Zeitschrift: Schweizerische mineralogische und petrographische Mitteilungen = Bulletin suisse de minéralogie et pétrographie

Band: 59 (1979)

Heft: 1-2

Artikel: Recent activities in gravimetry and physical geodesy

Autor: Kahle, H.-G. / Kingelé, E.

DOI: https://doi.org/10.5169/seals-46061

Schweiz. mineral. petrogr. Mitt. 59, 207-217, 1979

Swiss National Committee for the International Geodynamics Project
Working Group 14: Gravity

Recent Activities in Gravimetry and Physical Geodesy

Report by *H.-G. Kahle*)* and *E. Klingelé**)*

1. Gravity Studies and Dynamics of the Swiss Alps

1.1 THE NEW GRAVITY MAP OF SWITZERLAND

The main experimental gravimetric activities carried out in Switzerland during the period 1971-1979 have been devoted to the completion of a new Bouguer gravity map of the country (KLINGELÉ and OLIVIER, 1979). The positions of the 2019 new gravity stations are shown in Fig. 1a. On an average, Switzerland is now covered by 1 gravity station per 20 km^2. The compilation of the new map was achieved through a joint research project of the Geophysical Institutes of the Swiss Federal Institute of Technology (ETH Zürich) and of the University of Lausanne. The project has been sponsored and financed by the Swiss Geophysical Commission - a subsidiary of the Swiss Academy of Sciences. The instruments which were utilized in the survey were LaCoste and Romberg model G and D gravimeters. In addition to the Swiss first-order gravity net a control net has been established. The resulting gravity values are estimated to have an accuracy better than ± 0.38 mgal in the Alpine area and ± 0.20 mgal in the Swiss Molasse basin. The Bouguer anomaly map is presented in Fig. 1b (KLINGELÉ and OLIVIER, 1979). A constant reduction density of 2.67 gcm^{-3} has been used for the topographic reduction. In addition to Bouguer corrections isostatic reductions have also been calculated. An isostatic anomaly map for Switzerland will be published in the near future (KLINGELÉ, 1979).

1.2 RECENT DYNAMICS, CRUSTAL STRUCTURE AND GRAVITY ANOMALIES IN THE ALPS

The gravity anomalies (Bouguer and isostatic) for the mountainous part of the country have been presented by KAHLE et al. (1979). They described the recent Alpine crustal dynamics in terms of crustal structure and attempted to

*) Institut für Geodäsie und Photogrammetrie, ETH-Hönggerberg, CH-8093 Zürich
**) Institute of Geophysics, ETH-Hönggerberg, CH-8093 Zurich (Switzerland)

