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On stratigraphic anomalies associated with major transcurrent faulting

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«Nous sommes toujours portés à reconstituer une géometrie de plis, mais peut-être dans ces régions, la part de ruptures nous obligera-t-elle à chercher une expression graphique un peu différente des accidents.»

P. FALLOT, 1930, speaking about the Betic Cordilleras.

ABSTRACT

The example of the Betic Fault System of southern Spain and the Sorong Fault zone of Irian Jaya (former Western New Guinea) show that major transcurrent fault systems may be accompanied by tectonic mega-breccia, containing stratigraphically distinct blocks of exotic material. In some instances these blocks may be of tens of square kilometres in size. The fault zones described run subparallel to the main trend of the orogen and main horizontal displacements appear to have taken place in a late stage of the orogenic history. Examples from other mountain belts are cited from the literature.

Such fault zones and fault systems are likely to be a more common feature of orogens than has been hitherto recognized, because of the common practice of interpreting the associated anomalous stratigraphic relationships within the framework of a nappe model, a diapir model or a combination of the two.

RÉSUMÉ

Les exemples du «Système de failles bétique» de l'Espagne méridionale et de la «Zone failleuse de Sorong» de l'Irian Jaya (antérieurement: Nouvelle Guinée Occidentale) montrent que des systèmes de failles transversales majeures peuvent être accompagnés de méga-brèches tectoniques contenant des blocs stratigraphiquement distincts d'apparence exotique. Dans certains cas ces blocs peuvent atteindre des dimensions de dizaines de kilomètres. Les deux zones de failles décrites sont subparallèles à la direction générale de l'orogène. Il apparaît que des déplacements horizontaux importants se sont produits dans une phase tardive de l'histoire orogénique. Quelques exemples de la littérature sont cités afin de démontrer que des phénomènes semblables se présentent également dans d'autres chaînes de montagne.

Les auteurs concluent que des zones et des systèmes de failles comparables pourraient bien représenter un caractère d'orogènes plus commun que l'on ait reconnu jusqu'à présent à cause d'une pratique générale d'interpréter les relations stratigraphiques anomales associées dans le cadre d'un modèle de nappe, d'un modèle de diapir ou d'une combinasion des deux.

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1. Introduction

The existence of major transcurrent faults, which involve considerable relative horizontal displacements of the adjoining blocks, is nowadays widely recognized. Especially since satellite photographs have become available, a large number have been reported from all over the world, mainly because of their readily recognizable morphologic expression. In quite a few cases, offsets amounting to hundreds of kilometres may be geologically proven.

Various structural phenomena, associated with transcurrent faulting, have been described in the literature. "En échelon" arrangements of deformation structures and the simultaneous occurrence of compression- and extension-structures seem to be characteristic (WILCOX et al. 1973; HARLAND 1971). Major transcurrent faults are not necessarily simple features. Two or more, parallel or "en échelon" faults may form a transcurrent fault system. Smaller transverse faults may connect the major faults, resulting in an anastosmosing fault pattern and the formation of "fault blocks". The main fault zone of such a system is not straight but sinuous. For that reason, adjoining crustal blocks only display pure strike-slip movement along certain parts of the transcurrent fault zone. Along other parts they show either convergence or divergence, introducing deformation with an important vertical

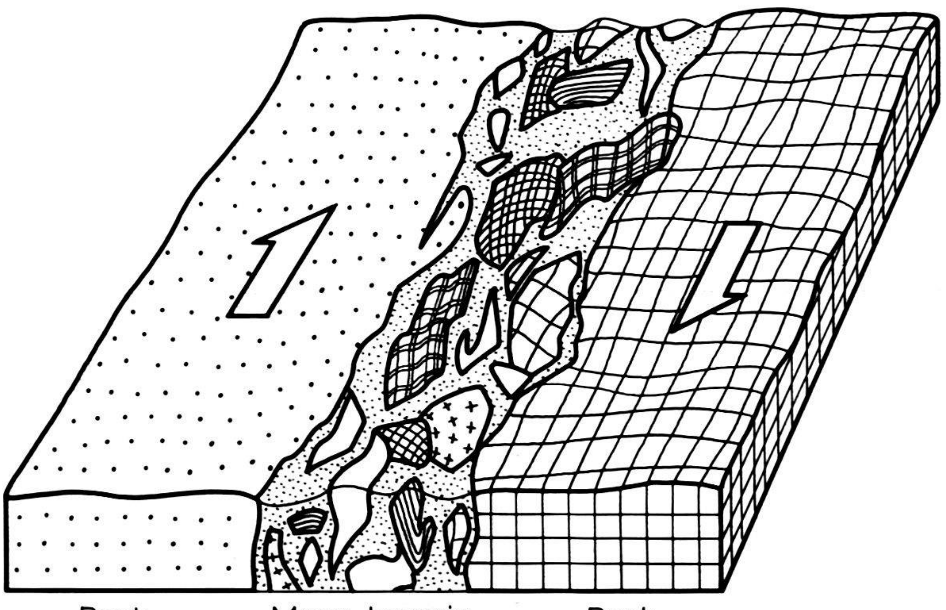

Fig. 1. Diagrammatic representation illustrating a transcurrent fault zone that is accompanied by a mega-breccia in which blocks from different stratigraphic sequences float within a matrix of incompetent components from those sequences. In a N-S dextral transcurrent fault zone within a given area, blocks within the mega-breccia must have come from the south if they originated on the eastern side of the fault zone and must have come from the north of the area in question if they originated on the western side of the fault zone.

