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Computer-aided evaluation of the major fracture pattern in Austria derived from Landsat Data

By MANFRED F. BUCHROITHNER*)

With 16 Figures, 3 Plates and 6 Appendices

Schlüsselwörter
Ost-Südalpen
Satellitenaufnahmen
Störungsmuster
Interpretation
Methodik

CONTENTS

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*) Author's Address: Österreichische Akademie der Wissenschaften, Institut für Kartographie, Abteilung für Satellitenkartographie, Bäckerstraße 20/III, A-1010 Vienna, Austria.

Zusammenfassung

Mit Hilfe der Computerprogramme DIGLIN, RGRAM und PLLIN werden die geologischen Großeinheiten Österreichs (Abb. 2) in bezug auf ihre Störungsmuster untersucht und charakterisiert. Neben Kurzbeschreibungen der Programme werden Bemerkungen zur Methodik der Interpretation tektonischer Lineamente aus LANDSAT-Bildern gegeben. Probleme, die sich beim Vergleich von detaillierten und Übersichts-Interpretationen ergeben, werden an Hand der jeweiligen Störungskarten und Kluftrosen von Satellitenaufnahmen aufgezeigt. Einige z. T. divergierende Ansichten bezüglich der früheren und rezenten strukturellen Entwicklung in Zusammenhang mit den heutigen megatektonischen Modellen werden dargelegt.

Abstract

On the basis of the computer programs DIGLIN, RGRAM and PLLIN the major geological units of Austria (fig. 2) are evaluated concerning their fracture patterns. Beside brief descriptions of the programs methodical remarks on tectonic lineament tracing from LANDSAT imagery are given. Problems arising when comparing detailed and large scale interpretations are shown by means of corresponding fracture maps and rose diagrams derived from satellite images. Some partly diverging assumptions on past and Recent structural history in connection with present-day megatectonic models are set forth.

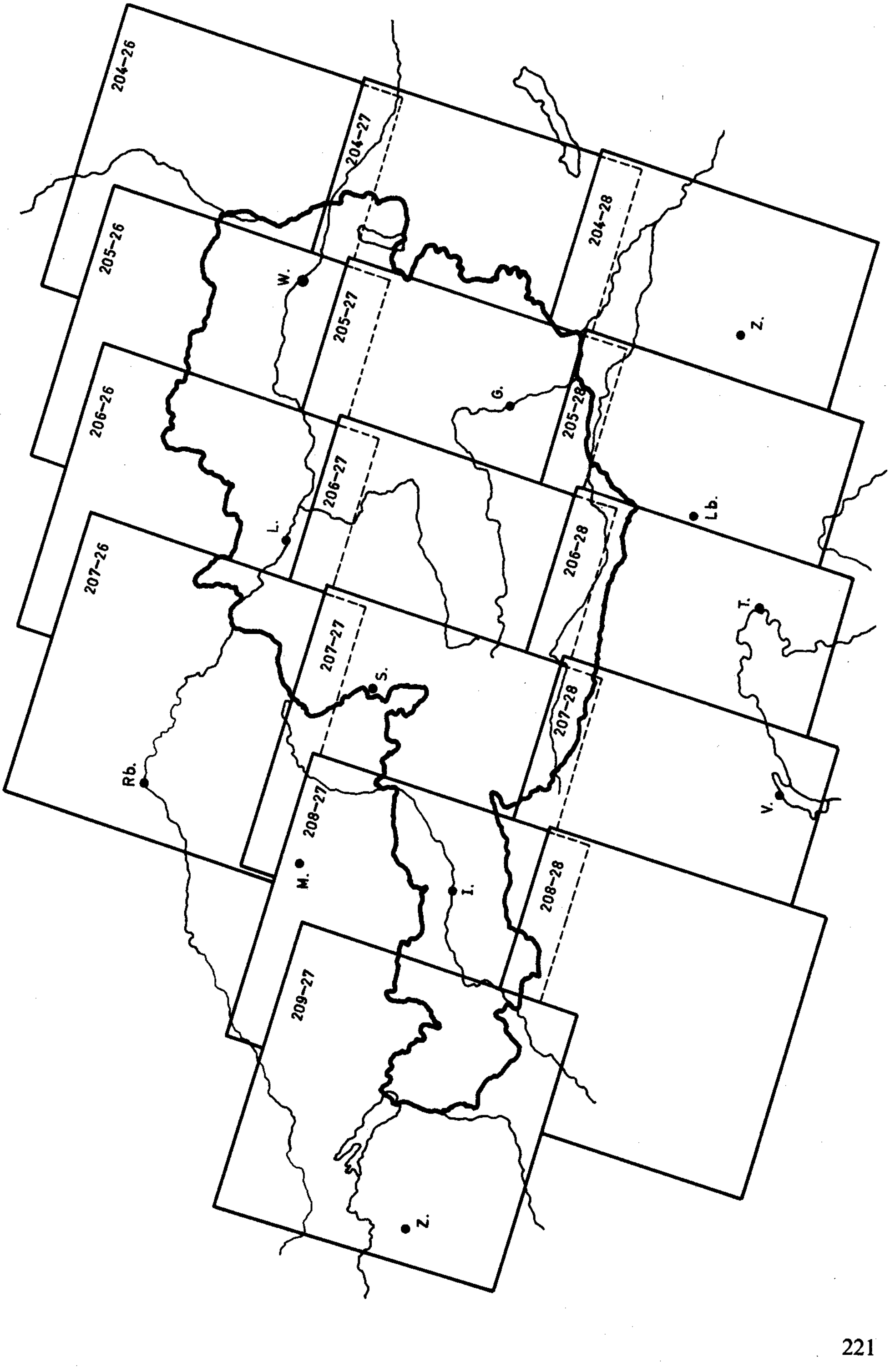
Résumé

Par le moyen des procédures automatiques DIGLIN, RGRAM et PLLIN les grandes unités géologiques de l'Autriche (fig. 2) sont examinées et caracterisées à l'égard de leurs systèmes de fracture. A part de brèves descriptions des programmes nous avons fait des remarques sur la méthodologie de l'interprétation des linéaments tectoniques des images LANDSAT. Des problèmes, quise dégagent en comparant des interprétations détaillèes et en gros, sont montrés au moyen de cartes defracture et de rosaces correspondantes dérivées des images de satellite. Quelque opinions, en partie divergeantes, concernant le developpment tectonique ancien et recent en rapport avec les modèles mégatectoniques d'aujourd'hui sont exposées.

1. Introduction

Since the first commercial products of LANDSAT data in the form of black and white hard copies have been available for geologists, i. e. 1972 (NDPF/NASA 1972), their usefulness for lithological but predominantly structural mapping on a smaller scale has been proved many times (for a review see, e. g., A. FISCHER 1976 cum lit.). For the Eastern Alps J. BODECHTEL & B. LAMMERER 1975, R. P. GUPTA & J. NITHACK 1976, R. P. GUPTA 1977, A. TOLLMANN in L. BECKEL 1976 resp. A. TOLLMANN 1977 a, P. CARDAMONE et al. 1977 and F. DEGAN et al. 1980 made first evaluations of LANDSAT imagery for geological purposes.

The objective of this paper is to show a method of machine-processed evaluation of lineament systems (diagrams) by the example of the major geological units of Austria and to discuss the relationship of its results to the structural setting of the East Alpine/Central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Central European region. Further, some methodical remarks on lineament tracing, on the relationship between field survey and satellite image mapping of fractures/faults [1]) and on generalization of fracture patterns respectively are given. The intention was only to put forward observations and interpretations which are not yet mentioned in the papers cited above. In one or the other case, however, it was necessary to refer to previous statements and to recapitulate briefly to make the context clear.

2. Data Acquisition

The present paper originates in some fracture pattern analyses of smaller test sites in Austria from digitally treated LANDSAT 2 data (cf. chapter 3. 1.). Multispectral scanning (MSS) computer compatible tapes (CCTs) of more or less completely cloudless scenes from 1976 between path 204 to 208 and row 26 to 28 (fig. 1) were ordered at the Earthnet Organization of the European Space Agency (ESA). The results of these interpretations, usually from digitally treated colour composites of band 4 (500–600 nm), band 5 (600—700 nm) and band 7 (800–1000 nm), sometimes only from band 7, were generalized according to certain aspects (see p. 231). It turned out that the results were rather identic with the lineament analysis by A. TOLLMANN 1977 a (cf. section 6.2. and 7.). Random checking still confirmed this first impression, so that finally TOLLMANN's map and his „nomenclature" of faults was taken over with only few emendments which partly derive from R. P. GUPTA 1977 (fig. 2).

3. Methodical Remarks

3.1. Interpretation of Lineaments

In all papers dealing with tectonic interpretations in the Eastern Alps, which were mentioned in section 1., conventional methods of structural geological photo interpretation were used, i.e. usually band 7, which covers the near-infrared range. Sometimes

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[1]) The terms „fracture" and „fault" are used according to A. A. G. SCHIEFERDECKER 1959. Between „lineament" and „linear", however, no differentation referring to magnitude as proposed by R. A. HOPPIN 1974 has been made.

Fig. 1: Index map of LANDSAT imagery covering Austria. The slight displacements within the paths (revolutions) are only due to greater legibility of the map. In reality scenes of one path form a „flight strip" with continuous E and W limits. As the locations of the single scenes vary within a certain range (some 10th of km) they only represent average positions of the last few years. For the sake of clearness the frames were drawn in that way that the scenes scanned last cover the older ones thus indicating the N-S flying direction and E-W trend of the satellite's revolutions. Nevertheless it can easily be inferred that most of Austria can be interpreted in real stereoscopy.

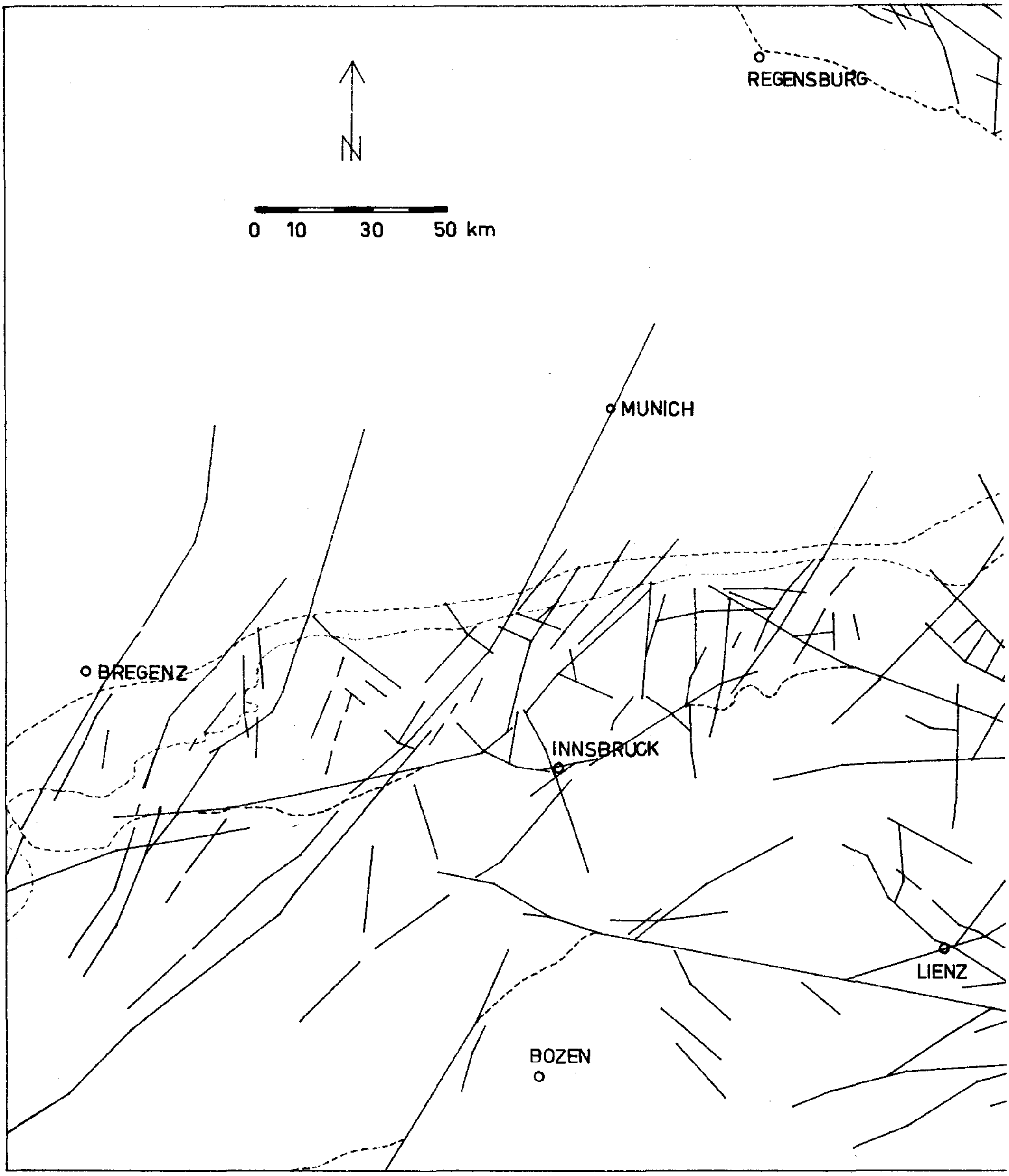
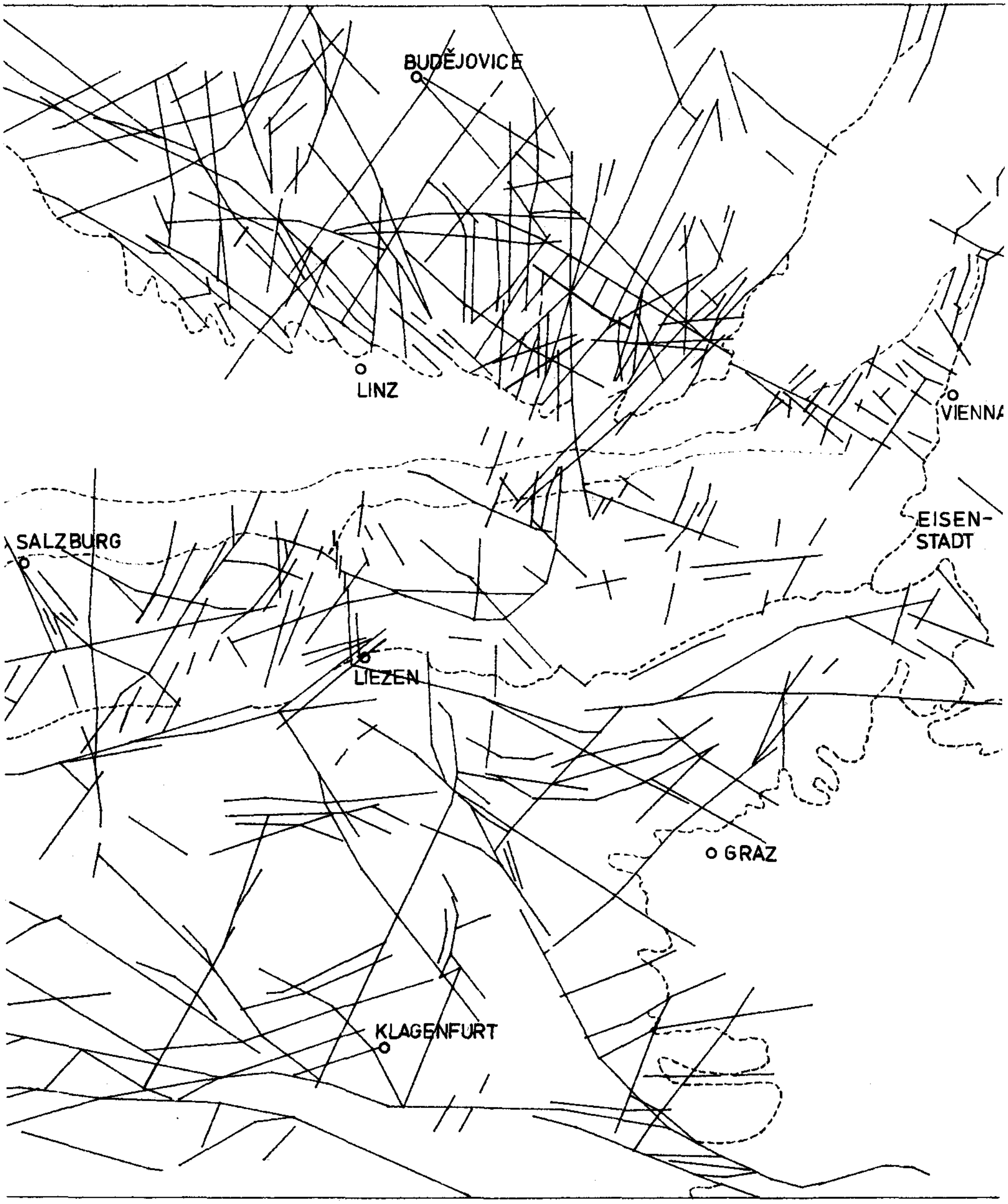


Fig. 2: Plot of digitized major LANDSAT lineaments (fractures) of Austria and some adjacent areas. Dotted lines indicate borders of the major geological units (cf. plate 1 – 3).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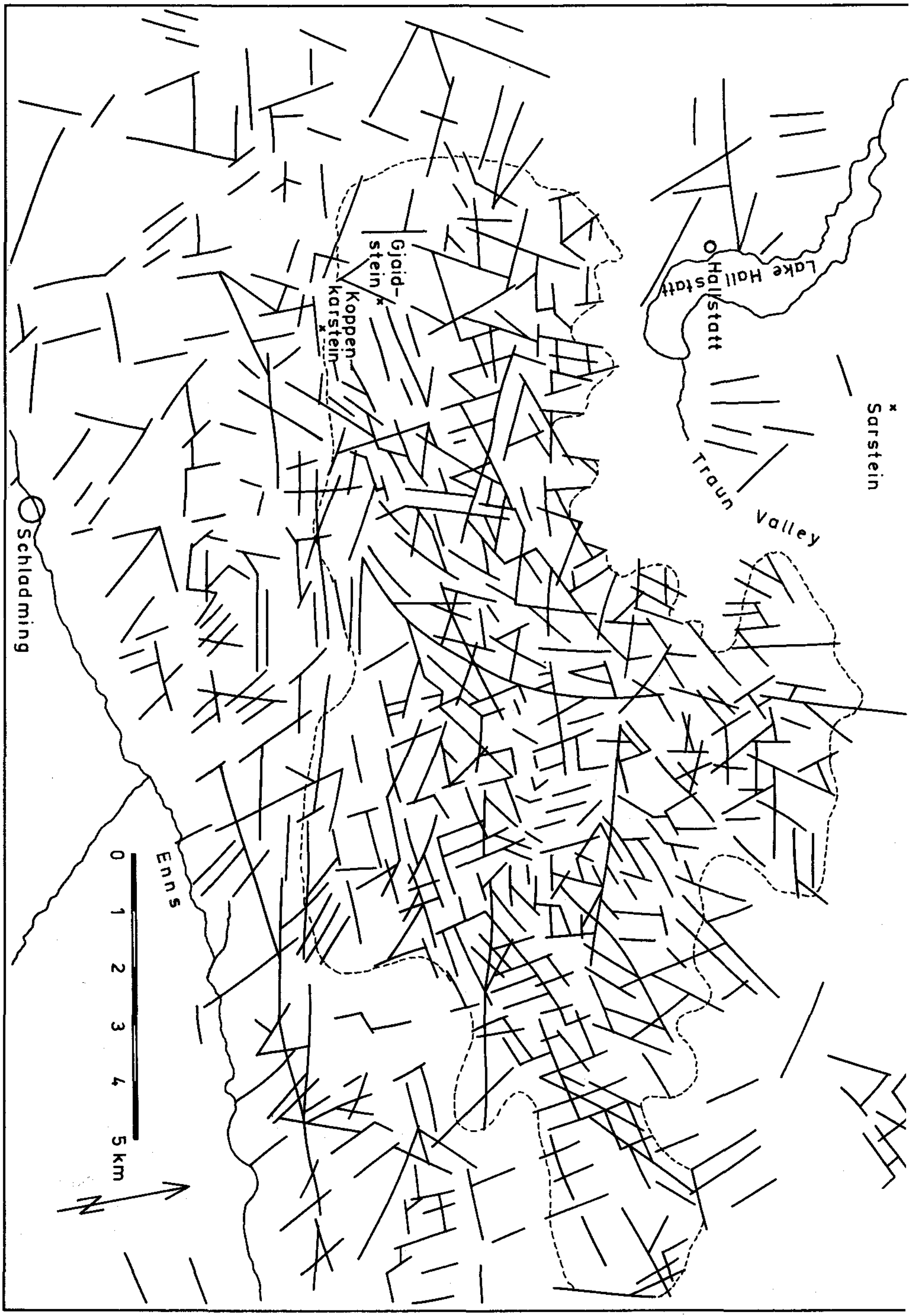
multitemporal imagery of this channel was utilized in order to eliminate errors due to illumination conditions (B. S. SIEGAL 1975) and to strengthen the validity of the observations and interpretations respectively (J. BODECHTEL & B. LAMMERER 1973 a, 1973 b, J. BODECHTEL & J. NITHACK 1974, R. P. GUPTA & J. NITHACK 1976, R. P. GUPTA 1977). In a terrain with strong relief which is prevailing in Austria the appropriate season of scanning is of great importance. In contrast to plain or rolling terrain you cannot always use images with a very low sun angle (and with snow cover), which set off most morphological indications for tectonic lineaments very well. In many cases one also has to look at spring (snow still in concave morphological forms, thus tracing and emphasizing the faults) and even summer scenes. The selection of the proper image always depends on the morphology of the area to be interpreted. For high altitude plateaus in the Alps, as we find them in the Northern Limestone Alps, December and January images are of quite good use. An example showing the mountain plateau „Am Stein" in the Dachstein Massif is given in fig. 3.