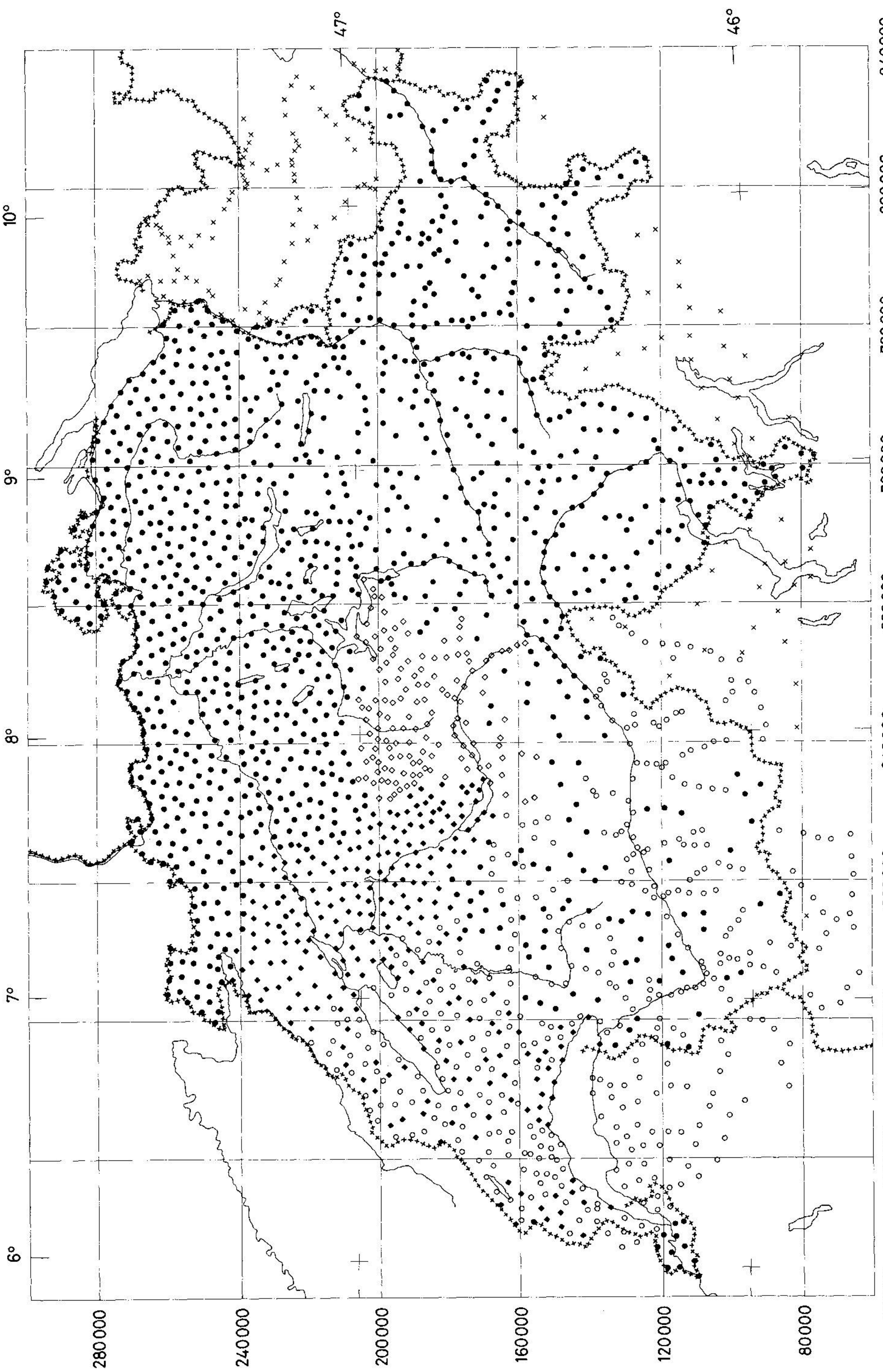


Fig. 1a Locations of gravity stations. ● □ LCR 317 {Zürich, Lausanne} ■ = LCR 369, ○ = Worden 805, × = Italian and Austrian Stations.

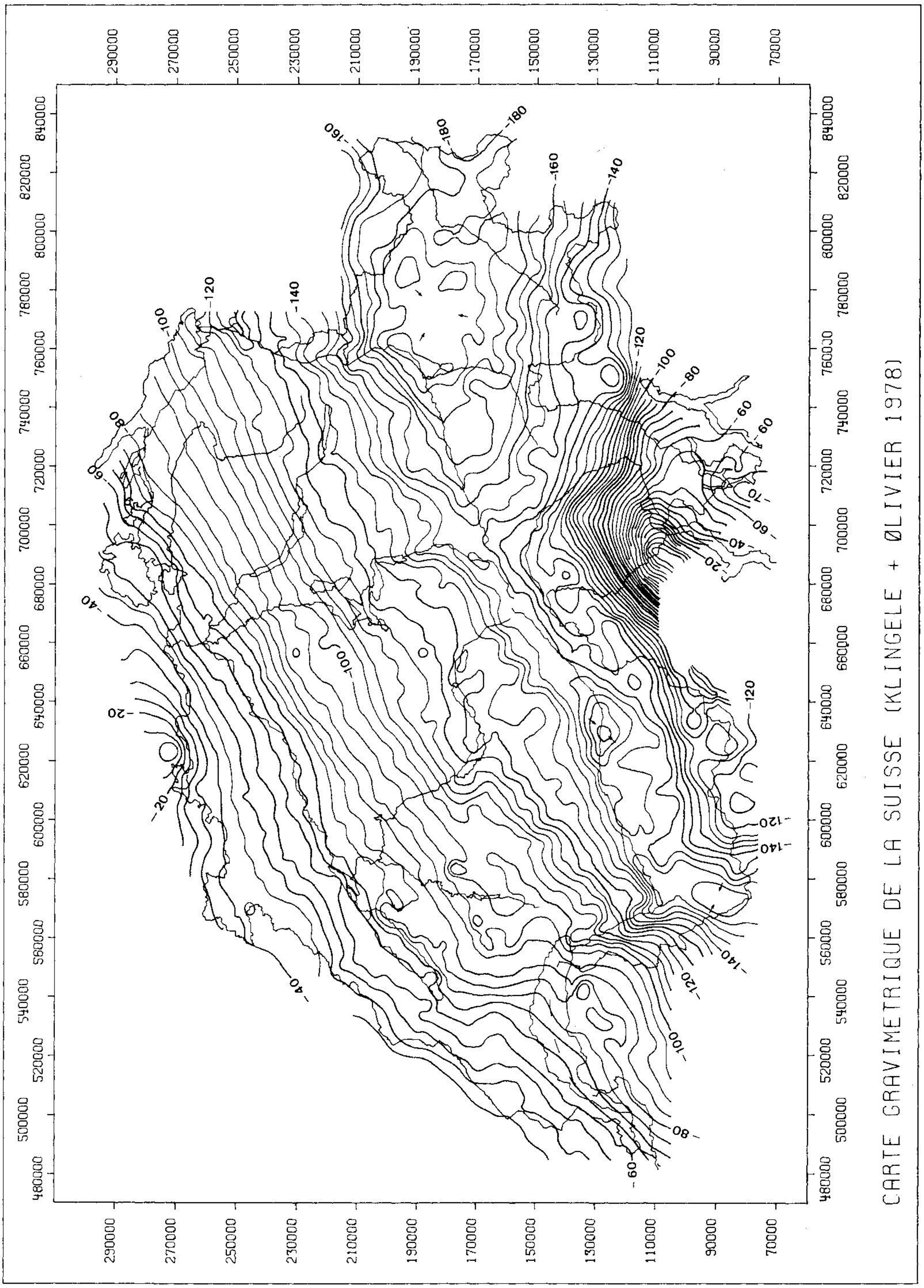


Fig. 1 b Gravimetric map of Switzerland (KLINGELE & OLIVIER 1978).

