, Yokohama and parts of Tokyo.

RESULTS AND DISCUSSION

The territory under investigation is shown on Fig. 1, which also reflects the hipsometry of a region. A chosen area of the South-Western part of the Kanto plane (mainly Kanagawa prefecture) contains many densely populated locations, such as Kawasaki, Yokohama and parts of Tokyo. With the highest point of the map being about 1250 m above the sea level, most of the territory lays below 100 m mark.

Figure 2 demonstrates the block structure of a chosen area, with the epicentres of the earthquakes, occurring between 1926 and 1998. Less accurate data earlier than 1960 comprises less than 20% of all the points. (Inset shows the area's location with a wider outlook, as well as neotectonic features of the Kanto Plain and vicinities – according to the map, published by Geological Survey of Japan). We have to mention that to create this map, it was necessary to cover a larger area, approximately 200 km x 300 km wide, in order to define the initial contours for the analysis. The finer the scale of the maps, used for the analysis, the finer the subdivision of the surface. Consequently, some of the blocks may be subdivided even further, subject to higher resolution input data. This dependence on the resolution of input layers along with the necessity of checking further geomorphological hypothesis about the subsurface structure of the region, explains why some of the points are located significantly far from the blocks contours. We believe that this is only a technical problem of the input data acquisition and quality of the maps used, rather than that of methodology applied. In our case, to process the necessary input layers, we were using not only modern 1 : 200 000 maps, commercially available from Geographic Survey of Japan with the mutual inaccuracies exceeding that of our contouring, but also decades old maps (1 : 200 000), compiled before the total urbanization of the area. For verification purposes, primarily 1 : 100 000 scale maps were utilized. Despite all sorts of technical problems, we succeeded in performing the analysis to the satisfactory level of differentiating local discrepancies in ground conditions, as can be seen from the figures presented herein.

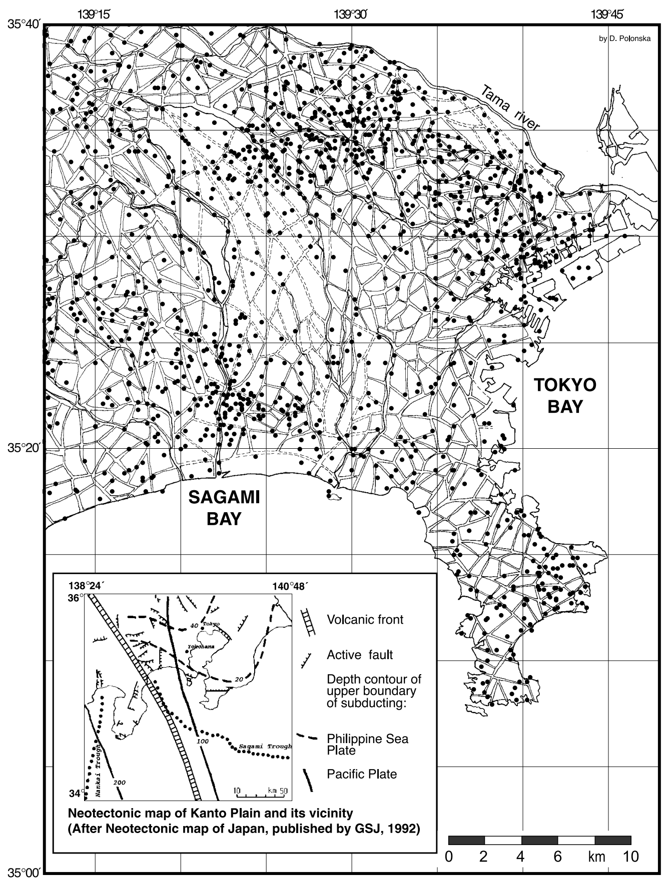

Figure 2: Block division and seismicity of the South-Western part of the Kanto plane. Earthquakes' epicentres occurred during the period between 1926 and 1998 are superimposed on the map, representing a block structure of the area. (Hypocentres' depth varies between 0 and ~ 170 km). Inset shows the area's location on a wider view, as well as known neotectonic features of the Kanto Plain and vicinities. Solid lines: well defined block division boundaries. Broken lines: inferred block division lines.

According to the fundamentals of the seismicity studies, an earthquake does not occur at a specific point, but is generated over a wide planar surface. It is especially so for shallow, or near-field earthquakes as depicted on Fig.3, where epicentres are grouped according to the hypocentres depth. Despite the fact that the definition of the point source supposedly has even less meaning for near-field zone cases, the striking correlation between the epicentres location and a proposed block structure of the region is readily apparent. Due to space restrictions for the manuscripts, we do not present here the 3-D projections of the deeper earthquakes occurring within the territory of our interest, as our main topic here is the proposed microzonation scheme, based on Morphotectonical Analysis. We will just mention that the relevant correlation between the proposed block structure and the deeper earthquakes hypocentres is also in place and can be the subject of a separate study involving more detailed elaboration.