Although there exist software routines today based on more or less sophisticated algorithms of pattern recognition, which would allow the user to compile programs for digital scanning, storing and plotting of tectonic features (i. a. M. H. PODWYSOCKI, J. G. MOIK & W. C. SHOUP 1975, cf. J. AARNISALO 1978: 21), visual interpretation and manual tracing by an experienced geologist seems to be still the best way for the evaluation of fracture patterns from – rather contrast-enhaced – LANDSAT images (cf. also A. GOETZ in M. H. PODWYSOCKI et al. 1975; fig. 4). By this method wrong assignments of linear features to structural lineations, which happen with pure digital plotting (although they usually do not obviously influence the statistical distribution), can mostly be avoided. Moreover, stereoscopic view is an excellent additional tool for fault tracing wherever overlapping scenes are obtainable (Ch. CAZABAT 1975, N. POLYSOS 1981, M. F. BUCHROITHNER 1981).

Another method which has also been tested in western Carinthia and in the East Tyrol (Central Alps) and compared with the fracture pattern delineation by A. TOLLMANN 1977 a is the „shifted inverse diazo" method. It yields results which almost resemble some types of digital edge enhancements and can easily be „interactively" changed, i. e. adjusted for a smaller area under consideration. Fig. 5 displays the results of the application of digital enhancements which was, as these Optronics film prints were at hand, carried out with LANDSAT data treated with Principal Component Transformation, i. e. PC 3 and PC 5 in the 2-mode of band 4, 5 and 7. Fig. 5 obviously shows the advantages of digital techniques for more detailed fault tracing (cf. J.-Y. SCANVIC 1978). But on the other hand it also makes clear that the result of generalization in many cases yields a picture very similar (cf. sec-

Fig. 3: LANDSAT lineaments (fractures) of the mountain plateau „Am Stein" in the Dachstein Massif (Upper Austria/Styria; mainly limestones and dolomites). Interpretation from slightly digitally edge-enhanced image of Dec. 21st 1976. LANDSAT-2 frame no 206 – 27, geometrically not rectified (scale rough reference only). Broken line indicates the approximate edge of the plateau. Blank space in the NW of the plateau is caused by cast shadow due to low sun angle. Note that in a small scale most of the lineaments discarded turn out as minor ones and do not appear in fig. 2. A comparison of the photogeological map of the „Dachsteinplateau" by H. F. HOLZER 1964 shows the relative richness in detail of the satellite image.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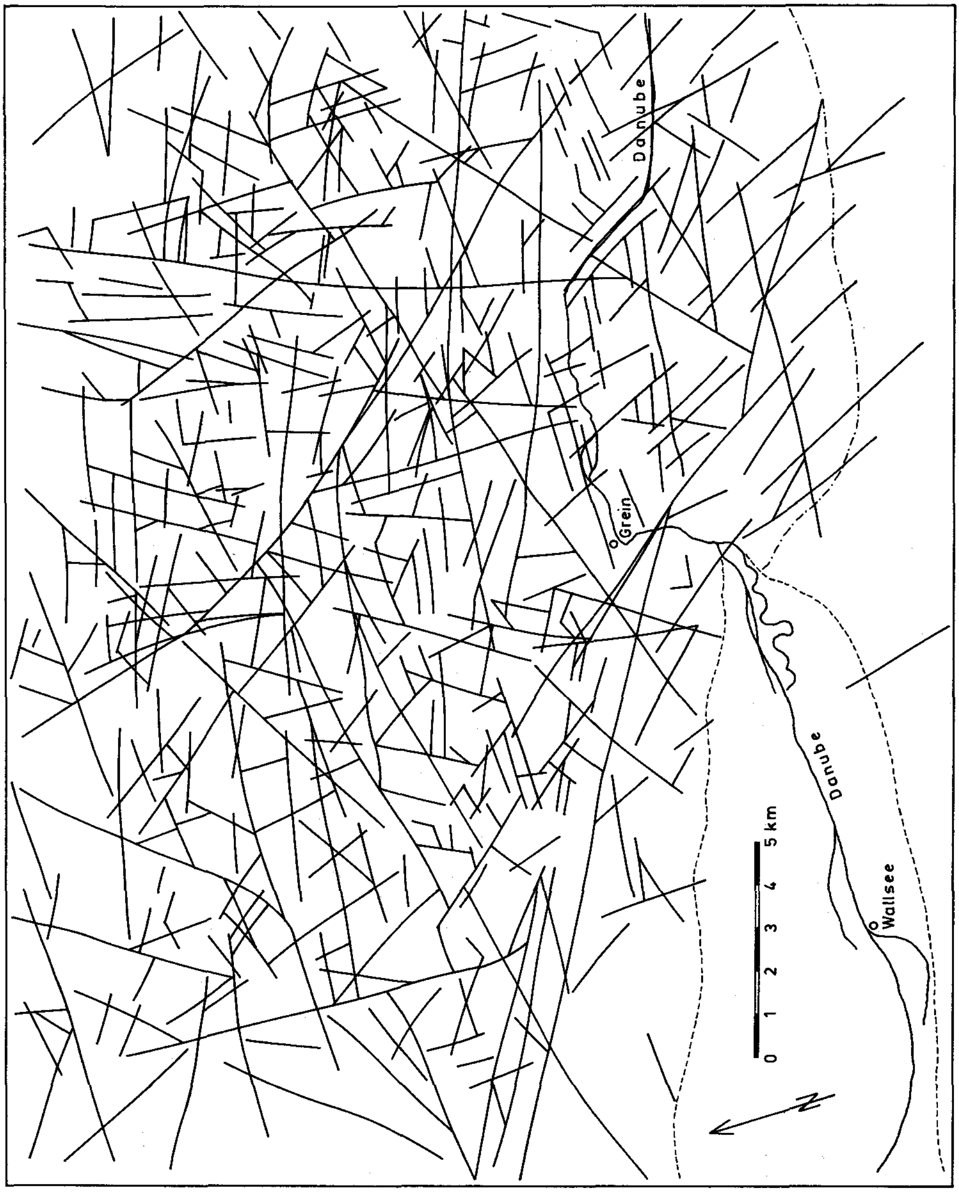

Fig. 4: LANDSAT lineaments (fractures) of a part of the southeastern Bohemian Massif in the surrounding of Grein (Upper and Lower Austria; granites and gneisses). Interpretation from digitally edge-enhanced image of Aug. 26th 1976. LANDSAT-2 frame no 206 – 26, geometrically not rectified (scale rough reference only). Broken line shows border of the fluvial plains of the Danube („Machland"), semicolon line indicates the approximate border of the crystalline basement S of the Danube. Fig. 2 clearly shows the main lines appearing in this drawing. Further note the obviously different fracture pattern in comparison with fig. 3 and 5 (lithological differences).


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tions 6. 2. and 7.) to that of A. TOLLMANN 1977 a (fig. 2). It must, however, be mentioned here that „objective" interpretations of LANDSAT images need experience and time (cf. J. AARNISALO 1978). To avoid the preference of one or two specific directions the images should be looked at from eight (not only four) different directions. The fact, that with experiments carried out in the USA only less than 0,5 percent of some 800 linears were recognized by all of the four operating geologists (mainly due to azimuth preferances; M. H. PODWYSOCKI et al. 1975) should be kept in mind. On the other hand comparative studies of fault tracings at the Technical University of Clausthal-Zellerfeld (FRG) showed „extensive accordance" of the interpretations (P. KRONBERG 1977). In my experience the statistic data should lie somewhere inbetween.

3.2. Graphic Presentation of the Statistic Data

Fora long time graphic depiction in the form of circular diagrams has been a very common way of synoptic characterization of tectonic trends for miners as well as for geologists (L. MÜLLER 1933). In many cases the „direction rosettes" represent an excellent tool for objective comparison of structural differences in geological units which are not that obvious in tectonic maps (G. KNEUPER 1960). Within the German speaking domain mostly 360° diagrams have been used which display symmetric figures in the upper and in the lower half, indicating the frequency per direction class (P. KRONBERG 1969, R. ADLER, W. FENCHEL & A. PILGER 1965, P. RÖLZ 1975). This type has also been used for representation of satellite image lineations (R. P. GUPTA & J. NITHACK 1976, R. P. GUPTA 1977, N. POLYSOS 1981; cf. p. 234). As one half of the diagram is actually unnecessary it was omitted by some authors (e. g. A. MIKKOLA & P. VUORELA 1973, J. AARNISALO 1978). Thus the upper part can be utilized to provide the length distribution of lineaments per direction interval (cf. J.-Y. SCANVIC & G. WEECKSTEEN 1978 a, 19768 b) as additional information (pl. 1–3), a graphic method which has been used successfully in the U S A e. g. (F. H. LAHEE 1961). Yet another method of circular presentation, the „probable orientation quadrant" of local stress (IFB-BEICIP without year) which can be assigned to each major lineament mapped from satellite imagery, shall be briefly mentioned here.

Although circular diagrams are of good use for synoptic view, bar diagrams are more suitable for matters of comparison, a fact which was already realized by E. KAISER 1926 (although he used them in a slightly different way than common today). The main advantage of histogrammatic graphs is that minor peaks, which are not so easily discernible in rose diagrams, can be clearly seen and compared in histograms (fig. 7 and 9). F. K. LIST & P. STOCK 1969 e.g. used frequency distribution histograms for the evaluation of fracture patterns derived from aerial photography, J. BODECHTEL & J. NITHACK 1974 for the comparison of interpretations from satellite images with different sun elevation and

Fig. 5: LANDSAT lineaments (fractures) of the Kreuzeck Massif (Carinthia; mainly gneisses and mica schists). Interpretation from a PC 2 Principal Component Analysis of band 6 and 7. LANDSAT-2 frame no 206 – 27 from Aug. 26th 1976, geometrically rectified (Gauss-Kruger). The photogeological map of the Kreuzeck Massif by H. F. HOLZER 1958 b only indicates some few percent of the lineaments shown here.

azimuth. Due to the facts and considerations briefly touched here it was near at hand to provide the options in the computer-aided lineament evaluation (program RGRAM) to plot length/frequency rose diagrams as well as length and frequency bar histograms. It becomes evident when comparing the figures of plate 1 to 3 that, the bigger the number of counts, the more symmetric becomes the rose diagram. This correspondence in shape, i. e. in statistic distribution, becomes even more striking with the histograms (fig. 7 and 9, appendix 2). The higher the diversity in km per azimuth class, the higher is necessarily the diversity in frequency distribution. As a rule of thumb we can make the following plausible statement: the higher the diversity of direction classes and the reciprocal value of the maximum length, the smaller tends to be the maximum value of frequency counts.

As visible in pl. 1 fig. a and pl. 3 fig. a the size of the distribution figure itself logically also has some bias on the comparison of different rose diagrams. One gets the „ideal", i.e. most appealing plot when the maximum peaks of length and frequency distribution exactly or nearly touch the periphery (pl. 1–3). In this case the information, also for minor distributions, is best. Nevertheless, in one case of this study (pl. 3 fig. b) the „distribution rosette" exceeds the outer tickmark of the rose diagram, that is with the comparative diagrams of the southern Bohemian Massif, the Eastern Alps and the cumulative rose diagram of both. If the maximum values in length and frequency of the whole area had been taken for the other two plots the size of the „rosettes" would have been too small for any reliable identification of the distribution. As the diameter of the rose diagrams is a default value and thus could not be extended for reasons of perspicuity the size of the „rosette" was selected bigger than the outer circle. It would not have been a solution to select different maximum values for these three diagrams because then the conditions of comparison would have been unequal, i.e. differently weighted.

Frequently continous lineaments resp. lineament zones of supraregional extension change direction, thus exceeding the five-degrees interval used in this study. The author is completely aware that by dividing these major lineations into ± straigt portions (due to the exclusively straight lineament plotting capability of the plotter) the length/frequency relation might give a slightly distorted impression. After all, it could be easily solved by putting „flags" to the lineaments in question. Anyway, the general picture will remain rather similar, although the number of counts per direction class will increase (which might be taken into consideration).

The circular or columnar distribution graphs of linears referred to direction classes in the ways above mentioned imply equal dips of the fault planes. For the delineation of fracture lines visible in satellite imagery one can assume rather steep dips (R. GÜNTHER 1977, R. HEINRICH 1977, P. KRONBERG 1977, N. POLYSOS 1977, A. TOLLMANN 1977), a fact that has been checked in the field in different areas of the European Alpidic belt (J. BODECHTEL & J. NITHACK 1974, P. KRONBERG & R. GÜNTHER 1977, N. POLYSOS 1977, 1981) and other parts of Europe (e.g. J.-Y. SCANVIC 1974, P. KRONBERG 1976, 1977, J. AARNISALO 1978). When comparing selected major lineaments and cross sections given by S. PREY 1980 cum lit., K. METZ 1973 and G. WACHTEL & G. WESSELY 1981 cum lit. it turned out that with just few exceptions, which are mostly still within the limits of statistic tolerance, the dips of the lineaments under consideration only diverge some ± 14 degrees from the vertical within the upper 5,000 m. Thus it seemed justified to use rose diagrams instead of SCHMIDT nets.

The criteria of selection for the generalization of lineaments (fig. 2 to 5) were those used by L. BISCHOFF 1975 and M. F. BUCHROITHNER 1980 a. The remaining structural lines fall into class I of the lineament classes established by J. AARNISALO 1978. By applying the selection criteria just mentioned a map rather identic with the one of A. TOLLMANN 1977 a was obtained.

3.3. Machine Processing of Data

After the considerations and activities mentioned above the data were digitally treated by the author at the International Institute for Aerial Survey and Earth Sciences (ITC) in Enschede, Netherlands. The kind assistance of N. H. W. DONKER from the ITC helped a lot to finish this work within a reasonable period of time. The computer programs used are treated in more detail in the following section.

4. Computer programs

Diagrammatic presentations have been proved to be very useful for statistic evaluation and graphic characterization of steeply dipping joint and fracture systems. But despite the increasing application of statistic methods and the use of computers in scientific geology only very few operational and user-friendly programs of this type exist. Hence it was obvious to write a program which allows easy digital assessment of lineations and provides diagrammatic graphs in an interactive manner.

One such set of three programs was installed on an HEWLETT & PACKARD microcomputer at the International Institute for Aerial Survey and Earth Sciences. These programs were developed and tested during a one year's stay of the author at this institute in 1979/80 and were still improved after further tests during the following months. They were written in BASIC by N. H. W. DONKER using a system consisting of an HP 9872A plotter/digitizer and an HP 9845B microcomputer with graphic terminal linked with an HP 9885S floppy disc unit. This floppy disc drive allows a reasonably big amount of data to be stored which is sufficient for most purposes. The programs are saved on magnetic tape minicartridge and can be loaded before usage.

The programs are named DIGLIN („digitize lineaments"), RGRAM („rose diagram") and PLLIN („plot lineaments"). In the following brief descriptions of these programs (N. H. W. DONKER 1981) are given.

4.1. Program DIGLIN

DIGLIN enables the user to digitize lineaments by means of a digitzer/plotter. The procedure is monitored on the screen of the graphics terminal. Thus digitizing errors of the two extreme points can be detected immediately, deleted („erased") and corrected. Position, length and direction of each digitizing lineament are subsequently stored on floppy disc in a simple file system. A subroutine provides the possibility of enlarging („blowing up") a subscene (appendix 1) of the area depicted on the plotter/digitizer tablet. This is a special advantage in regions with high intersection density of linears because it facilitates the checking whether the digitalization is correct and complete. The north arrow which has to be digitized in the very beginning is taken as angular calibration element („lineament 1“). Subsequently every lineament is listed with coordinates of the extreme points, its length in km and its direction given in degrees of a 360° circle (appendix 4).

As the lineaments of each unit are stored in one file the user has to decide in advance from which areas, i.e. geological (lithological, structural) units, he wants diagrams. From each file a corresponding rose diagram, length and/or frequency histogram can be produced (see section 4.2.). Several files can be grouped into one diagram but not be split. Moreover, the maximum number of lineations to be digitized has to be given in advance, although there exists also the possibility of extending the files later. The maximum size of the sheet used for digitalization is subject to the size of the digital tablet. In the present study a scale of 1 : 1,476,732 was used for digitizing and plotting the original „fracture map“. The exact indication of the scale is important for the accurate length calculation of the linears. Appendix 1 gives a flow diagram of the general organization of DIGLIN.