explain the present-day kinematics of the Alps within the framework of plate tectonics. From the isostatic anomaly pattern in the cantons Graubünden (GR) and Valais (VS) it is seen that the area of high uplift near Chur is clearly associated with negative isostatic anomalies reaching a minimum of −48 mgal located precisely in the area where the highest uplift rates of 1.7 mm/year (GUBLER, 1976) are observed (Fig. 2). Moreover, it is interesting to note that the uplift rate is almost linearly increasing from Andermatt to Chur whereas the isostatic anomalies are linearly decreasing from −15 to −48 mgal. This fact in itself may be considered as evidence that the uplift is controlled by isostatic rebound effects. A similar correlation is seen in the canton Valais. The complex structure of the high-density Ivrea zone associated with considerable positive

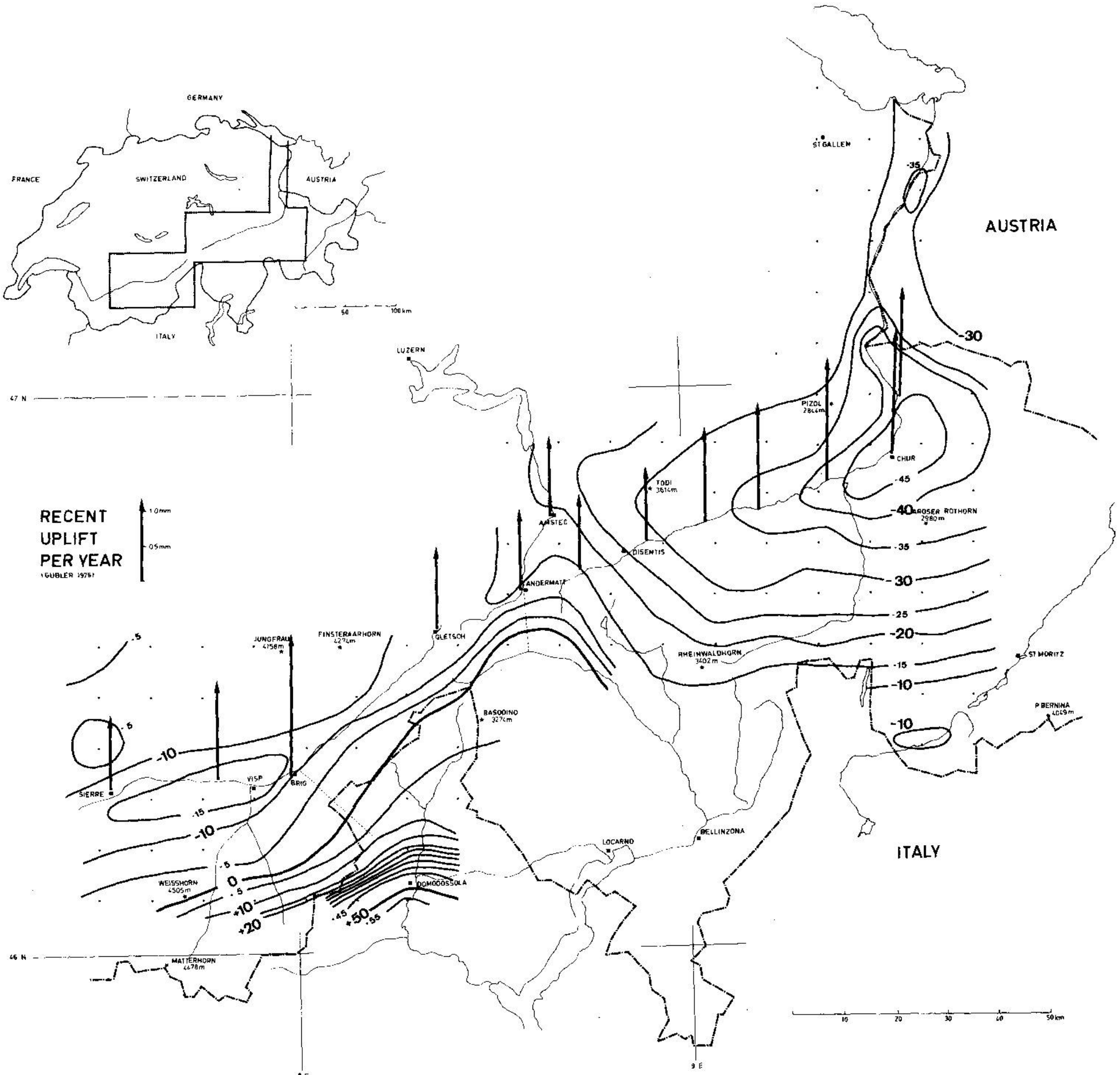


Fig. 2 Regional isostatic anomalies (mgal) (KLINGELE, 1979; KAHLE et al., 1979). Recent uplift rates after GUBLER (1976).

edge effects, however, seems to mask the isostatic low such that "only" −15 mgal are reached near Brig/Visp. Taking the edge effects of the Ivrea body into account this low would also decrease to values of at least −30 mgal. At present the gravity effects of the Ivrea body are measured and studied in great detail by KISSLING in order to clarify this matter.