component (WILCOX et al. 1973; HARLAND 1971). In the event of strong convergence (over-)thrust faults may develop, by which means one block partially overrides the other (CROWELL 1974). Where blocks diverge, they may be pulled apart (CAREY 1958; KINGMA 1958; CROWELL 1974).

Relatively little attention has been paid so far to the redistribution of stratigraphic units as a consequence of transcurrent faulting. The most obvious feature, the separation of originally connected rock units, is used to determine horizontal displacements along faults. In the present paper some other phenomena accompanying transcurrent faulting will be emphasized. On the basis of two examples familiar to the authors, it is argued that major transcurrent fault zones may contain mega-breccia, comprising stratigraphically incompatible blocks of varying sizes up to several square kilometres. Exotic elements within such a mega-breccia may reveal relative horizontal displacements of hundreds of kilometres. The matrix of the breccia comprises various incompetent rocks present in the stratigraphic column of the affected areas. During the deformation process they facilitate differential movement and mixing of stratigraphically heterogeneous blocks (Fig. 1). The great number of stratigraphically anomalous relationships developing in this way represents an obvious feature of such a transcurrent fault zone.

2. The Betic Fault System (southern Spain)

2.1 *Introduction*

The concept of a Betic Fault System was developed by HERMES (1978a) on the basis of stratigraphic and structural relationships in the area between Caravaca and Vélez Rubio, covering parts of the provinces of Murcia and Almeria. The system is subparallel to the main trend of the Betic Cordilleras and the main movement is believed to have taken place during the Neogene. It comprises a northern fault zone, trending N 70° E, which passes approximately 20 km south of Caravaca. Subparallel to this there is a southern fault zone, approximately 20 km farther south, in the Vélez Rubio Corridor. These two zones are connected by a transverse fault zone in the Zarcilla - Fuensanta depression (Fig. 2).

The northern fault zone separates the North Subbetic area from the South Subbetic area. The zone forms the westward continuation of the Garobera fault of PAQUET (1969), later renamed the Mula-Archena Fault zone (PAQUET 1972). FOUCAULT (1974) extended this fault zone farther east to the Mediterranean coast near Alicante and named it the Crevillente Fault, a denomination we also accept for the westward extension into the investigated area.

The southern fault zone finds its morphological expression in the Vélez Rubio Corridor, an area examined by staff members and students from the University of Amsterdam (i.a. GEEL 1973; SOEDIONO 1971). It extends eastward into the "Zone Limite" of PAQUET (1969) and separates the South Subbetic from the Malaguide complex of the Internal Betic zone.

Important stratigraphical differences exist between North Subbetic, South Subbetic and Betic. The stratigraphic sequence of various blocks, found within the fault zones separating them, cannot simply be explained as a transitional sequence.