4.2. Program RGRAM

This program provides the possibility to produce a rose diagram, a length histogram and/or a frequency histogram using one or more files created by the program DIGLIN. The rose diagrams show the distribution of the cumulative length of the linears per direction class (see below) over the range W (270°) – N (180°/0°) – E (90°) in the upper semicircle. The lower semicircle displays the distribution of the linear/lineament counts (pl. 1 to 3). The shape of the „rosette“ proper was selected according to E. ARNBERGER 1966. The commonly used types of diagrams (e.g. R. P. GUPTA 1977, J. AARNISALO 1978, J.-Y. SCANVIC & G. WEECKSTEEN 1978 a, 1978 b, N. POLYSOS 1981) is ARNBERGER's type 31, which he assigned to material separations, whereas the type used in RGRAM, which is ARNBERGER's type of diagrams no. 33, is reserved for spatial distributions. Length histrograms show the cumulative length of the digitized lineaments per direction class over the range W–N–E. The counts per direction class are only indicated in the frequency histrograms, covering the range W–N–E, too (appendix 5, fig. 7 and 9). The histograms are of the bar type.

Restrictions concerning the length of linears to be grouped in one diagram as well as direction class intervals of 2.5 or 10 degrees can be selected. Apart from that, the user will be prompted by the program for some more parameters which mainly concern the desired way of plotting. So e.g. tickmarks indicating the main, labelled subdivisions of the histograms y-axes can be introduced. In the rose diagrams these tickmarks are represented by the dotted circles and the continuous outer one. Appendix 2 gives an organization diagram of RGRAM showing the possibilities of interactively changing the explicative text, the shape (by varying the ratio of the maximum values of the upper and lower semicircle and/or the size of the diagrams proper (by modifying the maximum values of both the upper and the lower semicircle by the same factor; cf. pl. 1 fig. a and pl. 3 fig. a), etc. before plotting the „final drawing“ with the plotter.

4.3. Program PLLIN

The linear features digitized with the program DIGLIN can be plotted in order to produce a „map" on the same or on a different scale as the original drawing. The size of the desired plots can be easily determined by digitizing the lower left and upper right corners. A lineament map of the same scale as the original one can e.g. be very useful to verify that no lineament has been omitted during the digitizing procedure. Restrictions concerning the length and/or the direction of the lineaments can be introduced (fig. 10 to 16). Especially the second option is quite useful to study the spatial distribution of certain dominant directions (which e.g. derive from one of the RGRAM graphs). By means of PLLIN only the lineaments stored in one file can be plotted. Serveral files, however, can be plotted on the same sheet, of course. Options are provided to use 4 different colours for the plotting of different files and to plot north arrow and frame only once or even no frame at all, as can be seen in the flow diagram in appendix 3. For easier visual separation of the files in this study the various geological units have been plotted on a working sheet in different colours.

5. Validity of Lineaments Derived from LANDSAT Imagery

In former years it was especially hard for the „classical" field geologist to believe in structural information obtained by electronic scanning from satellites. This restrained behaviour was still backed up by strange „scrawls" (representing fracture patterns) which were in fashion for some years after the first launch of ERTS (= LANDSAT) 1 in 1972 and which sometimes looked rather confusing than informativ (e.g. Ch. CAZABAT 1975). Furthermore, over-enthusiastic tracing lead to misinterpretations like e.g. in the paper just mentioned where high intersection densities in southern France could be proved to be due to ± straight roads meeting in towns.

An argument which was and still is often used against the existence of fractures mapped from satellite imagery is the absence of any indiactions in the field. But apart from a narrower joint spacing which need not necessarily be noticed by ordinary geological mapping neither in the field nor in a tunnel or shaft (cf. R. HEINRICH 1976, 1977, A. TOLLMANN 1977 a, N. RENGERS & SOETERS 1980), it is a matter of fact that in many cases major structural features do not come out that clear in the field. As examples only the continuation of the „Pustertal Line" westwards across the Giudicarian Line (J. BODECHTEL & B. LAMMERER 1973 a, 1973 b, R. P. GUPTA & J. NITHACK 1976, R. P. GUPTA 1977), some German major structures (P. KRONBERG 1974 b), the Southern Pamir Fault (M. F. BUCHROITHNER 1980 a) and some transverse faults in the Himalayas (K. S. VALIDYA 1976, 1979, S. SINHA ROY 1978, K. S. MISRA 1979) which are all quite well visible in satellite imagery shall be mentioned here. One or the other of these fault lines which seem to be hidden in the field (even if there is no young sediment or glacial cover present) might be revealed by detailed microstructural (R. HEINRICH 1976) and petrological studies (H. J. BEHR 1980, F. SODRE BORGES & S. H. WHITE 1980, C. SIMPSON 1980). The question of the existence of the „Sölktal Fault" in the Niedere Tauern, Styria, (A. TOLLMANN 1977 a) whose presence could not yet be proved in the field (L. P. BECKER 1981 cum lit.) might be solvable by these methods (or it might also turn out that this structural element is „the

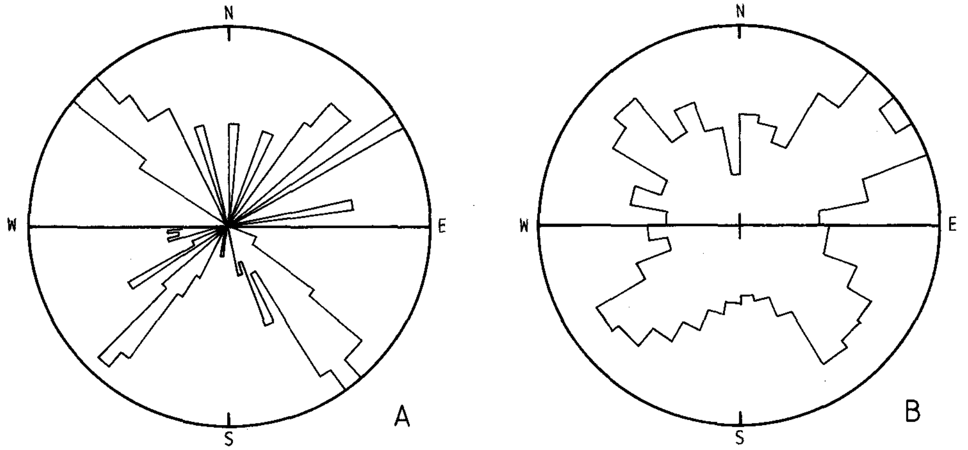


Fig. 6: Comparative rose diagrams showing the directions of fractures in LANDSAT imagery, inaerial photographs and in the field. Fig. a displays LANDSAT data from Central Greece in the upper and corresponding ground control data in the lower half. Fig. b gives LANDSAT lineaments from Central Italy in the upper and corresponding air photo information in the lower semicircle. Adapted from N. Polysos 1981 and J. Bodechtel & J. Nithack 1974.

exception to the rule". Anyway, this delicate topic will be treated by the author somewhere else.) In this paper only some references concerning this problem shall be given (H. Kinzl 1926, H. W. Flügel 1951, F. K. List 1969, F. K. List & P. Stock 1969, F. K. List & D. Helmcke 1970, A. Tollmann 1977 a: 20, A. E. Scheidegger 1979 b, 1979 c, 1979 d). Nevertheless, the importance of the „principle of antagonism" of A. E. Scheidegger 1979 a shall be stressed once more. Its „axionomic validity" was already proved by statistical means in 1977 (F. Kohlbeck & A. E. Scheidegger).

The correctness of the delineations of fracture systems from LANDSAT imagery has been demonstrated many times, directly with field checking as well as by conventional photogeological interpretation (H. F. Holzer 1958 a, 1958 b, 1964, J. Bodechtel 1968, 1969, F. K. List & N. W. Roland 1974 a, 1974 b, N. W. Roland 1974, J. Bodechtl & J. Nithack 1974, L. Bischoff 1975, P. Rölz 1975, D. Helmcke, F. K. List & N. W. Roland 1976, K. Mohr, P. Kronberg & R. Günther 1977, J. Aarnisalo 1978.) Especially the papers by P. Kronberg 1976, R. Heinrich 1977 and N. Polysos 1977, 1981 deal with comparative investigations of satellite image interpretation and the results of field survey. Polysos was able to show that in the Alpidic terrain of Greece the results of fracture tracing with LANDSAT imagery (in steroscopic view) still exceed those yielded from field work in accuracy and particularity. J. Bodechtel & J. Nithack 1974 got similar results from the comparison of aerial photograph and satellite image interpretation (fig. 6). Hence the validity of remotely sensed linears and of the generalization criteria mentioned in section 3.2. has been proved. The information provided by diagrams of geological units with only few major, i.e. generalized lineaments (Northern and Eastern/Southeastern Molasse Zone, Southern Alps) can be considered rather reliable, too.

6. Lineament Quantification

6.1. Selection of Files

A point of the present study one can argue about is the selection of geological units, i.e. files for digital evaluation, in the area investigated (fig. 2). It was clear from the beginning that the major geological units should be separated. Moreover, for good reasons a W-E division of these files seemed to be quite interesting, especially for the eastern part of the Alps, i.e. E of the line Passau–Pontebba (Zell Line and continuations), where the Alpidic belt starts bending northwards to the Carpathians. Further separation of the Paleozoic sedimentary areas within the Central Alps or at least of the Northern Greywacke Zone was also considered at first. But after a closer look at the „fracture map“ and further delineations it appeared feasible and justified to restrict to the units used in this paper, as the whole study should be carried out on a small scale. A major argument for this reasoning was to show the constancy (or inconstancy) of the main structural directions (cf. R. P. GUPTA & J. NITHACK 1976, R. P. GUPTA 1977; fig. 10 to 16) in all these ± W-E trending stripes. In the molasse forelands only the most obvious lineaments were ment to be taken into account, more or less as a supplement to the Eastern Alps proper.

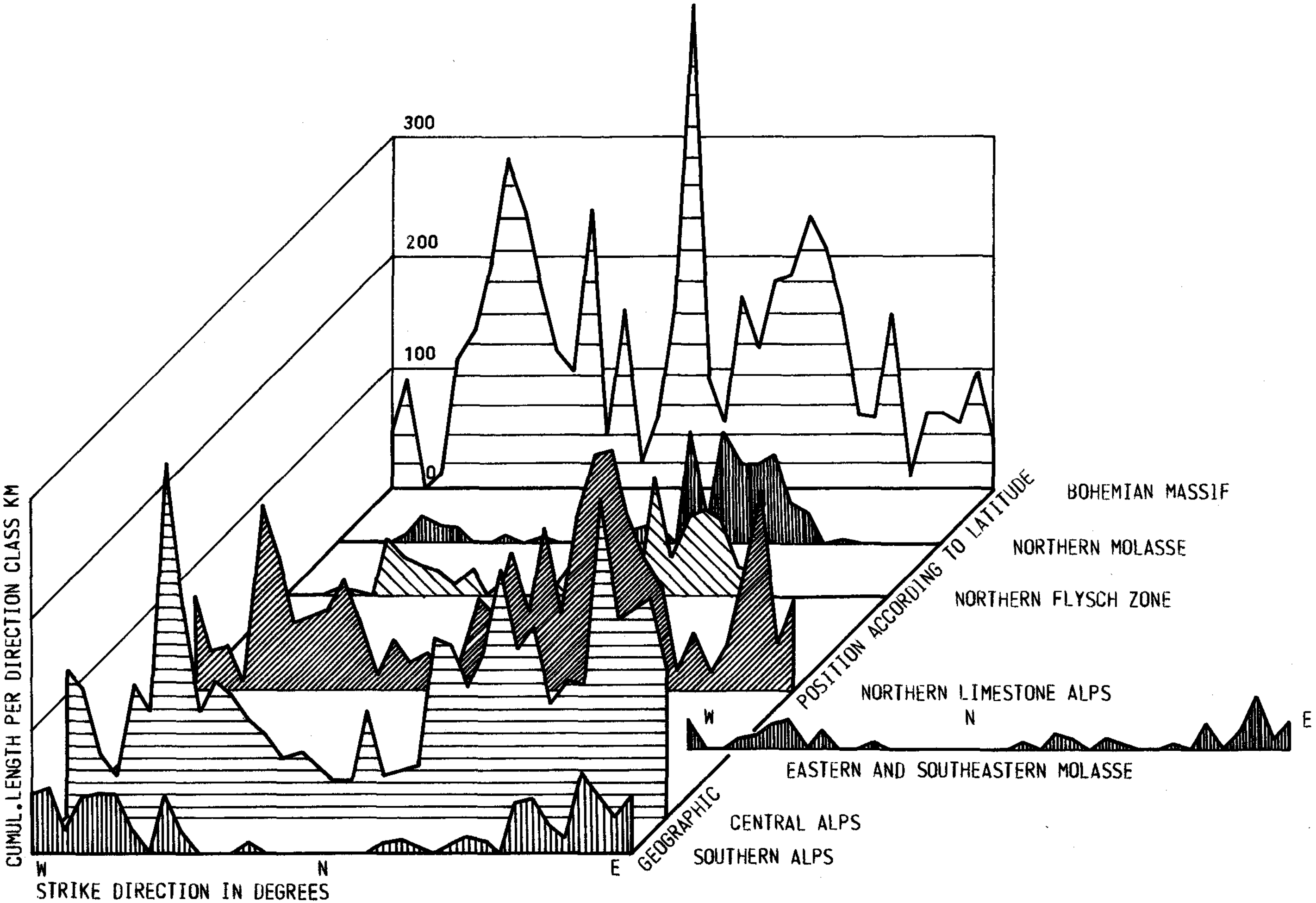
For evident reasons the Periadriatic Line (PAL) and its continuation W of the Giudicarian Line have been selected a file of their own in order not to bias the diagrams of either the Central or the Southern Alps. Logically, however, they were counted with the diagrams depicting the whole Eastern Alps.

6.2. Lineament Distribution

Although the counts per direction class also provide valuable information – mainly in connection with the length distribution – it usually was the length histogram which was taken into consideration for the evaluation of the fracture pattern. The cumulative length per azimuth interval seems to be a reliable tool to reach this goal.

Alltogether some 890 lineaments and parts of lineaments respectively have been digitized and evaluated. In this paper directions are given in letters over the range W–N–E (upper half of the circular diagram), figures only from 0° to 180°.

The major fracture pattern of the Austrian as well as of the adjacent southern Czechoslovakian and eastern Bavarian part of the Bohemian Massif is the best visible one of the whole region studied, due to reasons which were already mentioned by A. TOLLMANN 1977 a. For this area his „fracture map“ was taken over with only one change. The Bohemian Massif displays a prominent and distinct maximum of the lineament distribution exactly in N direction. A second order peak is situated in the NW (125°), whereas two equivalent minor peaks appear in NE and NNW direction (35° and 150°). Frequency counts and length distribution per direction interval show a very significant correspondence (cf. section 3.2.). The disposition of the maximum and the other peaks is in good accordance with the conception expressed by A. TOLLMANN 1977 a concerning the relationship of the present-day MOHR type and CLOOS type systems. The maximum is represented by the Haselgraben Fault, Waldhausen Fault and Kleine Isper Fault and their accompaning fractures respectively, the second order peak at 125° by Pfahl, Donau Fault and Ottenschlag Fault and their subparallel side-branches as well.


300
200
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CUMUL. LENGTH PER DIRECTION CLASS KM
W
N
E
STRIKE DIRECTION IN DEGREES
POSITION ACCORDING TO LATITUDE
GEOGRAPHIC
BOHEMIAN MASSIF
NORTHERN MOLASSE
NORTHERN FLYSCH ZONE
NORTHERN LIMESTONE ALPS
W
N
E
EASTERN AND SOUTHEASTERN MOLASSE
CENTRAL ALPS
SOUTHERN ALPS

The Northern Molasse Zone shows two narrow-standing equivalent maxima in NNE direction (15° and 25°) which might with more data most probably join each other. A second order peak lies in the NE at 40°, and another much smaller one in the ESE (115°). These peaks are clearly due to the directions of the main fractures cutting through the body of the Eastern Alps (R. P. GUPTA & J. NITHACK 1976, R. P. GUPTA 1977), as e.g. the Loisach Fault (eastern maximum), and are subject to the trends continuing from the Bohemian Massif southwards (cf. A. TOLLMANN 1977 a). Although these results only derive from a „generalized map“ they show good coincidence with the detailed structural setting in the western part of the Northern Molasse Zone (R. GÜNTHER 1977, R. P. GUPTA 1977, P. KRONBERG 1977). When using digitally enhanced MSS images from CCTs or even when „just“ looking at hard copies through the stereoscope it is also possible to trace more than only the major fracture pattern of the Bohemian Massif below the sedimentary molasse cover. (A more detailed study on this topic is going to be carried out).

The molasse in the eastern and southeastern forelands of the Alps, i.e. in the southern Vienna Basin and in the Austrian portion of the Pannonian Basin, is biased by the fracture trends in the Bohemian Massif and the other geological units of the Alps plunging below it. Thus it has a dominant maximum exactly in E direction (90°), a second order peak which is half as prominent as the maximum at 120° (WNW) and a minor third order peak in the NNE at 20°. The maximum evidently derives from the directions present in the eastern Central and Southern Alps, whereas the 20° and 120° peaks are biased by the Bohemian Massif (pl. 1, fig. 7).

Taking into account geological and geophysical background information (cf. K. KOLLMANN & O. MALZER 1980, A. KRÖLL, G. SCHIMUNEK & G. WESSELY 1981) it should be possible to obtain reliable information on the surface of the crystalline basement hidden by the molasse deposits and to draft a „three-dimensional“ block diagram, like J. BODECHTEL & J. NITHACK 1974 produced one for the Po Plains, using LANDSAT imagery, and M. F. BUCHROITHNER 1980 b for the southern Ebro Basin by means of conventional aerial photo interpretation.

In the Northern Flysch Zone the maximum is situated in the NNE at 20°, accompanied by a subordinate maximum at 35°. A second order peak is situated at 120° (WNW), and a third minor peak points exactly towards the N. This distribution very well correlates with that of the Northern Molasse Zone. The remarks given there are also valid for the Flysch Zone.

For the Northern Limestone Alps the general picture does not change too much compared with the northern units. A prominent maximum is shown in the NE (35°), two almost equivalent peaks of second order in the E and WNW (90° and 110°) and a third minor one at 135° (NW). The peak pointing at 15° (NNE) is caused by the fractures running (sub-) parallel to the Rhinegraben direction (cf. R. P. GUPTA 1977). The peak situated in the ENE (80°) is obviously represented by the major lineaments of Klostertal, Northern Peripheric Osterhorn Fault and Tauplitz Fault, which ± follow the main strike direction

Fig. 7: Axionometric representation of cumulative length histograms of the lineaments of the area studied (cf. fig. 2). The maxima shift between the various major geological units becomes obvious and partly reflects the differences in density of fig. 10 to 16. Direction intervals 5 degrees.

ofthe Northern Limestone Alps. In this unit the peaks can logically be assigned to a MOHR type system of diagonal faults and a CLOOS system, too. Only that the N direction of the latter is not that distinct. The WNW peak more or less represents the Pfahl (= Hercynian) direction of the Bohemian Massif, which is also present in the subalpine crystalline basement: e.g. Wolfgangsee Fault, Windischgarsten (= Teichl-Hengst) Fault, Hochwart Fault and Schwechattal Fault. Göstling Fault and Zell Line are trend equivalents to the N-S structural elements of the Bohemian Massif (fig. 10 – 13; A. KRÖLL, K. SCHIMUNEK & G. WESSELY 1981). Analogue statements are of course also valid for the Northern Molasse and the Northern Flysch Zone (pl. 1) as well as for the northern part of the Central Alps (fig. 2). A. TOLLMANN 1980 made identic observations and also stressed the importance of the deep seated fault system in the crystalline basement.