1.3 GRAVITY TRAVERSES AND LOCAL STUDIES OF THE GRAVITY FIELD IN SWITZERLAND AND ADJACENT AREAS

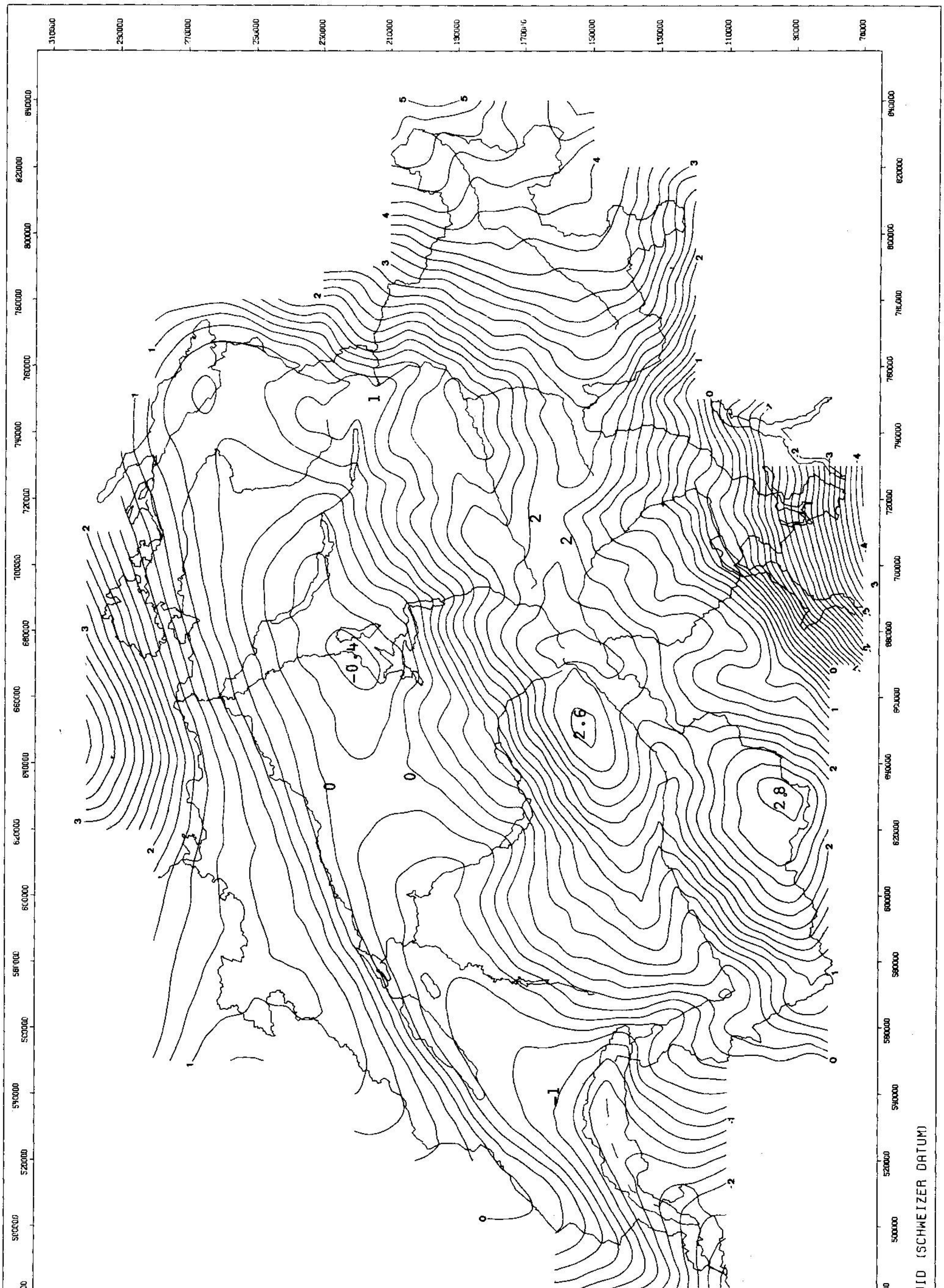
Several detailed gravity traverses across the Swiss Alps were observed to investigate the anomalies associated with crustal structure and the relief of the Mohorovicic (M-) discontinuity (KAHLE et al., 1976a, b, 1979). Special emphasis has been placed on deducing density models concordant with current seismic information (MUELLER et al., 1976). Near-surface features, such as basement morphology and varying thickness of Alpine glaciers have been studied by KLINGELE and KAHLE (1977, 1978). Further gravimetric work on shallow mass distributions has been performed in western Switzerland (OLIVIER, 1974; BUECHLI et al., 1976).

1.4 GEOID DETERMINATION IN SWITZERLAND

In the past 4 years extensive studies have been made to compute the geoid in Switzerland (WASSOUF, 1975; ELMIGER, 1975a, b). In a most recent publication GURTNER (1978a, b, c) obtained an improved geoid (Fig. 3) by introducing a cogeoid related to a crustal mass model concordant with gravimetric and seismic information (KAHLE et al., 1976a, b; MUELLER et al., 1976). This mass model included topography, the relief of the crust-mantle boundary and the anomalous Ivrea body. The cogeoid was calculated by means of multivariate prediction. According to GURTNER (1978c) the standard error of the resulting geoidal heights has been reduced to less than 10 cm.

2. Geodynamics of Rift Systems

KAHLE and WERNER studied interrelationships between gravity and temperature anomalies in the northern Central Indian basin (1975), in the vicinity of the Rhinegraben rift system of Central Europe (1979) and the Gulf of Aden. They presented evidence that sizable density and gravity anomalies are associated with the transient temperature field behind drifting continental plates and with hot rising mantle material in rift systems, such as the Rhinegraben (WERNER and KAHLE, 1979). Kinematic models for the evolution of the Rhinegraben and Gulf of Aden were constructed concordant with all geophysical informations being available at present.



Values in metres
Contour interval 0.2 m.