Earlier studies (see, for example, [Kasahara, 1985]) of the relative movement of the Philippine Sea, Pacific and Eurasian plates on the basis of the distribution of hypocentres and seismic data on waves propagation suggest that the earthquakes with the epicentres on Fig.3 are essentially intraplate ones [Ishida, 1992]. According to the author, the depth of the upper surface of the Philippine Sea Plate slab, lays within the range of ~ 40 km for the Northern part of a chosen region, and ~ 10 km for the Southern part. Therefore, epicentres' positioning correspondence to outlined blocks structure may point only to the deep interrelationship between the former and intrinsic characteristics of the latter.

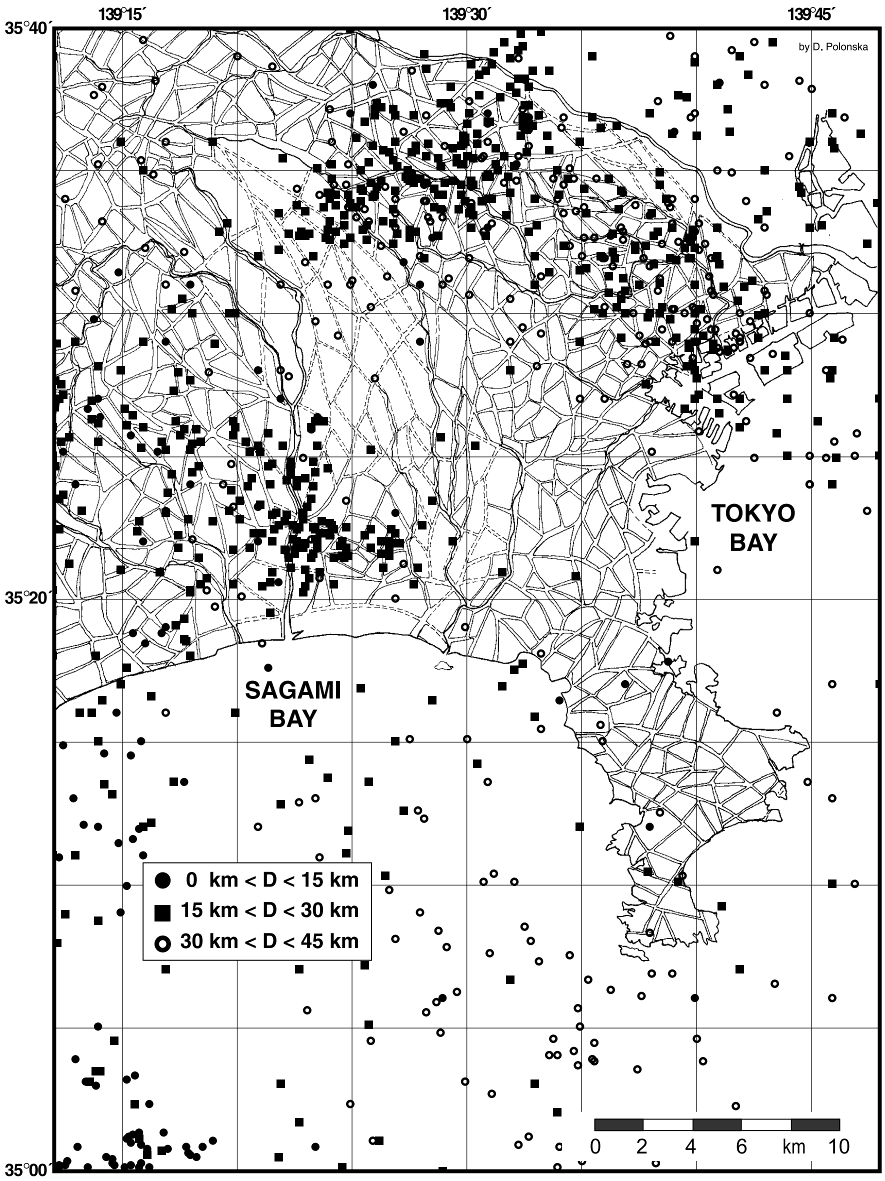

Figure 3: Block division of the South-Western part of the Kanto plane and epicentral distribution of shallow earthquakes (with the depth down to 45 km, and earthquakes' magnitude between 0 and ~ 5) occurred during the period between 1926 and 1998.

Figure 4 illustrates the analysis of the blocks' highest points, resulting in an idealized model of the "keyboard tectonics" of the territory. Under the respective geomorphological hypothesis, the real relief is replaced with the block model. Analysis of this map enables to determine the structural character of all the block borders – gaping faults and normal faults with the small displacement. It is thus manifested in clear contrasting combinations.

The idea that it is very wrong to assume the places on the fault trace lines are the most dangerous disregarding the regional difference in ground condition was strengthen in [Yamazaki, 1996]. This author put an emphasis on the necessity of opening information on active faults and promoting awareness of the public on these matters, alternatively to the independent profit system pursued by the construction companies. Yet, it is recognized (for reference, see the report on Seismic Activity in Japan, cited above) that, possibly, undiscovered active faults lie under the Kanto Plain.