The graphic presentation of the Central Alpine lineament pattern displays a clear maximum in the WNW (120°; cf. K. METZ 1978), a second order peak in the ENE (70°) and another third order peak at 40° in NE direction. The first two peaks belong to an obtuse-angled (with reference to the angle ß, which is equivalent to the dihedral angel 2Θ of the COULOMB-NAVIER criterion, I. W. FARMER 1968) MOHR system which is predominant in the southern part of the Central Alps and which was already noticed by A. TOLLMANN 1977 a. It is in contrast to the acute-angled system in the eastern central part of this unit and in the Northern Limestone Alps. The maximum clearly shows the importance of the old WNW direction which diagonally cuts through the East Alpine body (cf. section 7). It has its main representatives in the Bretstein-Hirschegg Fault and, above all, in the Mölltal Line. The latter can even be intermittently traced as far as to the Molasse Zone NW of Oberammergau in the Allgäu. (A fact which was, e.g., already noticed in the 1960ies by K. METZ, Graz, oral communication). The gap between the Kalser Tauern Pass and the Zillertal as well as many other white spots on the small scale „fracture map" are, at least partly, due to fluvio-glacial sediments and recent glacial coverage. WNW of the area of the Kalser Tauern the continuation of the Mölltal Line shows no seismic activity. It is cut by the Northern Peripheric Tauern Fault and some other lineaments (J. DRIMMEL, Vienna, oral communication). Recently (1980), however, U. MÜNZER & J. BODECHTEL were able to demonstrate that by rather simple enhancement techniques and linear combinations of MSS bands (i. a. Principal Component Transformation) known geotectonic patterns can be delineated through an ice cover of some 1000 m and even more. By application of this method it should also be possible in the Alps to give more detailed reliable information on the continuations of fractures below glaciers. This will become particularly interesting after the launches of LANDSAT D and SPOT.

The diagrams of the Southern Alps seem to show a clear maximum in NNE direction (30°). This maximum, however, only represents the Giudicarian Line and its accompaning faults. For certain reasons this lineament has been digitized with the Southern Alps. The real maximum which does not reflect the influence of this bordering lineament lies in the ENE at 75°. Two second order peaks are situated at 95° and 115° (E and WNW), a peak of third order in the ENE at 60°, too. The few lineaments which determine this distribution can easily spotted in fig. 2. The main trends of the PAL are quite similar to those in the southern part of the Central Alps, i.e. a rather obtuse angle ß of the MOHR system, a fact already noticed by A. TOLLMANN 1977 a. This wide angle between the diagonal branches of the fracture pattern resp. the acute angle with the PAL and the Val Canale Fault as well as, above all, the asymptotic approach („dragging") of the WNW and ENE trending lines towards these major lineaments deduced from LANDSAT imagery in the Carinthian domain of the PAL provide evidence of the well-established fact of dextral movement (A. GUILLAUME 1978 cum lit.). This right hand displacement was already interpreted from satellite imagery in the western Tyrol by R. P. GUPTA & J. NITHACK 1976 resp. R. P. GUPTA 1977. Bending of the side valleys and slight dragging of the tributaries in the Lesach Valley and Gail Valley (especially pronounced on the southern slopes) can be taken as one more relevant indicator for Recent or Subrecent lateral movements, too. Magnetic fabric analyses corroborate the existence of the western continuation of the Pustertal Line as well as the Recent horizontal displacements in the Lesach Valley (J. S. RATHORE & H. HEINZ 1979). A comparison of an overall rose diagram of the area studied in this paper (pl. 3 fig. c) with that of the Bohemian Massif (pl. 3 fig. a) clearly shows the influence of the densly and well developed fracture pattern of the crystalline basement on the structural trend analysis of Austria. It is especially the N and NNW trends of the Bohemian Massif which clearly bias the overall diagrams, whereas most of the other peaks give clear evidence that Austria is, also from the structural geological point of view, a real „Alpine country" (pl. 1 – 3).

The diagrams of the Eastern Alps obviously show the predominance of the E, E to ENE and „low" (i. e. close to WNW) NW direction (pl. 3). The „low" WNW trends are due to the biases of the PAL and the Southern Alps (fig. 2, pl. 2 and 3).

A look at the structural trends of the Eastern Alps N of the PAL (fig. 2, pl. 3 fig. d) reveals the corresponding diagrams to be combinations of the Central Alpine obtuse-angled MOHR type system and of the prominent NE direction which prevails in the combined „file" of the Northern Limestone Alps, the Northern Flysch and the Molasse Zone.

The interrelation between the trends in the various geological units can be seen in fig. 1 and 10 to 16 and even better in fig. 7, 8 and 9 as well as in pl. 1 to 3.

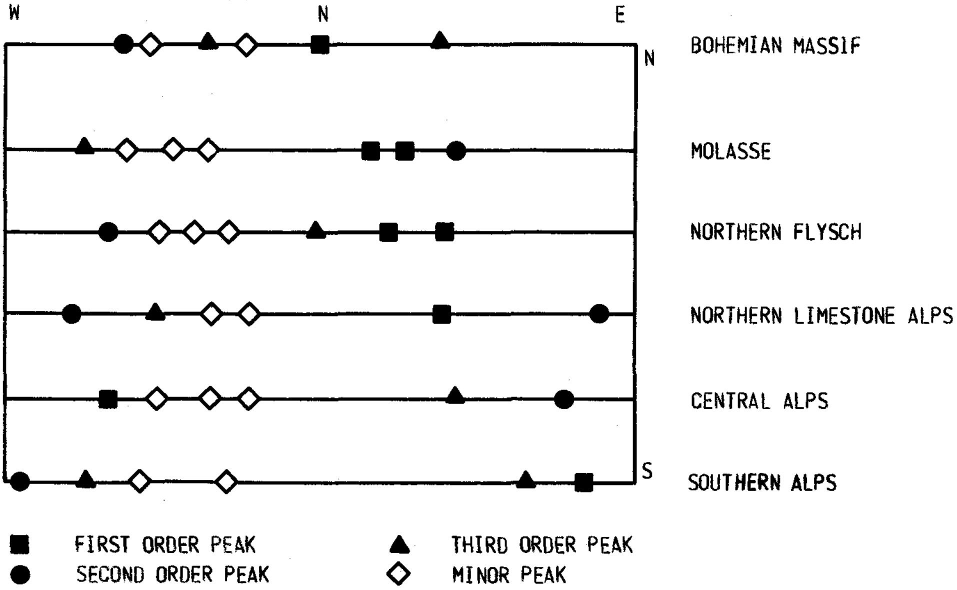

Fig. 8: Variation of maxima distribution in the cumulative length histograms (fig. 7) of the major geological units. Prevailing directions are indicated by „peak clusters".

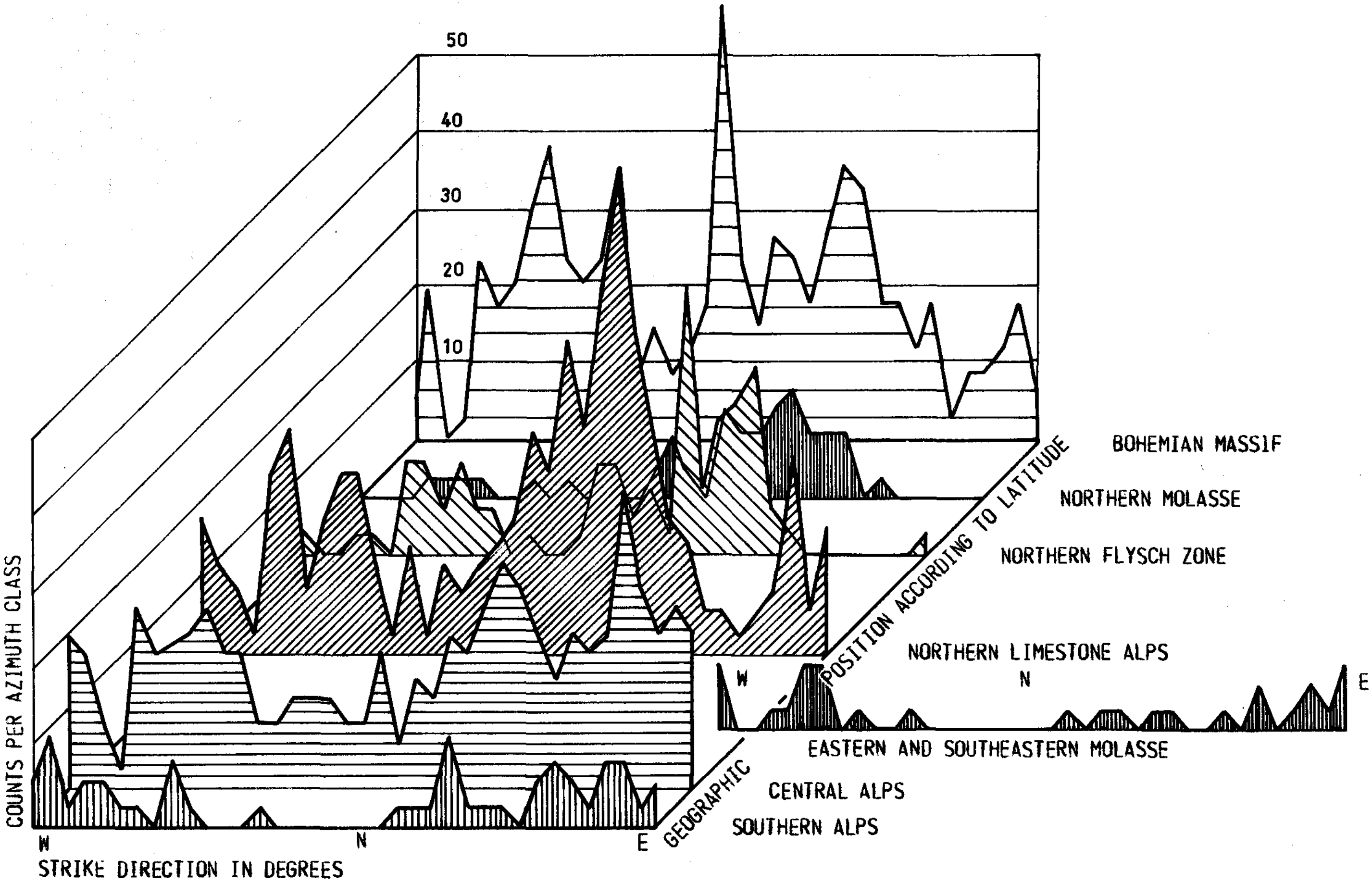

Fig. 9: Axinometric representation of frequency histrograms of the lineaments of the area studied (cf. fig. 2). Direction intervals 5 degrees. Note the correspondence with the peak distribution in fig. 7. For further explications see p. 235 ff.

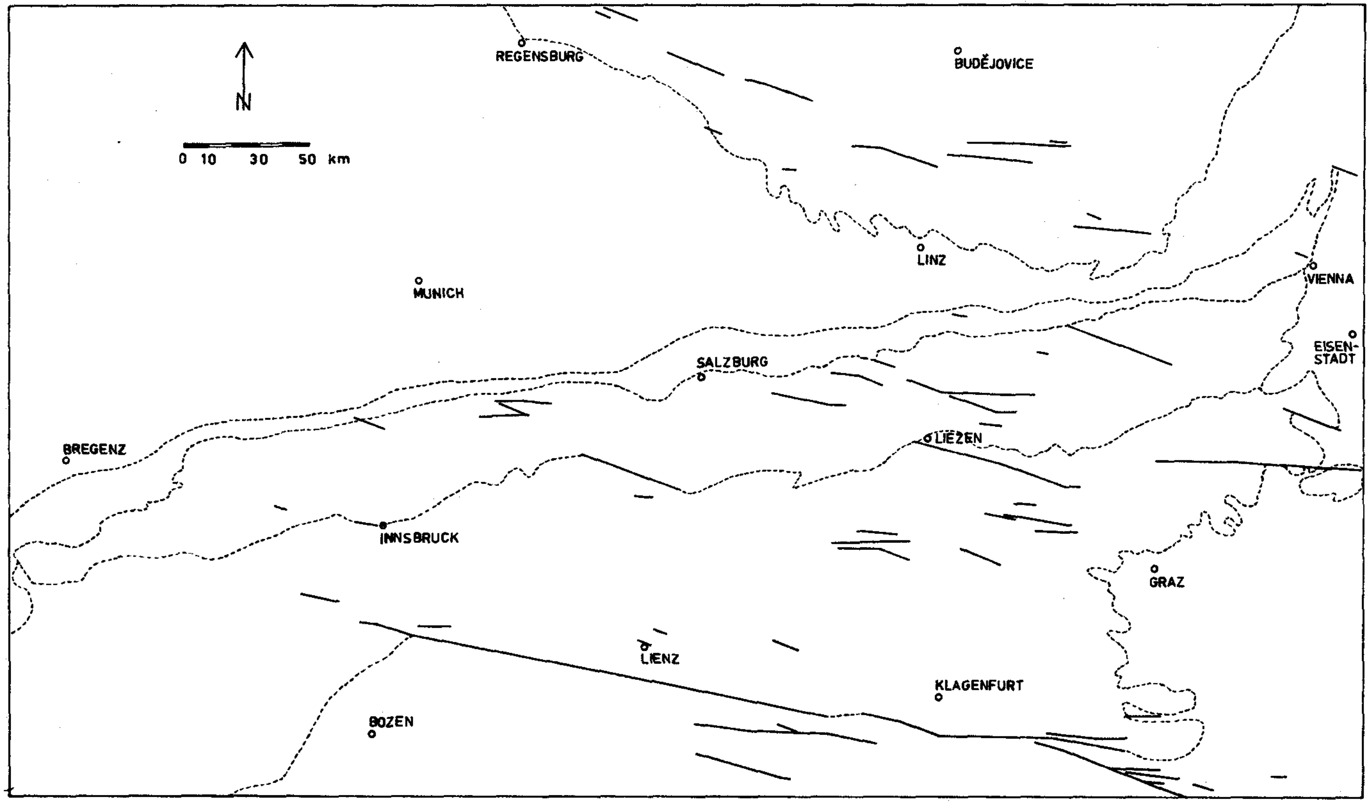

Fig. 10: Plot of digitally filtered LANDSAT lineaments between 265 and 290 degrees.

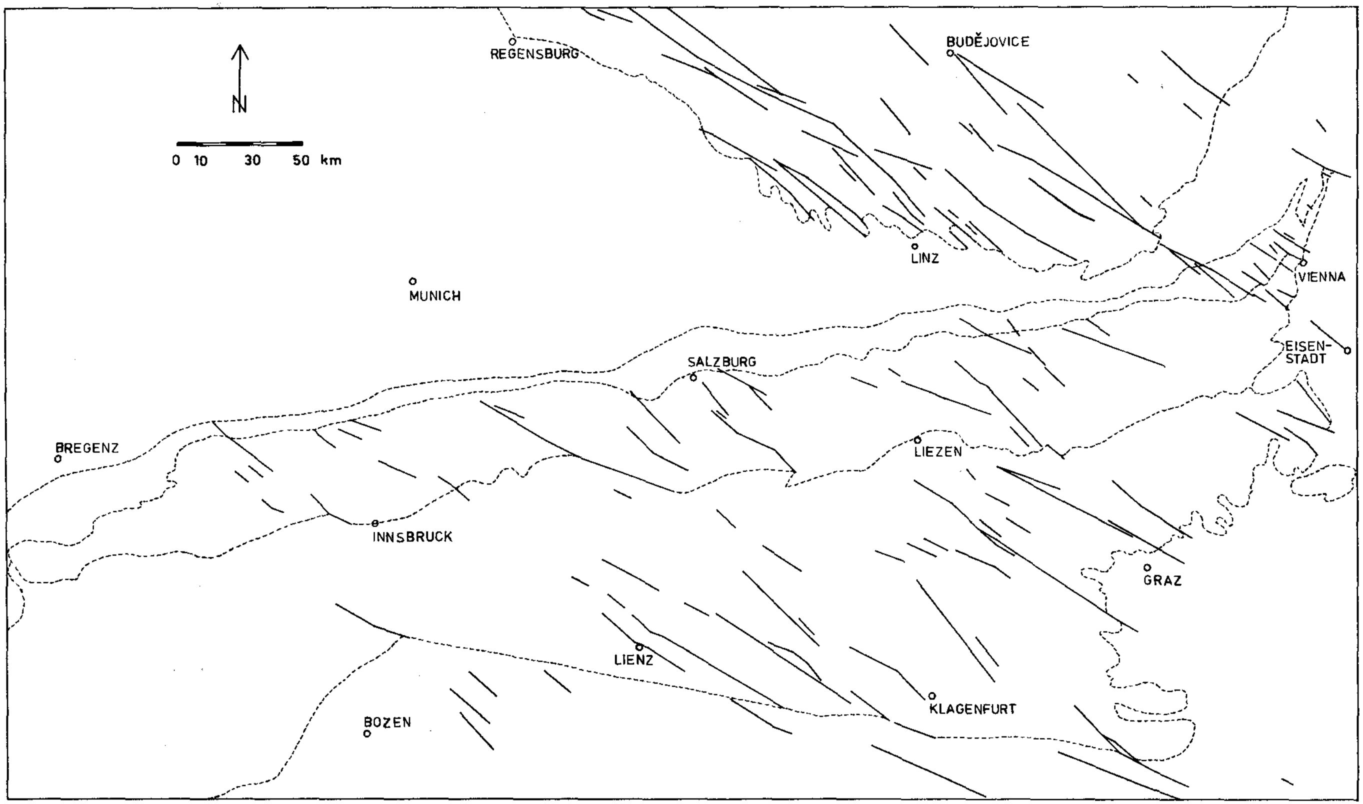

Fig. 11: Plot of digitally filtered LANDSAT lineaments between 290 and 320 degrees.