Fig. 3 Geoid (Swiss Datum) (GURTNER, 1978)

3. Geodynamic studies in the Indian Ocean

3.1 FREE-AIR GRAVITY MAPS OF THE INDIAN OCEAN

In the past 15 years the gravity coverage in the Indian Ocean has been considerably increased by means of continuous gravity measurements obtained aboard surface ships. Based on all gravity data acquired during the International Indian Ocean Expedition and measured during Lamont cruises TALWANI and KAHLE (1975) compiled free-air gravity maps for the entire Indian Ocean. At present these anomalies are being interpreted in terms of density inhomogeneities and kinematic models associated with the Central Indian Ridge system and with the subduction zones of the Indonesian deep-sea trenches.

3.2 INDIAN OCEAN GEOID

On the basis of the free-air anomalies published by TALWANI and KAHLE (1975) in the International Indian Ocean Atlas of Geology and Geophysics and

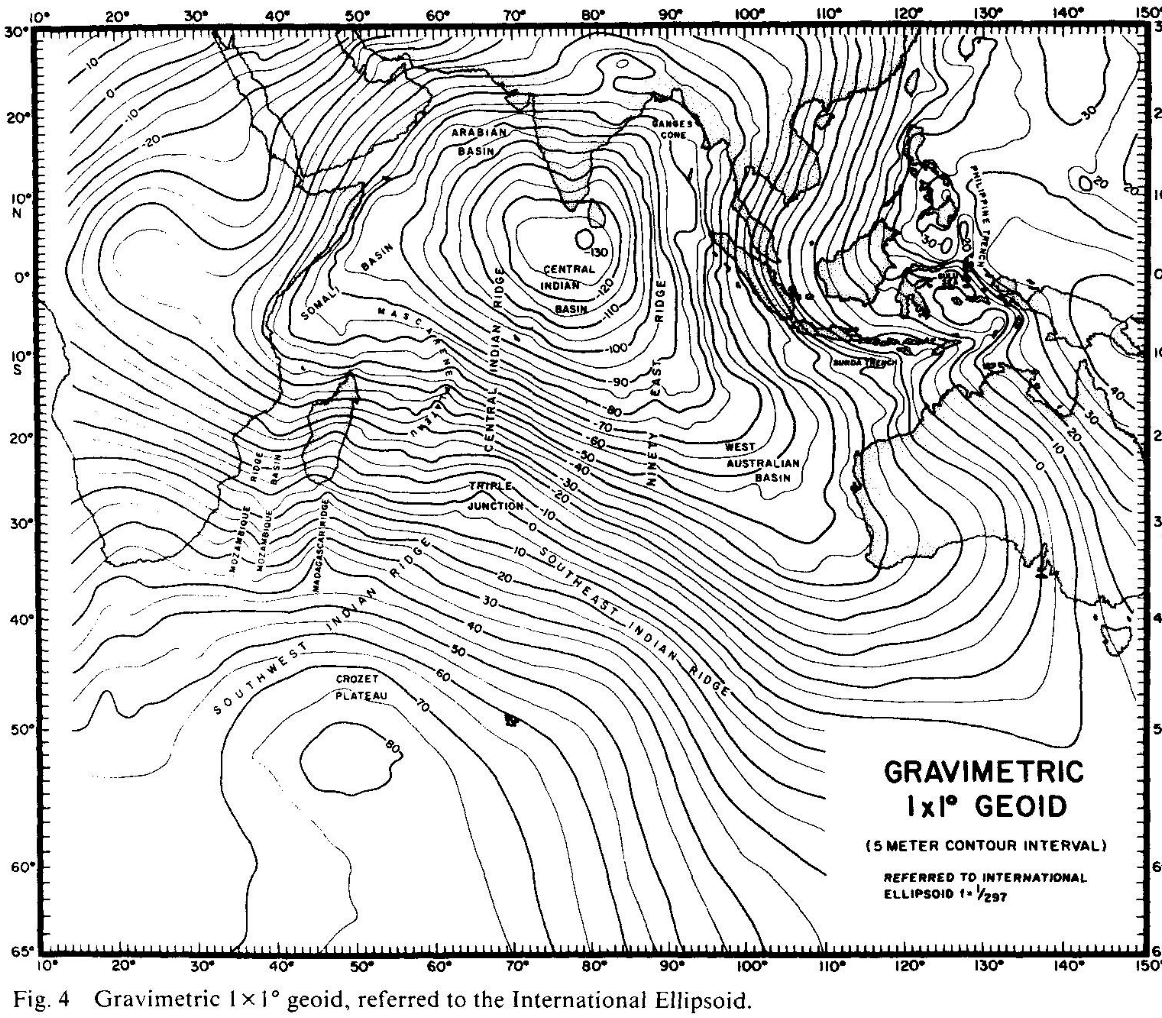


Fig. 4 Gravimetric 1×1° geoid, referred to the International Ellipsoid.