Based on the maps created during the verification of the ongoing geomorphological hypotheses, we outlined the mesoblock structures, comprising smaller elementary blocks. The borders of the mesoblocks exhibit all the features to be considered as possible faults. Further detailed analysis will unveil the most probable traces of unrevealed seismic faults.

At this stage, there has been no experimental verification of our model. Introduced in Japan technique of microtremors measurements [Seo, 1998, 1995, 1994] is one candidate for such a verification. In addition, apart from traditional geothechnical techniques, the best way to verify the suggested scheme is the use of high-precision technologies such as GPS geodesy. Nowadays, with the huge array of more than one thousand GPS receivers in Japan, deployed

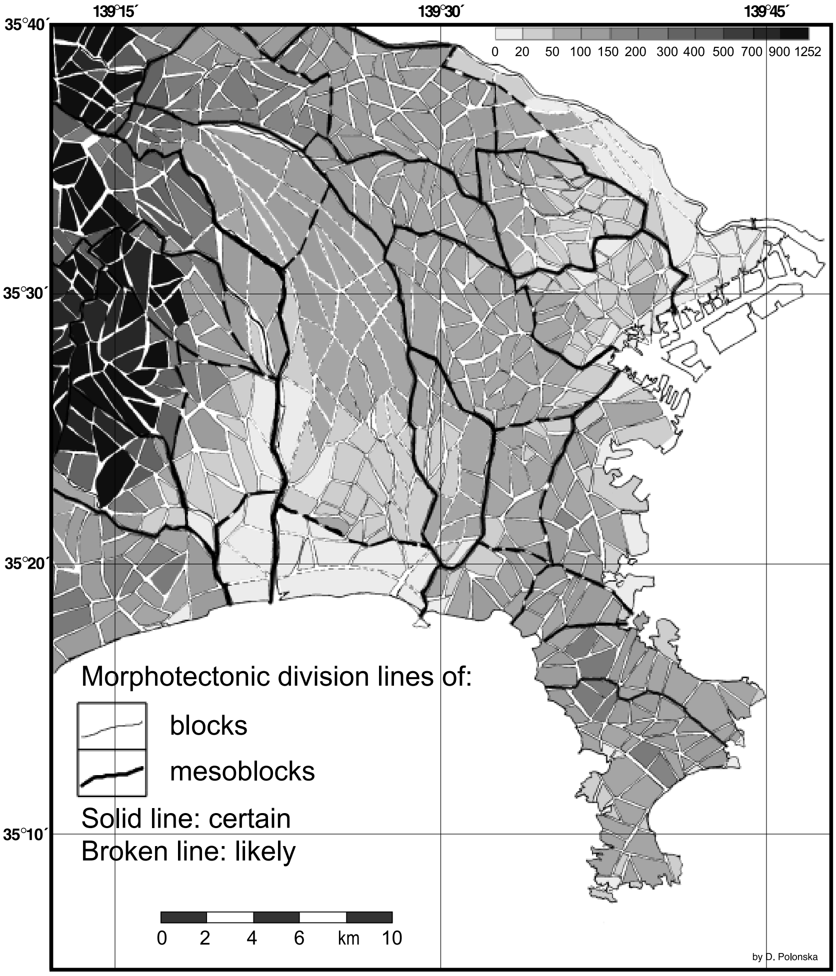

Figure 4: Model of the morphotectonical zonality of the South-Western part of Kanto plane based on preliminary morphometric analysis of the morphotectonic blocks. The block setting is analyzed according to the absolute heights of the blocks' top surfaces. Thick solid lines represent the borders between mesoblocks, predetermined by the subsurface geological structures. These mesoblock division lines may serve as a key pattern for further geotechnical surveys, including mictrotremors measurements and GPS interferometry.

after the Kobe earthquake nationwide, it is more a problem of time for interested parties rather than that of funding and other considerations. Ideally, placing an array of GPS receivers within the boundaries of each individual block on the specified territory, would produce enough data to effectively address the issue. The scientific importance of such an experimental undertaking would have a tremendous impact among geoscientists, apart from opening up new perspectives in the domain of applied science and engineering.

CONCLUSION

Our claim is that the proposed seismic microzonation scheme, based on Morphotectonical Analysis, undercovers the possible traces of unrevealed seismic faults, not reported by the earlier researchers. Detailed analysis depicts not only the places with high probability of future direct damage of varying intensity - caused by seismic fault displacement - but also shows the most dangerous zones, situated far from the major seismic faults. This became possible due to the capacity of the applied analysis not only to reveal the possible fault trace lines, but also takes into the account localized discrepancies in ground conditions, directly related to a subsurface geological structure. Such a cost-effective analysis overcomes many of the limitations and uncertainties associated with other hazards assessment procedures. It thus may serve as a framework for further geotechnical surveys to verify the suggested traces of unrevealed faults. In addition, described here analysis may effectively address the fundamental issues of Earth's surface evolution, especially when used in conjunction with GPS geodesy.

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