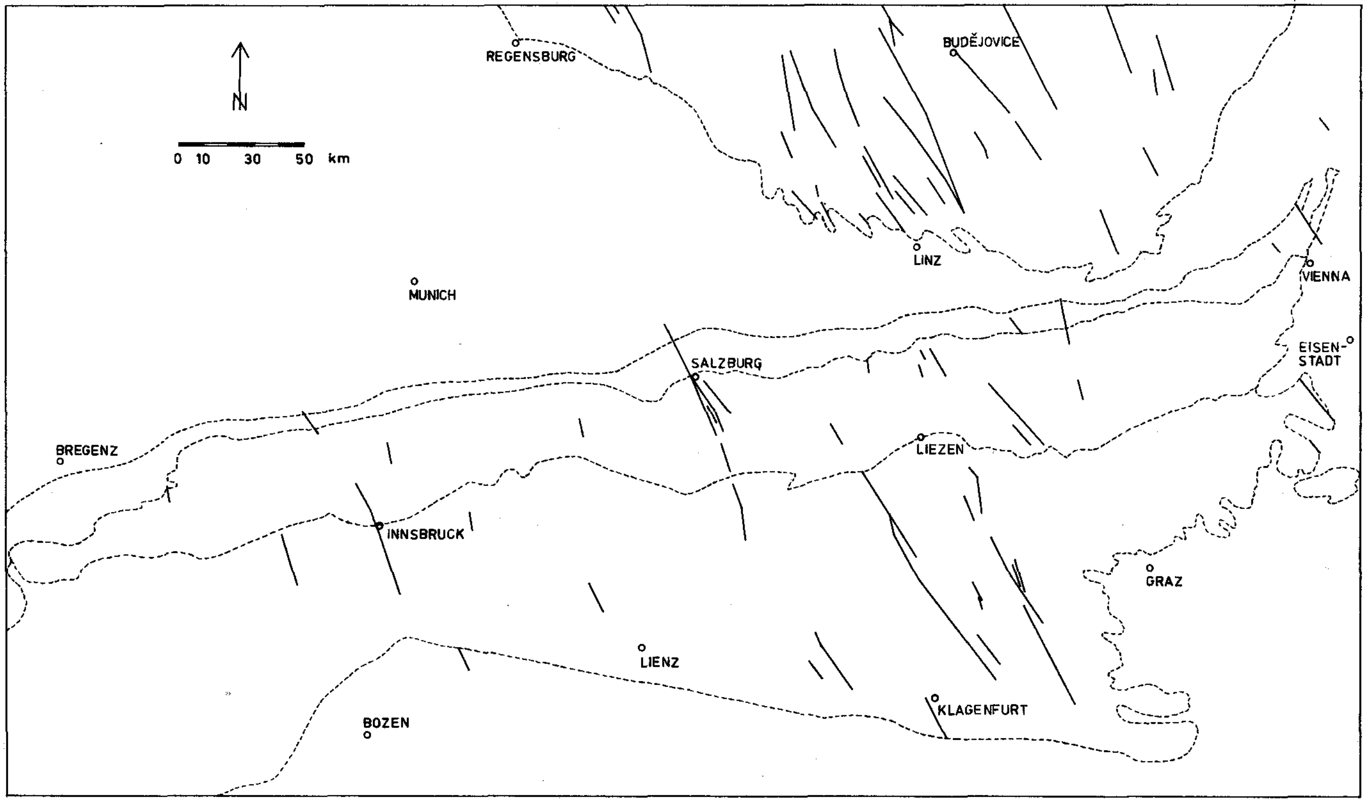

Fig. 12: Plot of digitally filtered LANDSAT lineaments between 320 and 350 degrees.

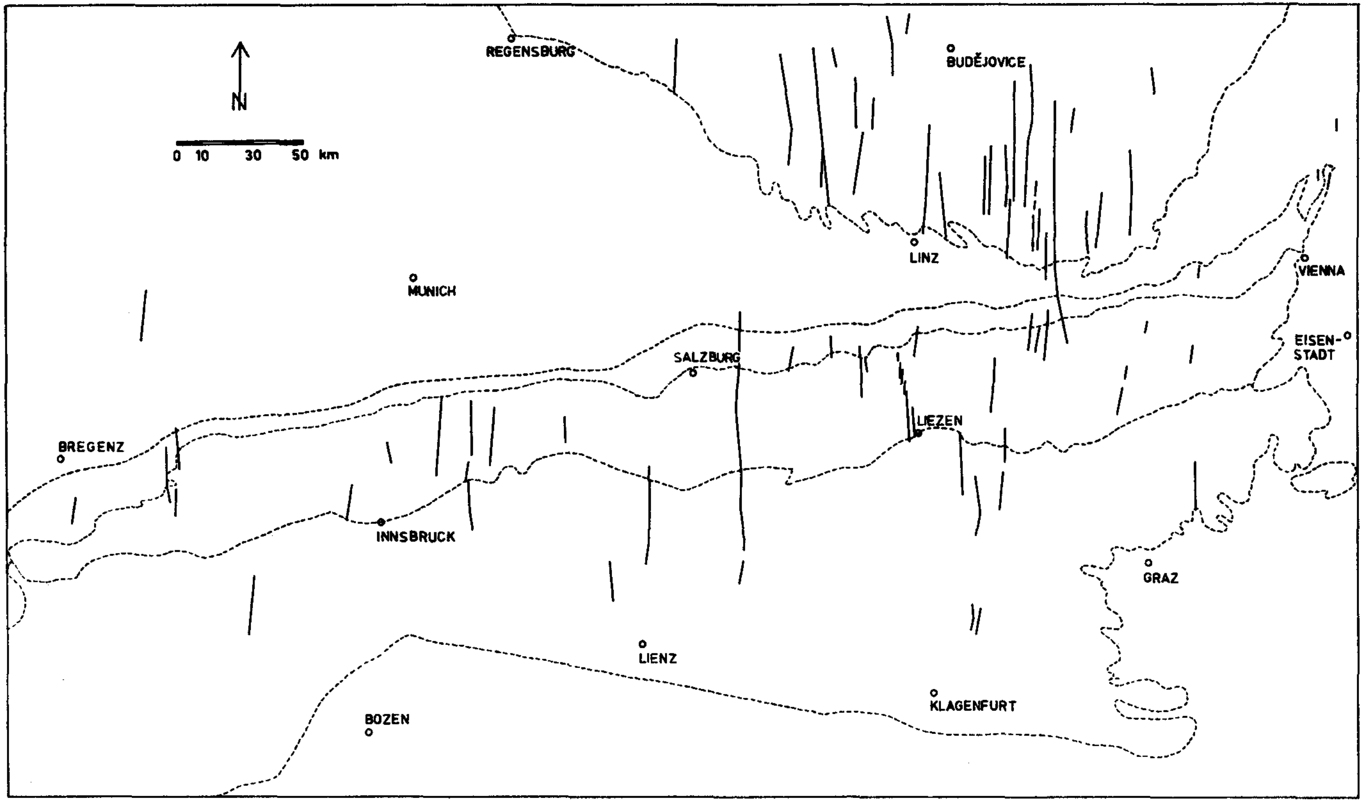

Fig. 13: Plot of digitally filtered LANDSAT lineaments between 350 and 10 degrees. Note the comparatively high density in the Bohemian Massif.

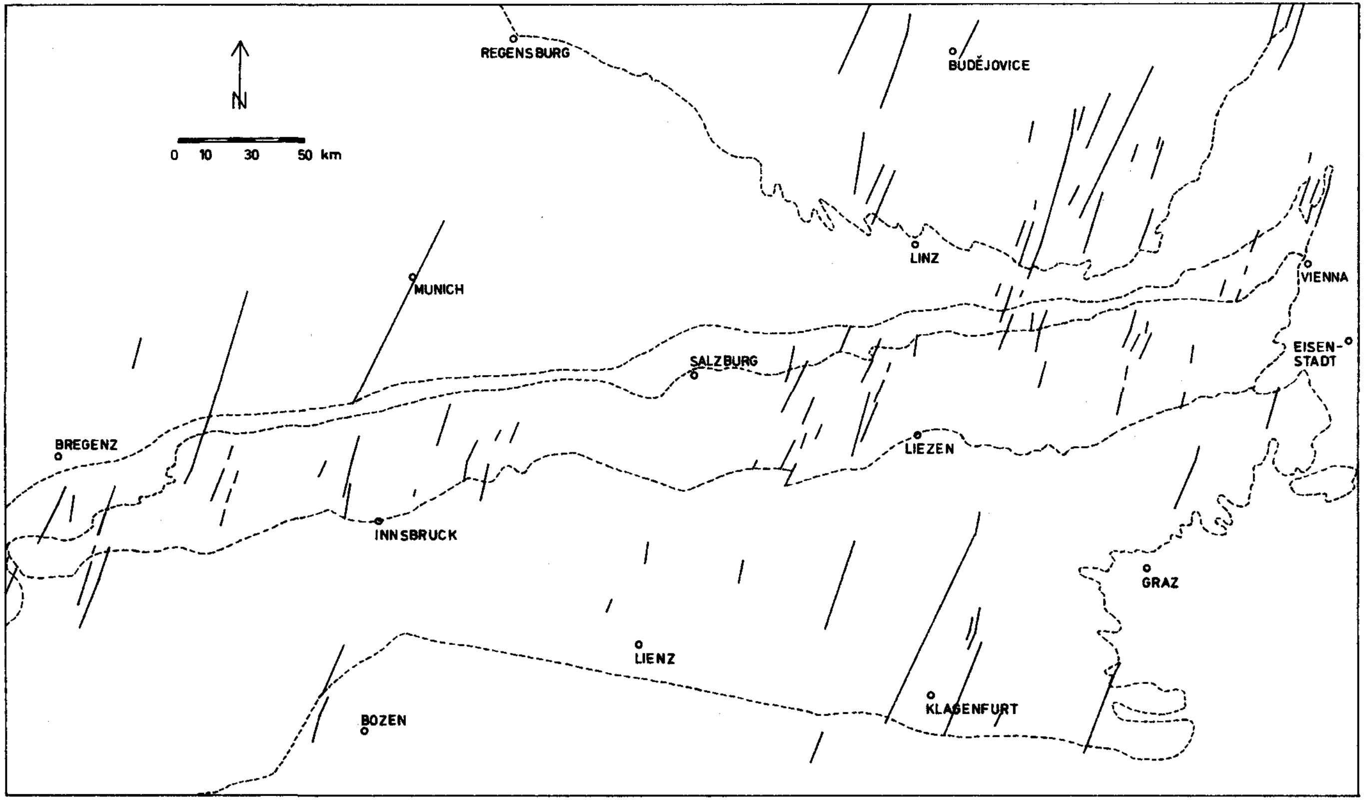

Fig. 14: Plot of digitally filtered LANDSAT lineaments between 10 and 25 degrees.

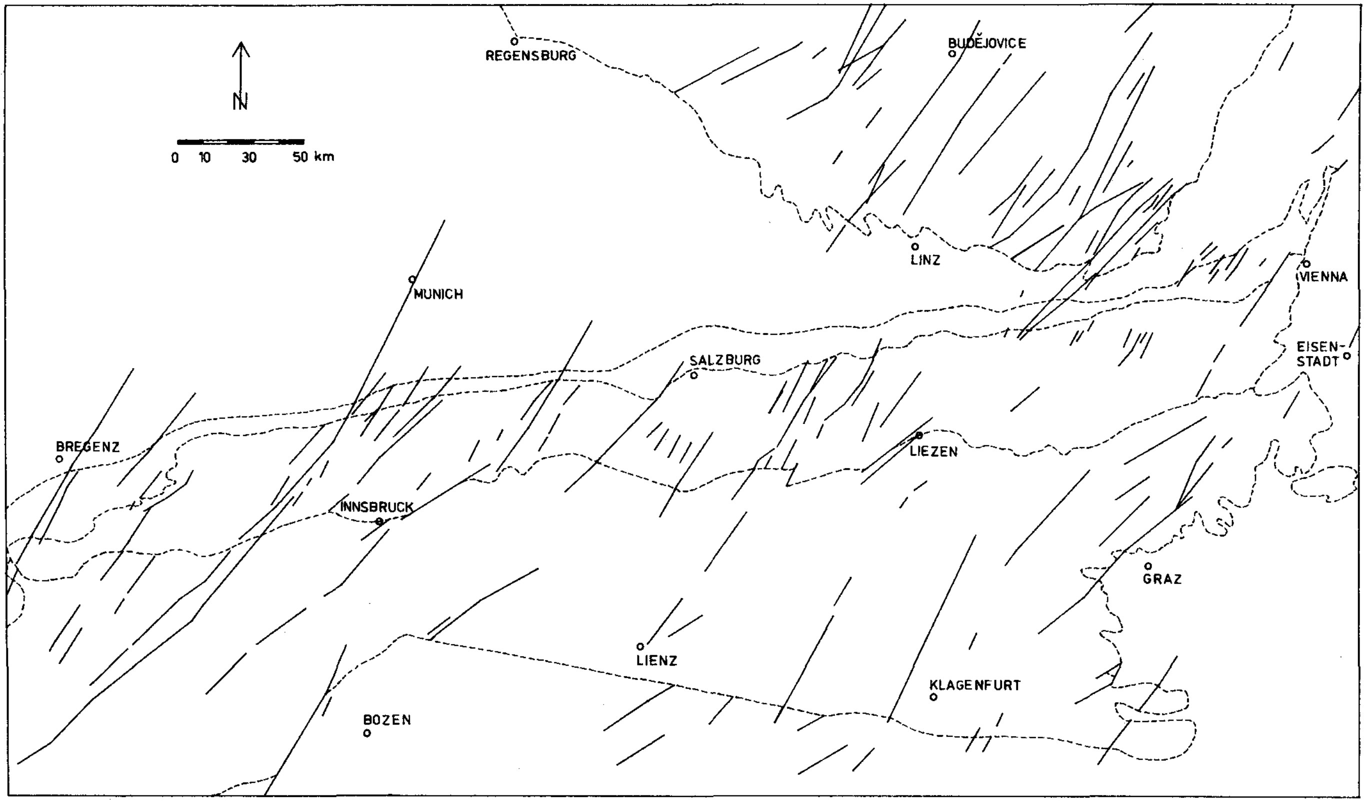

Fig. 15: Plot of digitally filtered LANDSAT lineaments between 25 and 60 degrees.

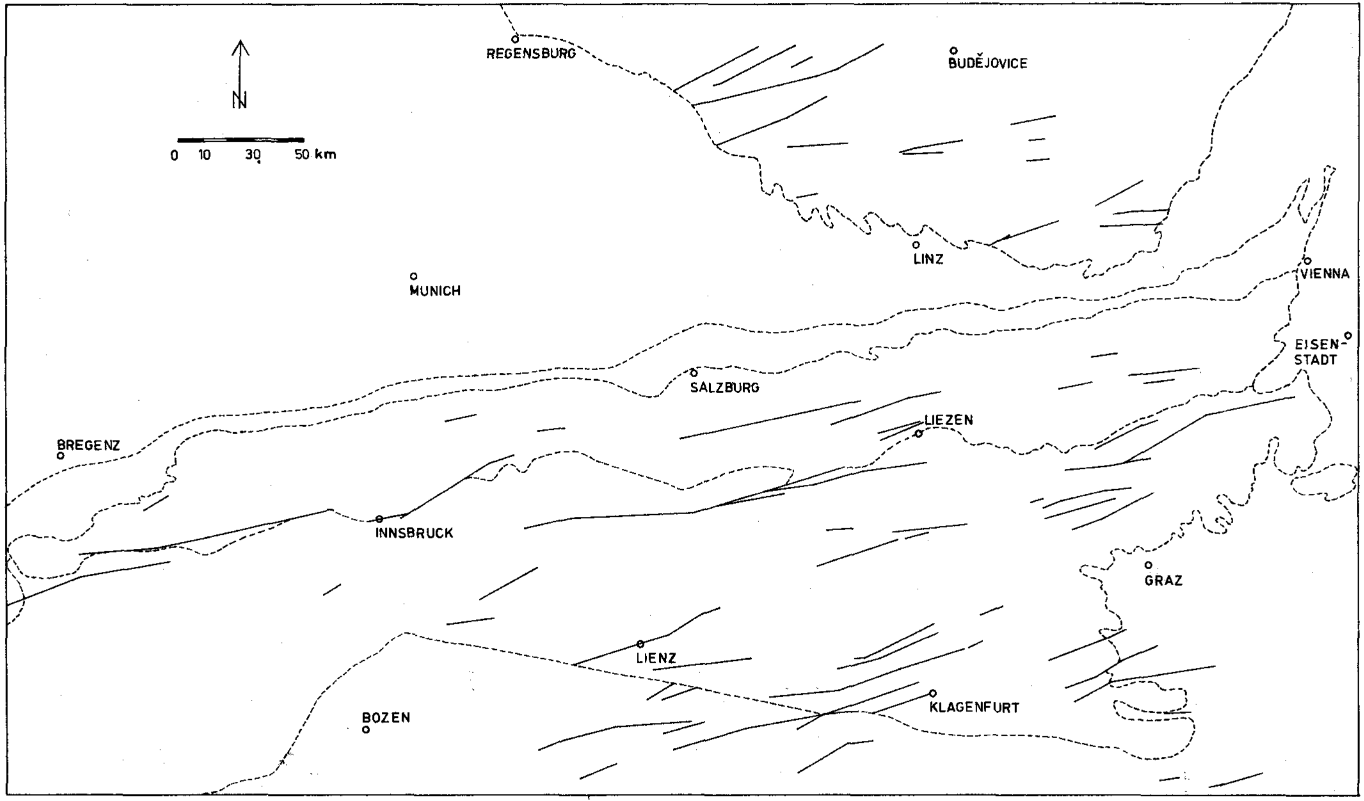

Fig. 16: Plot of digitally filtered LANDSAT lineaments between 60 and 85 degrees.

7. Supplementary Notes on Structural Geology

It was R. P. GUPTA who first (1977) delineated sets of faint W-E and NW-SE trending lineaments by means of LANDSAT 1 and 2 images and who revealed their importance as post-Alpidic features (which, logically, crosscut all earlier trends and boundaries). The validity of his statements on the relationship between predominant lineation trends, shear strength and tensile failure as well as on the relation of post-Alpidic faults in the Munich-Milano section and of the present-day stress field (H. ILLIES & G. GREINER 1976) could be proved in other parts of the Eastern Alps.

How do the quantitative results obtained in this study match the distribution of lineament trends discovered by R. P. GUPTA 1977 and the corresponding stress fields respectively (H. ILLIES 1975, G. RANALLI & T. E. CHANDLER 1975, H. ILLIES & G. GREINER 1976, A. E. SCHEIDEGGER 1981)? If we look at the overall rose diagram of the Austrian Part of the Eastern Alps (pl. 3 fig. c) we can clearly indentify the S_1 group (± 45°) of R. P. GUPTA 1977, which is of shear origin, as the prominent maximum in the NE. It is a striking and actually surprising fact that GUPTA's S_2 (± 165°) and T group (± 15°; which runs parallel to the Paleozoic „Rhenish" direction) do not come out obviously in the synoptic diagram of the Austrian Alps. In the Northern (and Eastern) Molasse Zone and in the Northern Flysch Zone, however, the T group is represented by clear peaks. In the discrete diagrams of the Northern Limestone Alps and the Central Alps T is represented by peaks but these are of minor nature. The significance of these tensile structure lines is reduced by the dominance of the other main directions. The T group of lineaments can, albeit not as obviously as shown in this paper, be identified from the Tyrol to the very eastern end of the Alps, if detailed large scale tracing is applied. By generalization, however, they become less evident, although they are still present in places (fig. 3 to 5). The S_2 group of R. P. GUPTA 1977 is, strangely enough, almost not represented in any diagram. Apparently the NE direction was so dominant in the Alpidic past of the Eastern Alps that it actually „overwhelmed" its conjugate direction, although S_1, S_2 and T have to be considered cogenetical. A fact which is well known with shear systems.