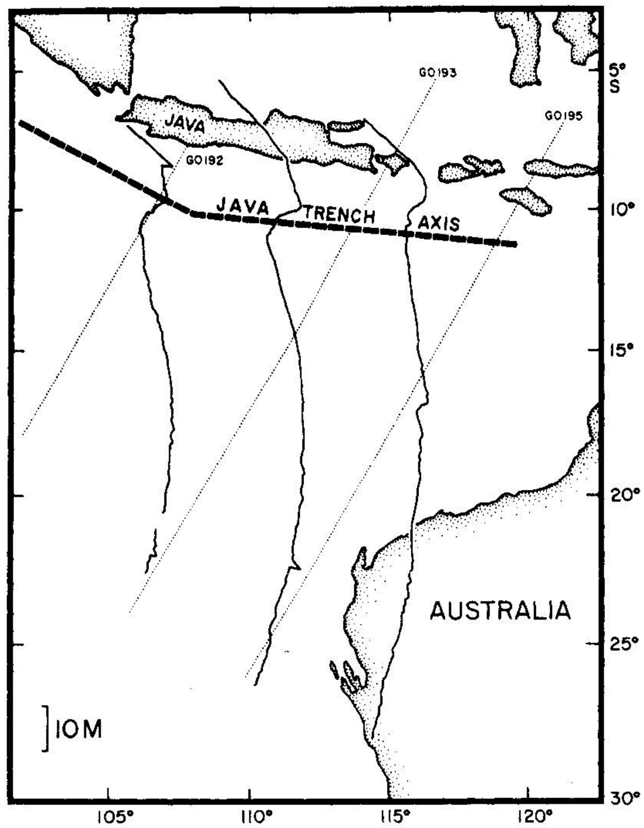


Fig. 5 GEOS-3 profiles in the Indonesian Island Arc region. Subsatellite track is dotted line, track designation (e.g. G0193) is at start of the pass. Geoid height is plotted perpendicular to track, positive values are northwards and the scale is indicated. An arbitrary constant was removed from each track.

including most recent gravity data, 1°×1° mean free-air values were computed for the entire Indian Ocean. These data were then used to compute the gravimetric Indian Ocean geoid (KAHLE and TALWANI, 1973 a, b; KAHLE, CHAPMAN and TALWANI, 1978) (Fig. 4). Comparisons have been made with GEOS-3 (Geodetic Earth Orbiting Satellite-3) data in selected areas of the Indian Ocean, such as the Indonesian deep-sea trenches (Fig. 5) and the SW Indian Ridge (Fig. 6). Possible causes for the detected geoidal undulations have been discussed. Special attention is paid to lateral variations of the depth to the Olivine - Spinel transition zone. These activites are due to a joint project of Lamont-Doherty Geological Observatory of Columbia University, Palisades (New York), and the Institute of Geophysics (ETH Zürich).

3.3 MARINE GRAVITY AND OCEANIC CRUSTAL STRUCTURE

In another joint Lamont/ETH project the continental margin structure south of India and west of Sri Lanka has been analyzed (KAHLE, NAINI, TALWANI and ELDHOLM, 1979). Free-air and isostatic anomalies as well as other marine geophysical data, such as seismic reflection and refraction measurements carried out in this are, revealed a prominent basement high (here named Comorin Ridge). From a comparison with other sheared margins it is suggested