In connection with the 15° T direction, which is represented in the diagram of the Bohemian Massif by a minor peak (pl. 1 fig. a, pl. 3 fig. a), one's attention may be drawn to the Boskovice Graben and to the Korneuburg Graben. At first it must be states that, in contrast to the opinions of A. TOLLMANN 1977 a and P. BECK-MANNAGETTA & A. MATURA 1980, by studying multitemporal LANDSAT scenes and applying simple transformations to MSS CCT data (Linear Intensity Transformation, Histogram Equalization, Ratios) I found no indications for a continuation of the Boskovice Graben into the Diendorf Fault. (A conjecture which was already made by F. BRIX, A. KRÖLL & G. WESSELY 1977, probably based on geophysical data; also W. VASICEK, Eggenburg, oral communication; not so A. KRÖLL, K. SCHIMUNEK & G. WESSELY 1981). It rather seems that this structure continues in SSW direction more or less straight down to the Austro-Czechoslovakian border and even farther. The aeromagnetic map of Czechoslovakia (O. MAN 1967) also corroborates this conception. The Paleozoic sediments ESE of Znajmo which can be visualized in digitally treated LANDSAT scenes are situated close to the southern clearly discernible end of this lineament, whereas the Upper Carboniferous and Permian deposits at Zöbing seem to fill the northeasternmost wedge-shaped end of a graben formed by the Diendorf Fault and (one branch of the) Steinbach Fault. The continuation of the Diendorf Fault to the NE is rather assumed to crosscut the Boskowice Graben in an acute angle.

At the northwestern margin of the Flysch Zone NW of Vienna we find a fault running subparallel to the Diendorf Fault along the (surface) border line between the Tulln Plains and the Vienna Forest. It seems to be cut by the „traverse" Donau Fault before it reaches the NNE trending Korneuburg Basin (cf. A. KRÖLL & G. WESSELY 1980). The latter structure only represents a minor feature which, as far as can be concluded from LANDSAT indications, forms an asymmetric graben structure with a very low eastern flank inside the general stair-like structure. In this context another major structural trend line running parallel to the Boskovice Graben appears remarkable. It is the lineament zone heading from E of České Budějovice in NNE direction to Mladá Boleslav and farther, which in places shows a graben structure, too (A. BIELY et al. 1967).

The structures just mentioned are also interesting to be looked at in the light of Recent tectonic movements. With two of them the Variscic formation can be proved. In contrast to A. KRÖLL, K. SCHIMUNEK & G. WESSELY 1981 cum lit. I also assume the Korneuburg „Graben" and its northern continuation to be caused by possibly Paleozoic features in the crystalline basement – which does not necessarily imply any ascertainable dislocations during this period at all – in that sense that old zones of weakness or discontinuity planes were (re-)activated by Mesozoic and later movements. Recent displacements along fractures with dominance of the vertical ones have been recorded from the Bohemian Massif. The strongest vertical and horizontal movements, however, take place in the border area between the Bohemian Massif and the West Carpathians. The horizontal dislocation of the Bohemian Massif in relation to the Carpathians has been calculated by geodetic methods to be about 1 cm per year, the latter unit relatively moving northwards (P. VYLKOČIL 1975, 1977). This result fits very well into the model of plate tectonics as proposed by J. F. DEWEY & J. M. BIRD 1970. – The importance of the southern spur of the crystalline Bohemian basement for the sharp deflection of the Alpidic fold belt is commented by A. TOLLMANN 1978 a and A. KRÖLL, G. SCHIMUNEK & G. WESSELY 1981.

The whole system of structural lineaments should also be seen from the view point of the intraplate tectonics conception of consolidated blocks (H. ILLIES 1975, H. ILLIES & G. GREINER 1976, A. TOLLMANN 1978 a). Young movements evidently reactivated old fracture lines and shear zones of the Variscic basement. If we follow the authors mentioned above in taking, among others, the Karlovy Vary – Usti Lineament in NW Bohemia (A. BIELY et al. 1967) and the Inneralpine Vienna Basin (cf. A. TOLLMANN 1969, 1970, 1978 a, b), as rift valleys (which follow, however, different Variscic directions: „Erzgebirge" and „Rhenish" direction, L. KOBER 1942) with a rifting activity culminating in the Middle Miocene to Lower Pliocene, we might also look at the Korneuburg Graben, the Boskovice Graben and the České Budějovice – Mladá Boleslav Lineament as tensile zones subparallel to the Rhinegraben. These linears, again, represent reactivated preexistent sets of fault lines („Wiederaufreißen der verklebten Narben alter Lineamente", H. IILLIES & G. GREINER 1976); whereby no statements about the ages of their original generation shall be made here. Anyway, in the general sense the Rhinegraben – Hohenzollern Graben area and the area N of the Eastern Alps lived more or less the same structural history in the northern foreland of the Alpine orogenic belt (a picture which changes farther to the E). Hence we may be authorized to see both areas in rather the same megatectonic light. – If we further assume Recent movements (P. VYSKOČIL 1975, 1977) to follow preexistent planes of inhomogeneity in the crystalline basement (cf. P. KRONBERG 1976, H. THURM et al. 1977, A. TOLLMANN 1978 b), these old fracture zones become more interesting. (A fact which might also have its implications for the determination of construction sites etc.)

Taking structurally controlled deviations of the Danube as connecting links, some remarks on linears not so clearly visible in LANDSAT imagery, which were not discarded by A. TOLLMANN 1977 a and which have not been taken into account for this digital evaluation yet, may be justified. All these features more or less follow a 155° NNW trend (cf. fig. 12; KRONBERG 1977). The westernmost, least visible one is the Isar Line which starts right at the Achen Pass (or even farther in the S) and continues at the western suburbs of Munich. Its northward continuation as well as the following line are known from petroleum exploration geophysics. This lineament („Freising Line“) starts E of Kiefersfelden near Kufstein, where the river Inn gets a sudden deviation into a straight NNW (155°) course. It passes by the cities of Freising and Ingolstadt and runs right into a nick in the Frankish Alb. At Rosenheim another lineament branches off in an acute angel, which runs slightly E of the Freising Line. The Salzach Traverse Fault (A. TOLLMANN 1977 a) is not that clearly visible and can only be vaguely identified in the foreland. Its relationship to the Landshut-Neuötting Fault (R. MÜHLFELD 1968) has not been clarified by means of satellite imagery in this study. The assumption of A. KRÖLL, G. SCHIMUNEK & G. WESSELY 1981 that the Windischgarsten Fault represents the eastern continuation of the Landshut-Neuötting Fault seems quite possible, although a more detailed study of digitally treated LANDSAT data has still to be done to prove this presumption.

Another, clearly traceable feature is the Mattig Line which starts at Mondsee and crosscuts the Zell Line. It can even be delineated southwards into the Kammer Gebirge. To the NNW it seems to cross the Inn and the Danube (causing some river deviation there) and to continue into the Bohemian Massif (cf. pl. 1 fig. a). The existence of the latter deep-seated feature has also been proved in Bavaria by geophysical means. K. KOLLMANN & O. MALZER 1980 show a part of this lineament in the surrounding of Braunau, also as a small graben-like structure, in their map of Upper Oligocene faults. I even assume the lobular deflection of the border line of the „Central Jurassic High“ in the Mauerkirchen area SE of Braunau (F. WEBER, E. BRAUMÜLLER & L. WAGNER 1980) to be subject to structural conditions in the basement.

Inbetween the four linears just mentioned still several minor faults exist (cf. H. KRAMER & A. KRÖLL 1979, A. KRÖLL, K. SCHIMUNEK & G. WESSELY 1981). These subparallel faults fit quite well into the conception of the lineaments arranged in pairs of A. TOLLMANN 1977 a (cf. R. GÜNTHER 1977) which in places might later either develop to step-like faults or even to graben-like structures by vertical movements (cf. K. KRÖLL, K. SCHIMUNEK & G. WESSELY 1981). The Mattig Line might represent such a slight graben structure. – All these linears quite well correspond with the S_2 group of shear lineaments of R. P. GUPTA 1977. The maximum shown in the digitally derived rose diagram (pl. 1 fig. c) represents his S_1 lineation group.

In connection with the structural control of the river course of the Danube another feature shall be mentioned here which is clearly discernible on summer LANDSAT false colour composites. E of Korneuburg the ancient river bed of the Danube runs eastwards into the area N of Bratislava, turning slightly southwards farther to the E. (Attention was first drawn to this fact by L. BECKEL, Vienna.) I assume that the direction of this part of the river course was also controlled by one or a set of E-W trending faults which might represent a continuation of the fault passing by Spitz an der Donau. Only later the river was diverted by the wrench fault of the „Donaubruch“ (F. BRIX et al. 1977) which shows a displacement up to 1.5 km and which cuts the Korneuburg Basin in the south. Possibly the Donau Fault also represents a deep-seated element which, as far as one can deduce from LANDSAT imagery, continues towards the village of Grossmugl and even farther to the NW (cf. A. KRÖLL & G. WESSELY 1980).

It may be noted briefly that, from the remote sensing point of view, there exist no indications for a „connection“ of the Tonale Line and the „Thermenlinie“ (in the common definition used in geo-scientific literature) as claimed by A. GUILLAUME 1978. On the other hand I quite agree with a continuation of the Insubric (Jorio) – Tonale Line into some other lineaments farther to the E (which are more or less obvious in LANDSAT imagery and) which would of course imply a modification of the palinspastic model of H. P. LAUBSCHER 1973 (cf. also the model by J. S. RATHORE & H. HEINZ 1979, 1980). Possibly A. GUILLAME's interpretation is just due to nomenclatorial misunderstanding. Anyway, this question will be touched upon somewhere else.

One more word about the length of the lineaments and their relation to horizontal displacements: According to G. RANALLI 1976, 1977 there exists a significant relationship between offset and length in strike-slip faults with $40 \leqslant L < 1600\,\mathrm{km}$, L being the length (not taking into account some minor dislocations by crosscutting lineaments). The total offset D can, in a simplified way, be expressed as

$D = \text{const.}\ L.\ \log L$

This implies that the longer the preexisting fault is, the less likely are individual seismic ruptures (slips) to add up along the same part of the fault and to the overall fault length, because this empirically derived equation represents a state of equilibrium which is reached comparatively early during the tectonic life of a fault (G. RANALLI 1977). On the other hand a close correspondence between length and depth of structural lineaments is a well-proved fact. P. VYSKOČIL 1975 could demonstrate that there also exists a good correlation between the velocity of displacements, the depth of the mantle and the depth of the crust:

$V = f\,(d_{moho}) = f(d_{conrad})$

which means that length and velocity of tectonic movements along a lineament are correlated, too.

With regard to these facts satellite images which provide a rather accurate and fast tool for length mapping of lineaments can also be used to draw conclusions on seismic events and thus well assist in decisions concerning construction sites and in regional planning. The implications of the above mentioned correlations on the fault system of Austria can easily be deduced when looking at fig. 2 and 10 to 16. In this respect the map given by J. DRIMMEL 1981 may be an excellent supplement.

For further information about the genetic aspects of the structural lineaments treated in this study the reader is kindly referred to the papers by A. TOLLMANN 1969, 1970, 1977 a, 1977 b, 1978 b and A. KRÖLL, K. SCHIMUNEK & G. WESSELY 1981 cum lit.

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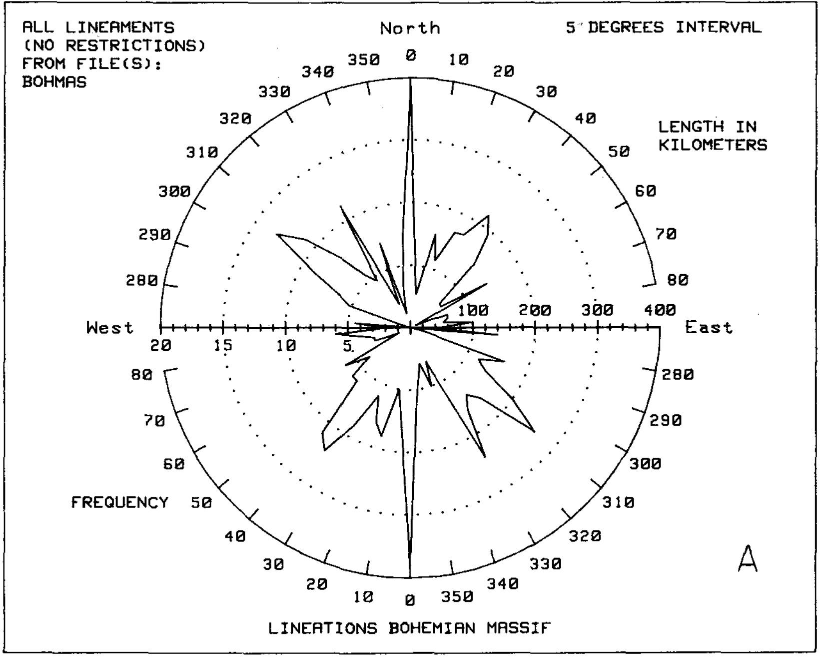
Manuskript bei der Schriftleitung eingelangt am 25. 1. 1982.



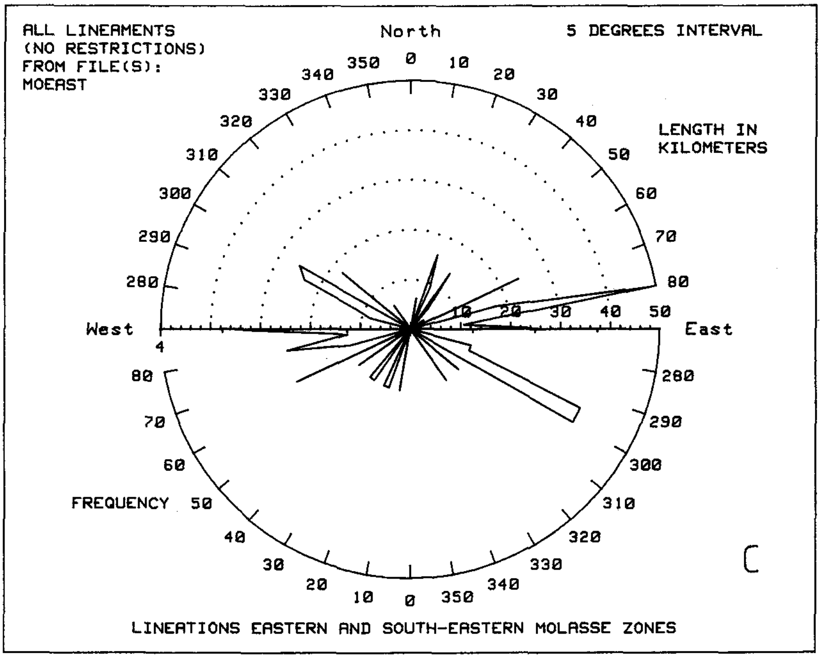
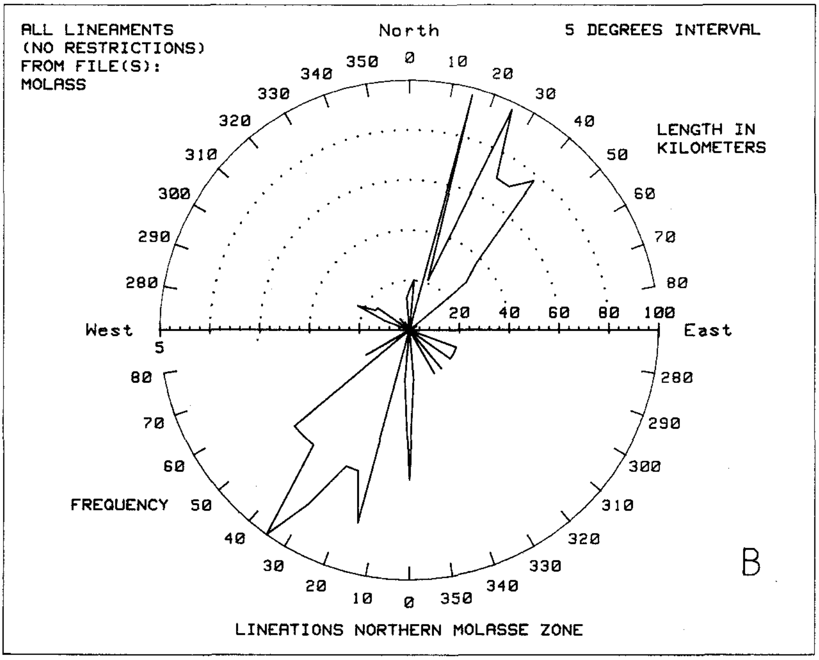
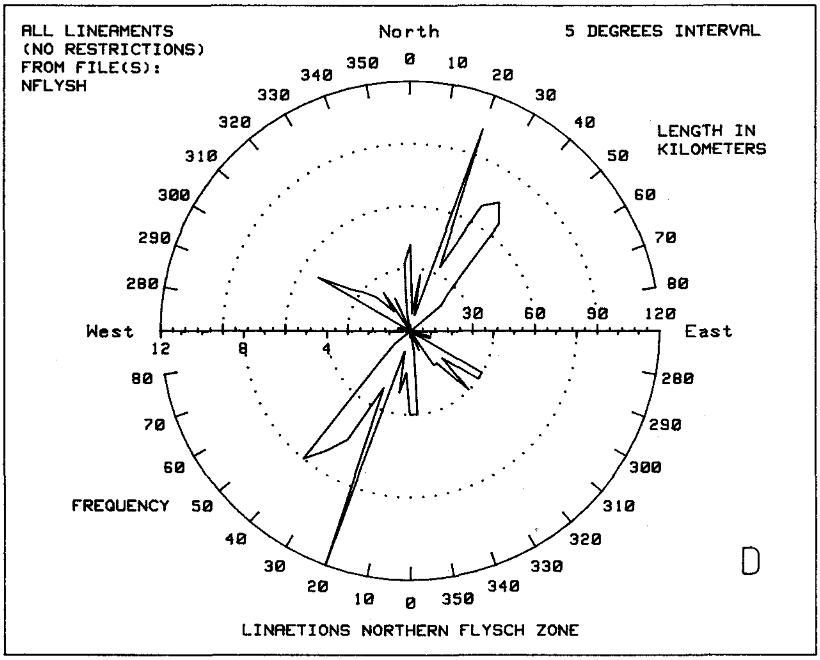
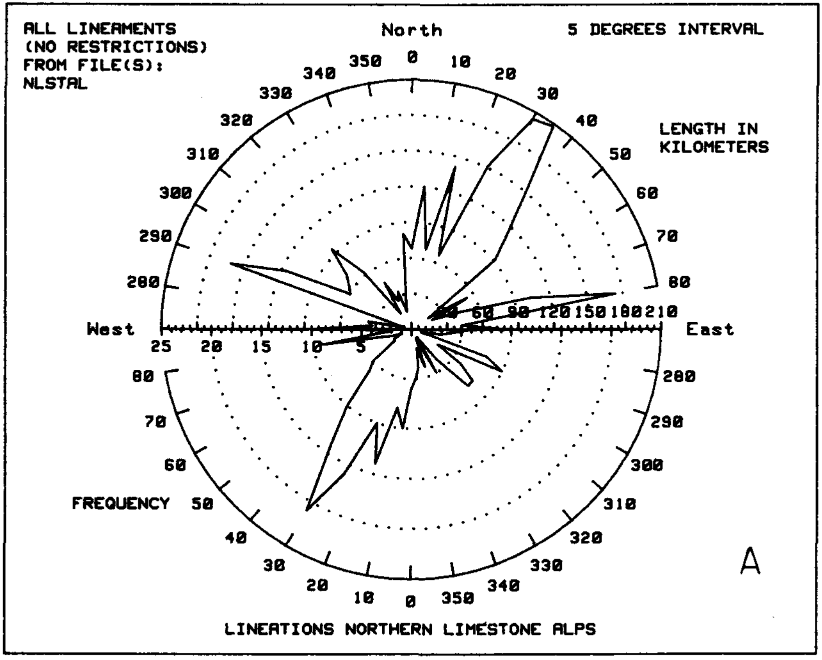


Plate 1: Fig. a – d: Rose diagrams of the Bohemian Massif, the Northern, Eastern and Southeastern Molasse Zone and the Northern Flysch Zone. For more detailed explications see section 6.2.