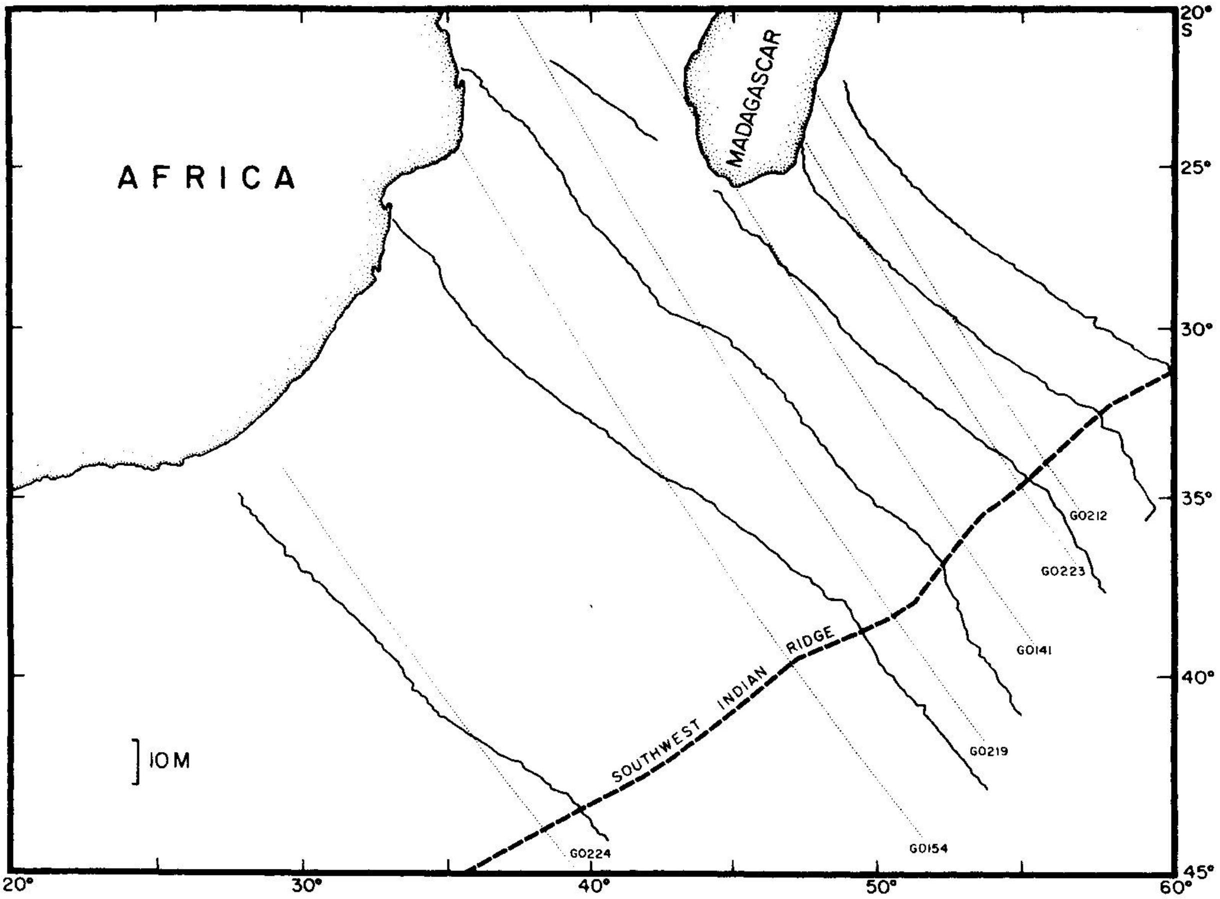


Fig. 6 GEOS-3 profiles in the Southwest Indian Ocean. Subsatellite track is dotted line, track designation (e.g. G0154) is at start of pass. Geoid height is plotted perpendicular to track, positive values are northwards and the scale is indicated. An arbitrary constant was removed from each track.

that this feature may mark the structural boundary between oceanic and "rifted" continental crust.

4. Secular Changes in Gravity and Special Techniques in Gravimetry

- Absolute gravity measurements have been carried out at 2 stations (Zürich and Chur) by MARSON and ALASIA with the mobile absolute gravity apparatus of "Istituto di Metrologia, Torino" as a basis for detecting secular changes in gravity as well as for the purpose of establishing high accuracy gravity calibration lines in Switzerland.
- Detailed high-precision gravity data have been obtained by the Institute of Geophysics, ETH Zürich, with the LaCoste and Romberg model D 16 gravimeter along the Fennoscandian gravity calibration line (KLINGELÉ and KAHLE, 1979) and in the Rhinegraben net-work (DEICHL et al., 1978).

5. Bibliography

BÜCHLI, H., PAQUIN, R. & A. DONZÉ (1976): Etude géoélectrique et gravimétrique du Chablais entre Anières et Evian. Mat. Géol. Suisse, Série Géophysique, no. 18, Kümmerly & Frey, Bern.

CHAPERON, F. (1972): Studien zur Ausgleichung des schweizerischen Schwerenetzes. Protokoll der 117. Sitzung der Schweiz. Geodätischen Kommission, p. 77-85, Kloten.

Commission géodésique suisse et Service topographique fédéral (1975): Rapport sur les Travaux géodésiques excécutés de 1971 à 1974. 3. Gravimétrie, p. 7-9, Kloten.

DEICHL, K., GROTEN, E., KAHLE, H.-G., KLINGELÉ, E., KIVINIEMI, A. & B. WEICHEL (1978): Precise gravimetry in the Rhinegraben net. Report to the International Gravity Commission, Paris.

DONZÉ, A. (1976): Etude gravimétrique du Chablais entre Anières et Evian. Thèse. Mat. Géol. Suisse, Série Géophysique, no. 18, Kümmerly & Frey, Bern.

ELMIGER, A. (1975a): Erste Ergebnisse einer Geoidbestimmung für die Schweiz aus astronomischen und interpolierten Lotabweichungen. Schweiz. Geodätische Kommission, 33 p., Zürich.

ELMIGER, A. (1975b): Das Geoid in der Schweiz. Schweiz. Z. für Vermessung, Photogrammetrie und Kulturtechnik, Fachblatt III/IV: 171-176.

FUCHS, K., ANSORGE, J., BONJER, K.-P., EMTER, D. & H.-G. KAHLE (1978): Lateral variation or anisotropy in the subcrustal lithosphere of the Rhinegraben: - Implications of velocity anomalies deduced from explosion and local earthquake data. Abstract 5th EGS-Meeting, Strasbourg.

GERSTENECKER, C. & E. GROTEN (1976): Messung der vertikalen Erdgezeitenkomponente in Mitteleuropa. In: Groten, E., Beiträge zur Gravimetrischen Geodäsie und Gezeitenforschung. Deutsche Geodätische Kommission, Reihe B, Heft Nr. 217, München, p. 49-55.

GERSTENECKER, C. (1978a): Erdgezeitenmessungen mit dem LaCoste-Romberg Erdgezeitengravimeter LCR-ET-16. In: Groten, E., Beiträge zur Physikalischen Geodäsie. Deutsche Geodätische Kommission, Reihe B, Heft Nr. 233, München, p. 87-95.

GERSTENECKER, C. (1978b): Zur physikalischen Interpretation von Messungen der vertikalen Erdgezeitenkomponente. In: Groten, E., Beiträge zur Physikalischen Geodäsie. Deutsche Geodätische Kommission, Reihe B, Heft Nr. 233, München, p. 96-106.

GUBLER, W. (1976): Beitrag des Landesnivellements zur Bestimmung vertikaler Krustenbewegungen in der Gotthard-Region. Schweiz. min. petr. Mitt., 56: 675-678.

GURTNER, W. (1978a): Das Geoid in der Schweiz. Astronomisch-geodätische Arbeiten in der Schweiz, 32, 103 pp, Bern. Editor: Swiss Geodetic Commission.

GURTNER, W. (1978b): Indirekte astrogeodätische Geoidbestimmung. Zeitschrift f. Vermessung, Photogrammetrie, Kulturtechnik, Heft Nr. 7.

GURTNER, W. (1978c): Indirect astrogeodetic determination of the geoid in Switzerland. Proceedings of the Int. Symp. on the geoid in Europe and Mediterranean area, Ancona. Società Italiana di Fotogrammetria e Topografia: 132-132.

KAHLE, H.-G. & M. TALWANI (1973a): Gravimetric Indian Ocean geoid. Z. Geophysik, 39, 167-187.

KAHLE, H.-G. & M. TALWANI (1973b): Nachtrag zur «Gravimetric Indian Ocean geoid». Z. Geophysik, 39, 491-499.

KAHLE, H.-G. (1975): Interpretation der Schwereanomalien im Indischen Ozean. Habilitationsschrift, ETH Zürich, 234 pp.

KAHLE, H.-G., KLINGELÉ, E. & ST. MÜLLER (1975): Zur Bedeutung der Schwerereduktion bei der Bestimmung der Figur und Massenverteilung der Erde. Zeitschrift f. Vermessung, Photogrammetrie, Kulturtechnik, III/IV, 157-162.

KAHLE, H.-G. & D. WERNER (1975): Gravity and temperature anomalies in the wake of drifting continents. Tectonophysics, 29, 487-504.

KAHLE, H.-G. (1976): Zur Ursache von globalen Schwereanomaline. Verh. Schweiz. Naturforsch. Ges., 134-138.

KAHLE, H.-G., KLINGELÉ, E., MÜLLER, ST. & R. EGLOFF (1976a): The variation of crustal thickness across the Swiss Alps based on gravity and explosion seismic data. Pure and Applied Geophysics, 114, 479-494.

KAHLE, H.-G., KLINGELÉ, E., MÜLLER, ST. & R. EGLOFF (1976b): Gravimetrie, Sprengseismik und Krustenmächtigkeit entlang der Schweizer Geotraverse. Schweiz. min. petr. Mitt., 56, 679-684.

KAHLE, H.-G., MÜLLER, ST. & E. KLINGELÉ (1978): National Report on gravimetric activities in Switzerland 1974-1978. IGC-Meeting, Paris.

KAHLE, H.-G., CHAPMAN, M. & M. TALWANI (1978): Detailed 1°×1° gravimetric Indian Ocean geoid and comparison with GEOS-3 Radar altimeter geoid profiles. Geophys. J. R. astr. Soc., 55: 703-720.

KAHLE, H.-G. & D. WERNER (1979): A geophysical study of the Reingraben. Part II: Gravity anomalies and geothermal implications. In press.

KAHLE, H.-G., MÜLLER, ST., KLINGELÉ, E., EGLOFF, R. & E. KISSLING (1979): Recent dynamics, crustal structure and gravity in the Alps. In: N. Mörner (ed.), Earth Rehology and Isostasy. John Wiley & Sons. In press.

KAHLE, H.-G., NAINI, B., TALWANI, M. & O. ELDHOLM (1979): Geophysical Study on the continental margin south of India and west of Sri Lanka. In press.

KLINGELÉ, E. (1972): Contribution à l'étude gravimétrique de la Suisse romande et des régions avoisinantes: Matériaux pour la géologie de la Suisse, série Géophysique, no. 15. Kümmerly & Frey, Bern.

KLINGELÉ, E. & H.-G. KAHLE (1977): Gravity profiling as a technique for determining the thickness of glacier ice. Pure and Appl. Geophysics, 989-998.

KLINGELÉ, E. & H.-G. KAHLE (1978): Prominent gravity anomalies in western Switzerland and possible models for the basement structure. In Symp. on "The Role of density". Aarhus (Denmark), Geoskrifter, 10: 95-110.

KLINGELÉ, E. & R. OLIVIER (1979): The new gravity map of Switzerland. In press. Matériaux pour la géologie de la Suisse, série Géophysique, no. 20. Kümmerly & Frey, Bern.

KLINGELÉ, E. (1979): Isostatic gravity anomalies in Switzerland. In press. Matériaux pour la géologie de la Suisse, série Géophysique. Kümmerly & Frey, Bern.

KLINGELÉ, E. & H.-G. KAHLE (1979): Assessment of secular gravity changes in Fennoscandia. Abstract XVII IUGG General Assembly, Canberra.

MÜLLER, ST., EGLOFF, R. & J. ANSORGE (1976): Die Struktur des tieferen Untergrundes entlang der schweizerischen Geotraverse. Schweiz. min. petr. Mitt., 56: 685-692.

OLIVIER, R. (1974): Elaboration d'un système de traitement gravimétrique géré par l'ordinateur (Etude gravimétrique du Plateau romand de Versoix [GE] à Concise [VD]). Mat. Géol. Suisse. Série Géophysique no. 17. Kümmerly & Frey, Bern.

PAVONI, N. (1973): A structural model for the San Andreas Fault zone along the Ne side of the Gabilan Range. In: Kovach and Amos (eds.), Proceedings of the Conference on tectonic problems of the San Andreas Fault System. Geol. Sc. Vol. XIII: 259-267.

SCHNEIDER, F. (1978): Nivellement und Schweremessungen am Gotthard. ETH Zürich, Institut für Geodäsie und Photogrammetrie, Bericht Nr. 17, Mai 1978.

TALWANI, M. & H.-G. KAHLE (1975): Free air gravity charts of the Indian Ocean. The atlas of geology and geophysics of the International Indian Ocean Expedition, Moscow, 85-106.

WASSOUF, Y. (1975): Contribution à l'étude des déviations de la verticale dans la région du Tessin et au nord-ouest de l'Italie. Doctoral Thesis. ETH Zürich.

WERNER, D. & H.-G. KAHLE (1979): A geophysical study of the Rheingraben. Part I: Kinematics and geothermics. In Press.

Manuscript received July 23, 1979