ALL LINEAMENTS
(NO RESTRICTIONS)
FROM FILE(S):
MOLASS
North
5 DEGREES INTERVAL
LENGTH IN
KILOMETERS
0
10
20
30
40
50
60
70
80
350
340
330
320
310
300
290
280
West
East
20
40
60
80
100
5
280
290
300
310
320
330
340
350
0
10
20
30
40
50
60
70
80
FREQUENCY
B
LINEATIONS NORTHERN MOLASSE ZONE


ALL LINEAMENTS
(NO RESTRICTIONS)
FROM FILE(S):
NFLYSH
North
5 DEGREES INTERVAL
LENGTH IN
KILOMETERS
0
10
20
30
40
50
60
70
80
350
340
330
320
310
300
290
280
West
East
30
60
90
120
12
8
4
280
290
300
310
320
330
340
350
0
10
20
30
40
50
60
70
80
FREQUENCY
D
LINAETIONS NORTHERN FLYSCH ZONE



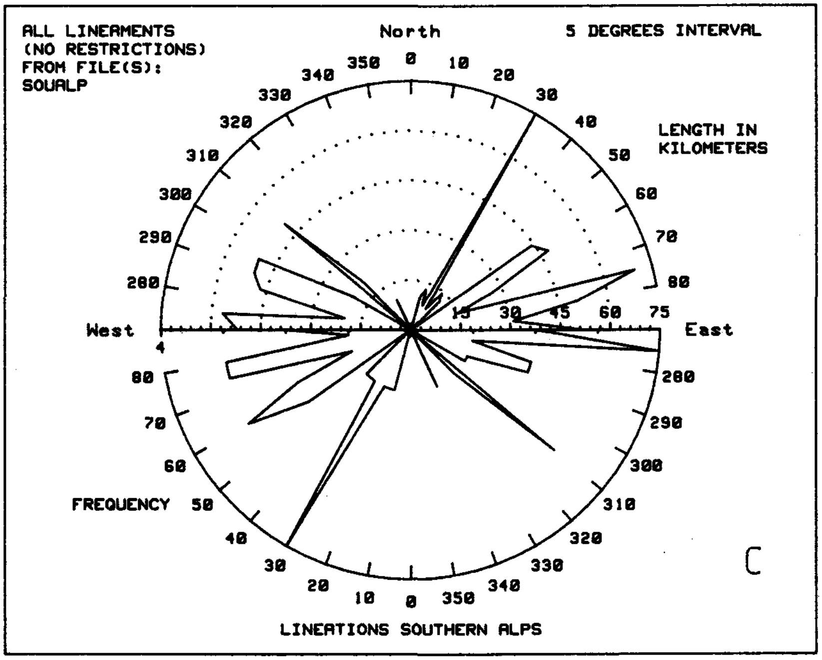
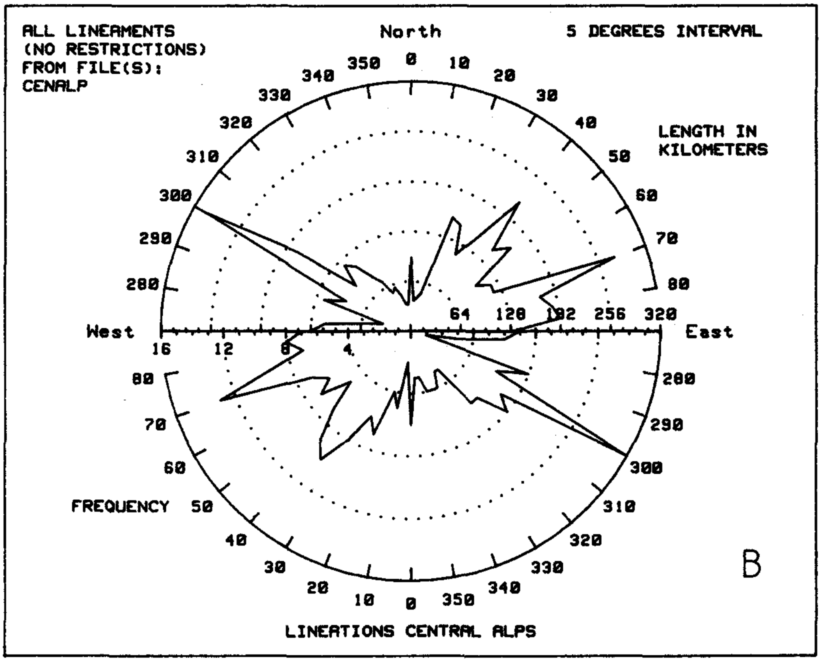
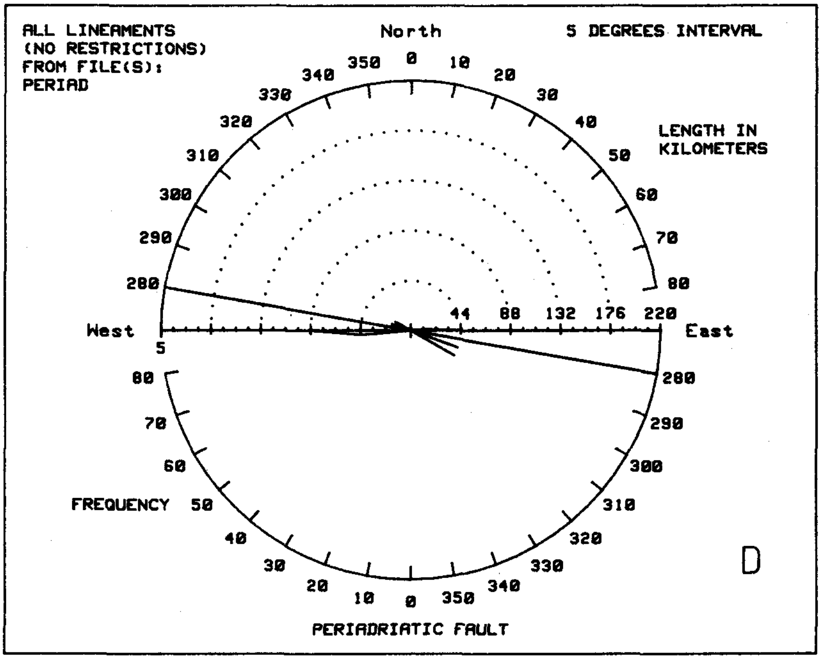


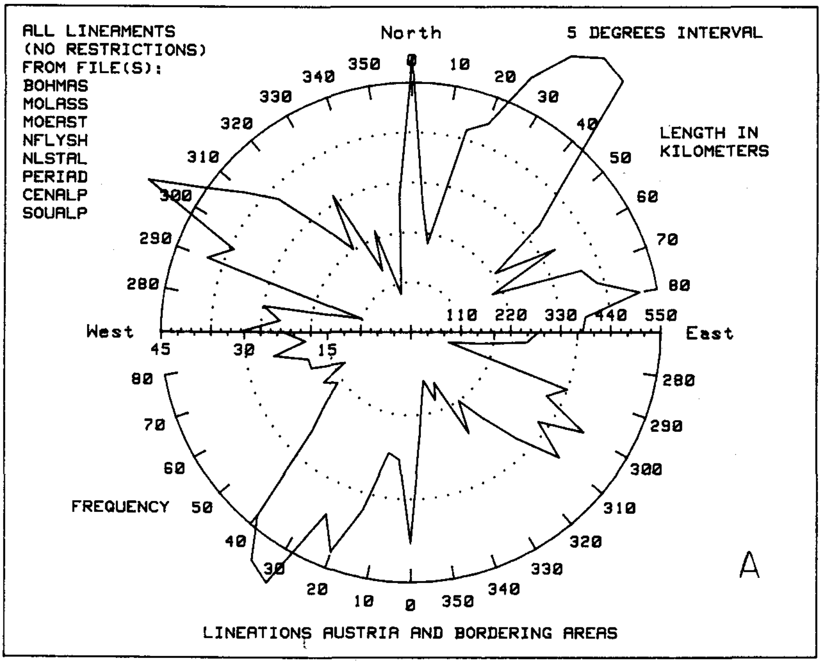
Plate 2: Fig. a – d: Rose diagrams of the Northern Limestone Alps, the Central Alps, the Periadriatic Line and the Southern Alps. For more detailed explications see section 6.2.



LINEATIONS CENTRAL ALPS



PERIADRIATIC FAULT



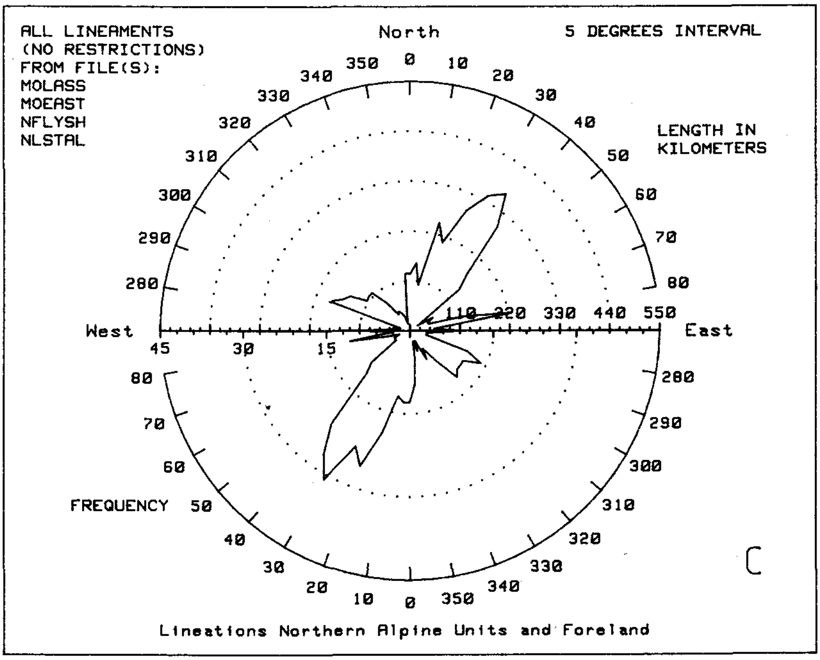
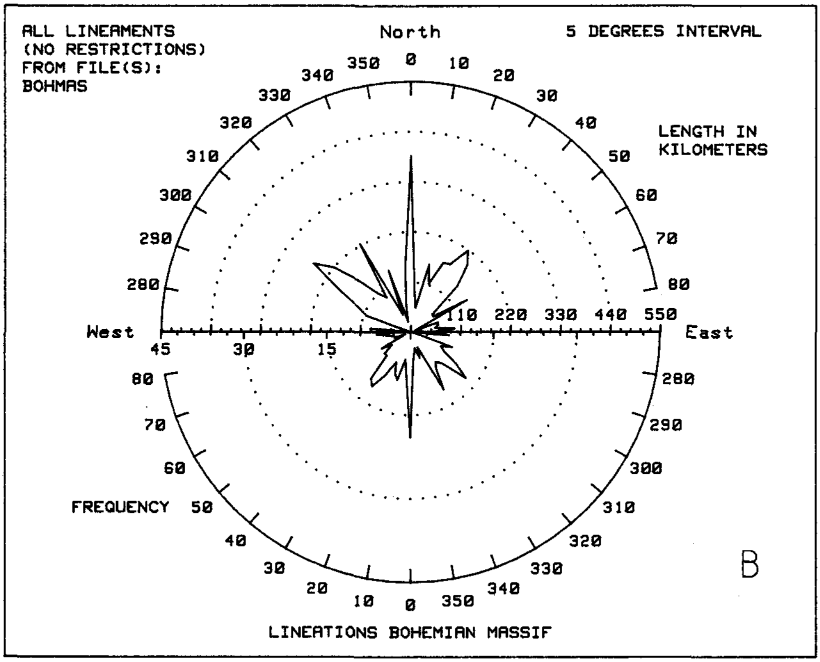
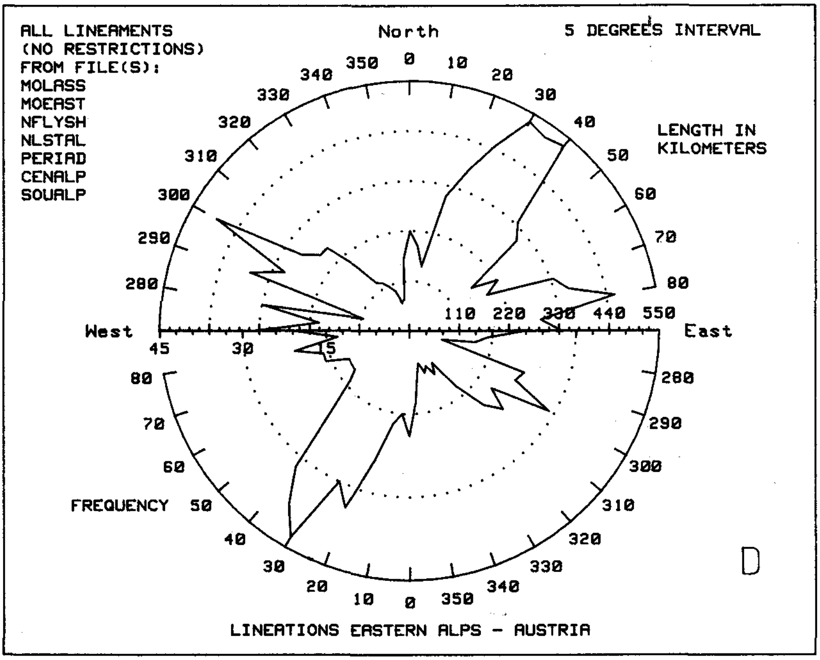
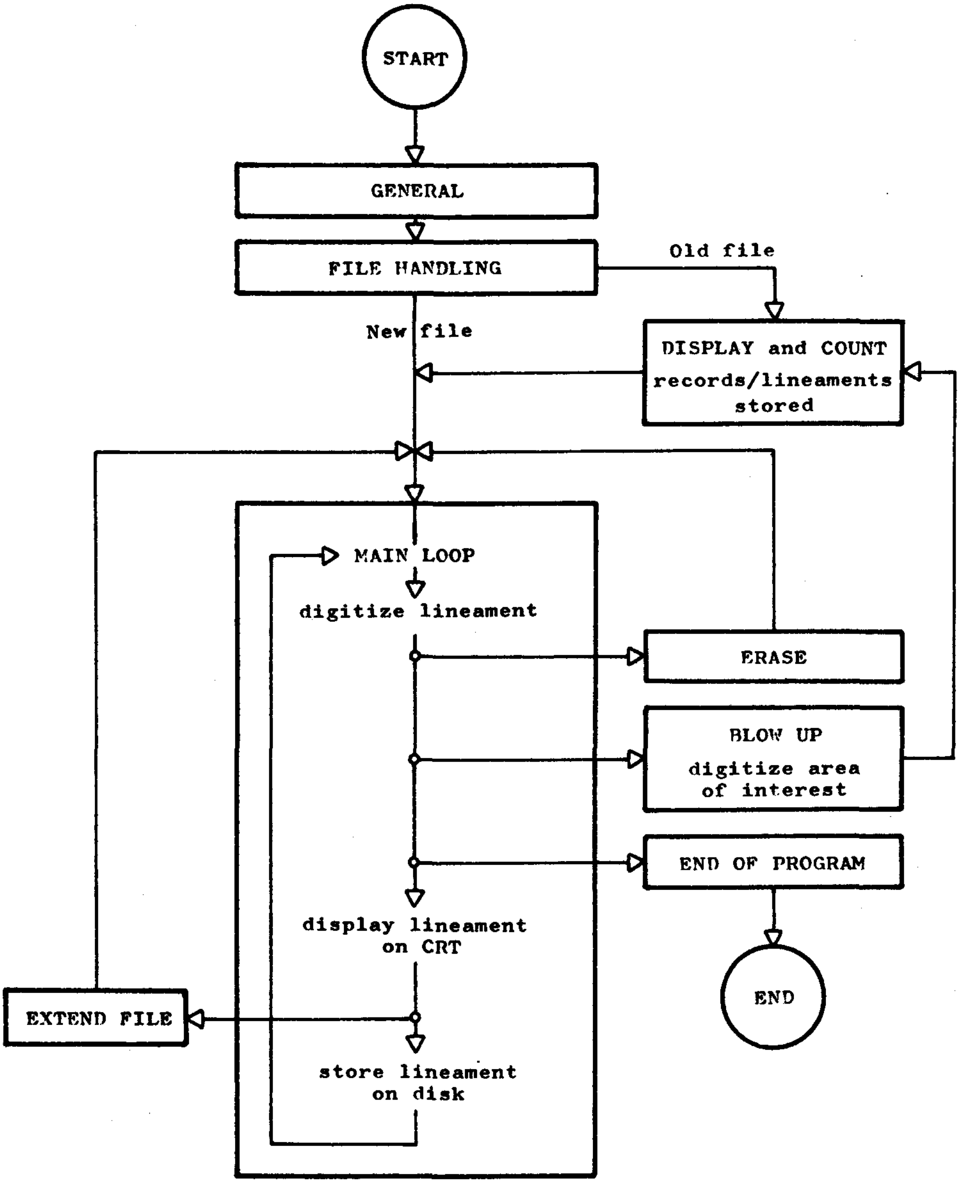


Plate 3: Fig. a – d: Cumulative rose diagrams of the whole area under investigation, the Bohemian Massif, the major geological units N of the Central Alps and the Alpine part of the area studied. For further explications see section 6.2.

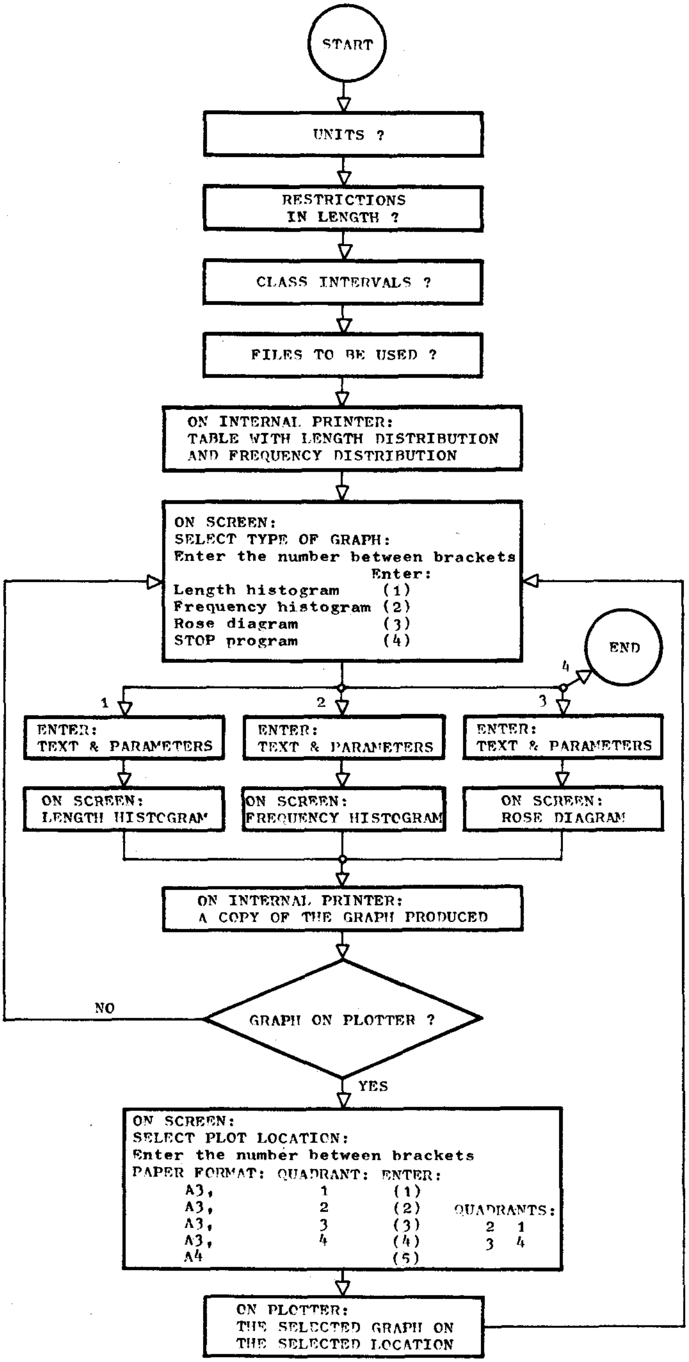

ALL LINEAMENTS
(NO RESTRICTIONS)
FROM FILE(S):
BOHMAS
North
5 DEGREES INTERVAL
LENGTH IN
KILOMETERS
0
10
20
30
40
50
60
70
80
350
340
330
320
310
300
290
280
West
East
110
220
330
440
550
45
30
15
80
70
60
FREQUENCY 50
40
30
20
10
0
350
340
330
320
310
300
290
280
B
LINEATIONS BOHEMIAN MASSIF


ALL LINEAMENTS
(NO RESTRICTIONS)
FROM FILE(S):
MOLASS
MOEAST
NFLYSH
NLSTAL
PERIAD
CENALP
SOUALP
North
5 DEGREES INTERVAL
LENGTH IN
KILOMETERS
0
10
20
30
40
50
60
70
80
350
340
330
320
310
300
290
280
West
East
110
220
330
440
550
45
30
15
80
70
60
FREQUENCY 50
40
30
20
10
0
350
340
330
320
310
300
290
280
D
LINEATIONS EASTERN ALPS - AUSTRIA

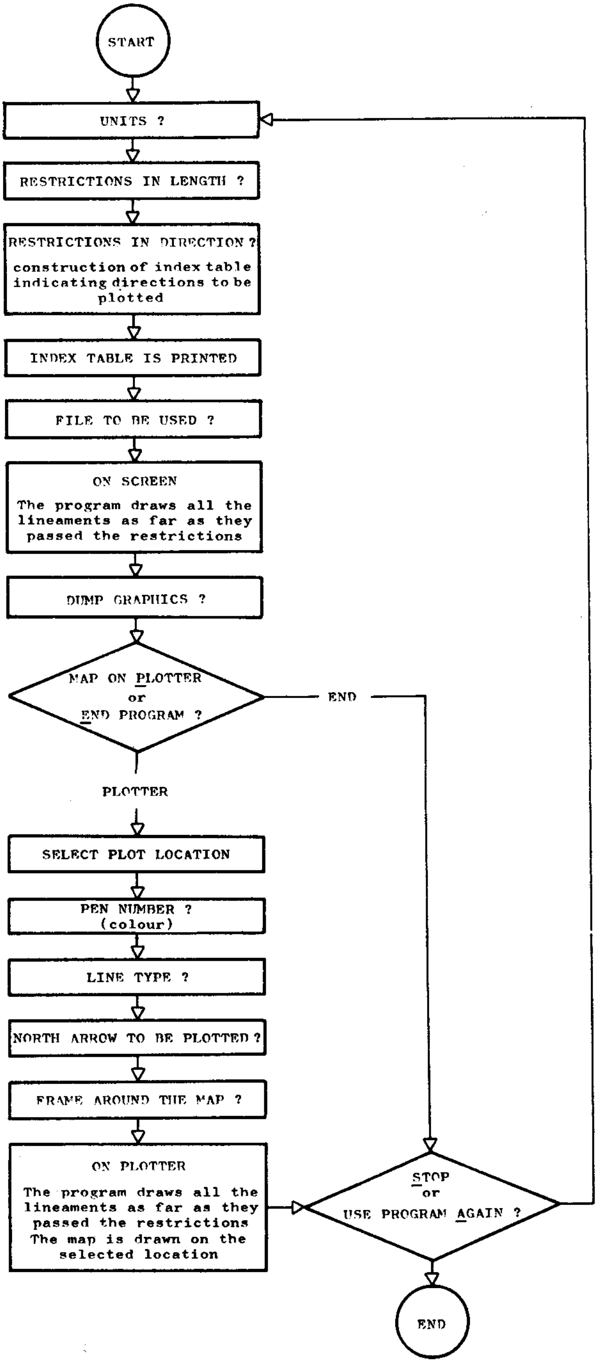
Appendix 1: Flow chart giving the general organization of program DIGLIN.



Appendix 2: Flow chart giving the general organization of program RGRAM.



Appendix 3: Flow chart giving the general organization of program PLLIN.



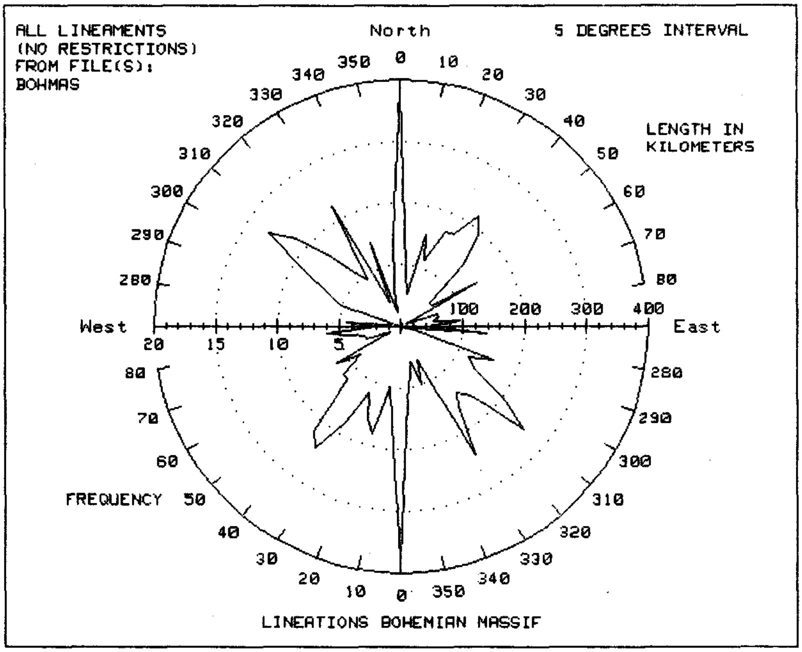
Appendix 4: Example of printer output of program DIGLIN.

```
* PROGRAM DIGLIN *  TO DIGITIZE LINEAMENTS.
==========================================

READ INSTRUCTIONS IN PROGRAM LISTING CAREFULLY!

TO PROCEED WITH PROGRAM: Press CONT


SCALE = 1: 1476732


LENGTH OF LINEAMENTS IS EXPRESSED IN KILOMETERS.






THE FOLLOWING FILES ARE PRESENT ON DISK F8,1:

NAME   PRO TYPE REC/FILE  BYTES/REC    ADDRESS
F8,1        65

BOHMAS     DATA    300        24         2/00
MOLASS     DATA    200        24         2/29
MOEAST     DATA    100        24         3/18
NFLYSH     DATA    300        24         3/28

NEW FILE:NLSTAL

THE FOLLOWING FILES ARE NOW PRESENT ON DISK F8,1.

NAME   PRO TYPE REC/FILE  BYTES/REC    ADDRESS
F8,1        65

BOHMAS     DATA    300        24         2/00
MOLASS     DATA    200        24         2/29
MOEAST     DATA    100        24         3/18
NFLYSH     DATA    300        24         3/28
NLSTAL     DATA   1000        24         4/27

START DIGITIZING LINEAMENT 1  (North arrow !)

   NO.     X1     X2     Y1     Y2(mm)  Length: Angle:
     1     69     69    222    240          26.8   89.6
IS LINE 1 NORTH ARROW?
IF NOT, ERASE THIS LINE AND DIGITZE NORTH ARROW!

     2      8     12     97    104          11.8   60.9
     3     25     46     99    101          31.3    4.5
     4     46     60    101    104          20.3   11.0
     5     60     93    104    111          50.7   12.5
     6     29     30    100    102           3.1   69.8
     7     31     32    105    110           8.7   72.6
     8     33     34    100    101           2.2   72.5
     9     37     45    100    112          21.3   56.2
    10     43     50    111    115          11.6   30.4
    11     50     54    115    119           8.7   36.2
    12     54     56    119    123           6.2   62.5
    13     56     59    123    132          14.7   72.2
    14     51     52    110    118          10.9   87.9
    15     50     49    114    119           6.4  100.3
    16     52     53    128    123           7.8  274.1
    17     68     66    129    125           5.4  251.8
    18     65     62    123    114          13.8  247.7
    19     64     65    107    112           6.3   75.3
    20     66     67    114    117           5.5   71.4
    21     68     69    119    122           4.9   72.5
    22     66     78    133    123          23.3  323.0
    23     75     72    122    125           7.0  142.1
    24     71     68    120    123           6.7  140.2
    25     92     83    135    124          20.7  227.7
    26     83     78    121    113          13.5  237.7
    27     69     95    104    130          54.9   45.6
    28     95     99    130    137          11.0   58.1

LOCATE AREA TO BE SHOWN ON SCREEN:
DIGITIZE LOWER LEFT CORNER,
DIGITIZE UPPER RIGHT CORNER AND WAIT FOR MESSAGE: START/CONTINUE DIGITIZING


CONTINUE DIGITIZING LINEAMENT 29

   NO.     X1     X2     Y1     Y2(mm)  Length: Angle:
```

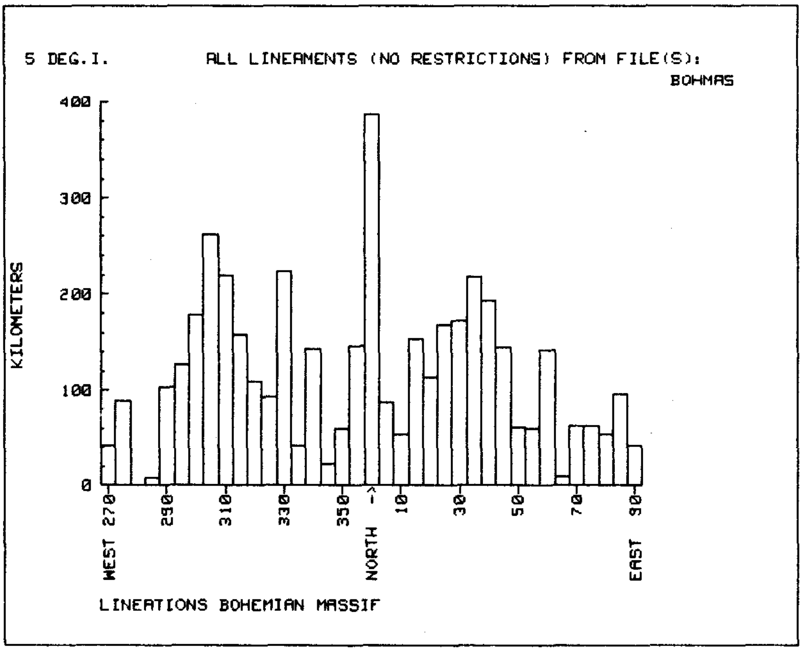
Appendix 5: Example of printer output of program RGRAM.

```
* PROGRAM RGRAM *
=================

LENGTH HISTOGRAM, FREQUENCY HISTOGRAM AND ROSE DIAGRAM CAN BE PLOTTED
USING FILES CREATED BY PROGRAM DIGLIN.


UNITS:KILOMETERS

NO RESTRICTIONS CONCERNING THE LENGTH OF THE LINEAMENTS.

CLASS INTERVAL: 5  DEGREES.

THE FOLLOWING FILES ARE PRESENT ON DISK F8,1:

NAME  PRO TYPE REC/FILE  BYTES/REC   ADDRESS
F8,1        65

BOHMAS    DATA    300        24        2/00
MOLASS    DATA    200        24        2/29
MOEAST    DATA    100        24        3/18
NFLYSH    DATA    300        24        3/28
NLSTAL    DATA   1000        24        4/27
PERIAD    DATA     50        24        8/01
CENALP    DATA    700        24        8/06
SOUALP    DATA    300        24       10/12
DUMMY     DATA      5        24       11/11

FILENAME 1 = BOHMAS


FILE:BOHMAS
NORTH DIRECTION:  89.4
 236 LINEAMENTS


                    DEGREES          KILOMETERS  FREQUENCY
                (Azimuth North)

     CLASS   CLASS    CLASS BOUNDARIES
     NUMBER  MIDMARK  LOWER-, UPPER LIMIT

      #  1    270     267.5  -< 272.5      41.7      2
      #  2    275     272.5  -< 277.5      89.2      7
      #  3    280     277.5  -< 282.5       0.0      0
      #  4    285     282.5  -< 287.5       7.7      1
      #  5    290     287.5  -< 292.5     103.6      8
      #  6    295     292.5  -< 297.5     126.6      6
      #  7    300     297.5  -< 302.5     178.6      7
      #  8    305     302.5  -< 307.5     261.7     10
      #  9    310     307.5  -< 312.5     219.8     13
      # 10    315     312.5  -< 317.5     158.0      8
      # 11    320     317.5  -< 322.5     109.8      7
      # 12    325     322.5  -< 327.5      92.7      8
      # 13    330     327.5  -< 332.5     223.8     12
      # 14    335     332.5  -< 337.5      41.8      3
      # 15    340     337.5  -< 342.5     143.9      5
      # 16    345     342.5  -< 347.5      23.2      3
      # 17    350     347.5  -< 352.5      59.8      4
      # 18    355     352.5  -< 357.5     146.2      6
      # 19      0     357.5  -<   2.5     386.6     19
      # 20      5       2.5  -<   7.5      87.4      8
      # 21     10       7.5  -<  12.5      54.1      5
      # 22     15      12.5  -<  17.5     154.2      9
      # 23     20      17.5  -<  22.5     113.6      8
      # 24     25      22.5  -<  27.5     168.3      6
      # 25     30      27.5  -<  32.5     171.9      9
      # 26     35      32.5  -<  37.5     218.5     12
      # 27     40      37.5  -<  42.5     193.3     11
      # 28     45      42.5  -<  47.5     144.0      6
      # 29     50      47.5  -<  52.5      60.8      6
      # 30     55      52.5  -<  57.5      59.7      4
      # 31     60      57.5  -<  62.5     141.6      6
      # 32     65      62.5  -<  67.5       9.4      1
      # 33     70      67.5  -<  72.5      62.7      3
      # 34     75      72.5  -<  77.5      61.7      3
      # 35     80      77.5  -<  82.5      53.3      4
      # 36     85      82.5  -<  87.5      96.3      6

TOTAL NUMBER OF LINEAMENTS: 236

MAXIMUM VALUES:KILOMETERS   386.6
                FREQUENCY    19
```

Appendix 5: Continuation.

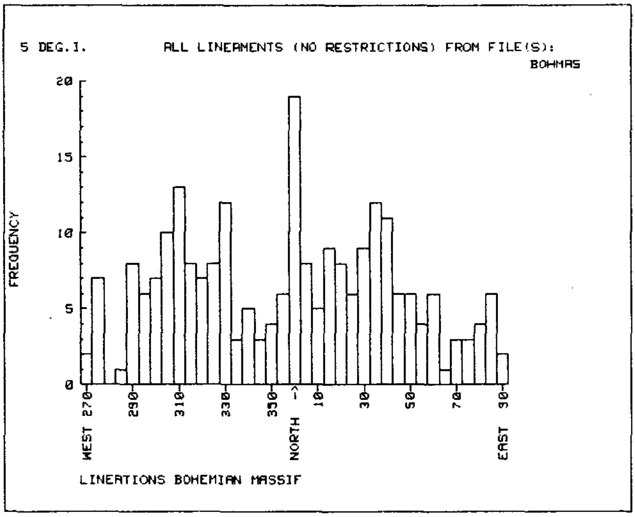


```
TO PROCEED WITH PROGRAM PRESS <CONT>
```



Appendix 5: Continuation.

```
TO PROCEED WITH PROGRAM PRESS <CONT>
```



```
TO PROCEED WITH PROGRAM PRESS <CONT>
### END OF PROGRAM RGRAM ###
```

Appendix 6: Example of printer output of program PLLIN.

```
* PROGRAM PLLIN *  TO PLOT LINEAMENTS DIGITIZED
================================================


NO RESTRICTIONS CONCERNING THE LENGTH OF THE LINEAMENTS.


CLASS INTERVAL: 5 DEGREES


INDEX TABEL FOR DIRECTION CLASSES TO BE PLOTTED:

     CLASS   CLASS     CLASS BOUNDARIES
     NUMBER  MIDMARK   LOWER-, UPPER LIMIT

      #  1    270      267.5 -< 272.5
      #  2    275      272.5 -< 277.5
      #  3    280      277.5 -< 282.5
      #  4    285      282.5 -< 287.5
      #  5    290      287.5 -< 292.5
      #  6    295      292.5 -< 297.5
      #  7    300      297.5 -< 302.5
      #  8    305      302.5 -< 307.5
      #  9    310      307.5 -< 312.5
      # 10    315      312.5 -< 317.5
      # 11    320      317.5 -< 322.5
      # 12    325      322.5 -< 327.5
      # 13    330      327.5 -< 332.5
      # 14    335      332.5 -< 337.5
      # 15    340      337.5 -< 342.5
      # 16    345      342.5 -< 347.5
      # 17    350      347.5 -< 352.5
      # 18    355      352.5 -< 357.5
      # 19      0      357.5 -<   2.5
      # 20      5        2.5 -<   7.5
      # 21     10        7.5 -<  12.5
      # 22     15       12.5 -<  17.5
      # 23     20       17.5 -<  22.5
      # 24 *   25       22.5 -<  27.5
      # 25 *   30       27.5 -<  32.5
      # 26 *   35       32.5 -<  37.5
      # 27 *   40       37.5 -<  42.5
      # 28 *   45       42.5 -<  47.5
      # 29 *   50       47.5 -<  52.5
      # 30 *   55       52.5 -<  57.5
      # 31 *   60       57.5 -<  62.5
      # 32     65       62.5 -<  67.5
      # 33     70       67.5 -<  72.5
      # 34     75       72.5 -<  77.5
      # 35     80       77.5 -<  82.5
      # 36     85       82.5 -<  87.5

FILENAME:CENALP

PRESS <CONT> TO PROCEED WITH PROGRAM.
```

Appendix 6: Continuation.