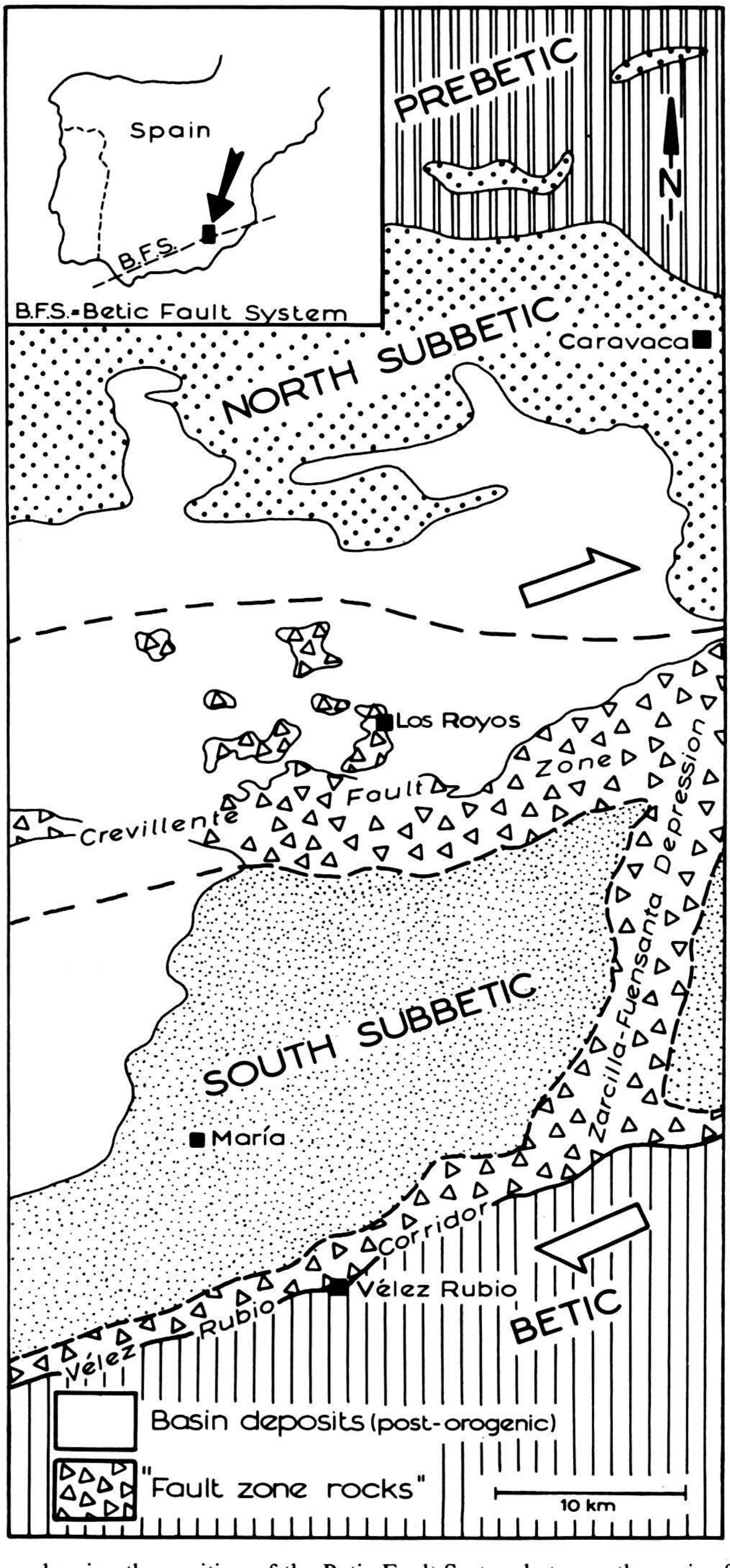

Fig. 2. Sketch map showing the position of the Betic Fault System between the major facies units in the investigated part of the Betic Cordilleras.

Some of those blocks are so distinctly different that they have to be considered truly exotic.

HERMES (1978a) suggested that the two fault zones form part of a chiefly dextral transcurrent fault system, the exotic blocks being transported along it. He also suggested that the South Subbetic itself consists of a number of large, stratigraphically distinct blocks, which are displaced relative to one another along the system.

2.2 *The northern fault zone*

The Crevillente Fault zone, the northern fault zone of the system, will be given special attention in this paper, because its characteristics have played an important role in the development of the present ideas. Within the investigated area the zone has a considerable width, of the order of 5–10 km. Part of it was examined in detail by the junior authors (GRAVEN, DE SMET, Fig. 3). When they started their fieldwork in 1976, it was known already that the geology in this particular zone was more complex than in the adjacent North and South Subbetic zones. The tectonic and stratigraphic discrepancies known at that time could not be satisfactorily explained in terms of nappe structures as was usually done in many other parts of southern Spain. It was decided, therefore, to investigate this zone in more detail and to test the idea that major transcurrent faulting might have determined its geologic structures.

As a result of these investigations the zone was found to consist of many solitary tectonic "blocks" of relatively competent material, floating in an incompetent matrix of mainly Triassic gypsum. As a whole, the complex has the aspect of a gigantic breccia. The sizes of the blocks range from centimetre/decimetre-scale up to kilometre-scale. They show minor and major differences in stratigraphic composition, both lithologically as well as time-stratigraphically.

We speak of "blocks", because these rock masses are often bounded by steep, rather straight faults, which lack any direct relationship to the strike and dip of the strata. Consequently the blocks are often angular and in some cases rhomb-shaped.

The internal deformation of the separate blocks show marked differences with respect to both the intensity of deformation and to the structural directions. Changes of direction and transitions from a less disturbed to a more tectonized zone are also common features within the individual blocks. There is no relation between the intensity of deformation and age; blocks consisting of Eocene deposits may be more tectonized than those of Jurassic age.

Gypsum, generally believed to be of Triassic age, forms the bulk of the matrix between the competent blocks. The amount of gypsum within the investigated part of the Crevillente Fault zone exceeds that of all other rock types. Outcrops form a connected irregular network, locally covering areas of several square kilometres, but elsewhere forming strips only metres in width, separating the blocks. The gypsum not only surrounds the blocks in plan view. It sometimes partially overlies the relatively larger blocks of post-Triassic rock and has often been found underlying them as well. Smaller blocks, with diameters of some tens of metres, are observed on steep slopes completely surrounded by gypsum. Almost everywhere the gypsum is strongly tectonized, and sometimes it looks like a true mylonitic breccia, containing

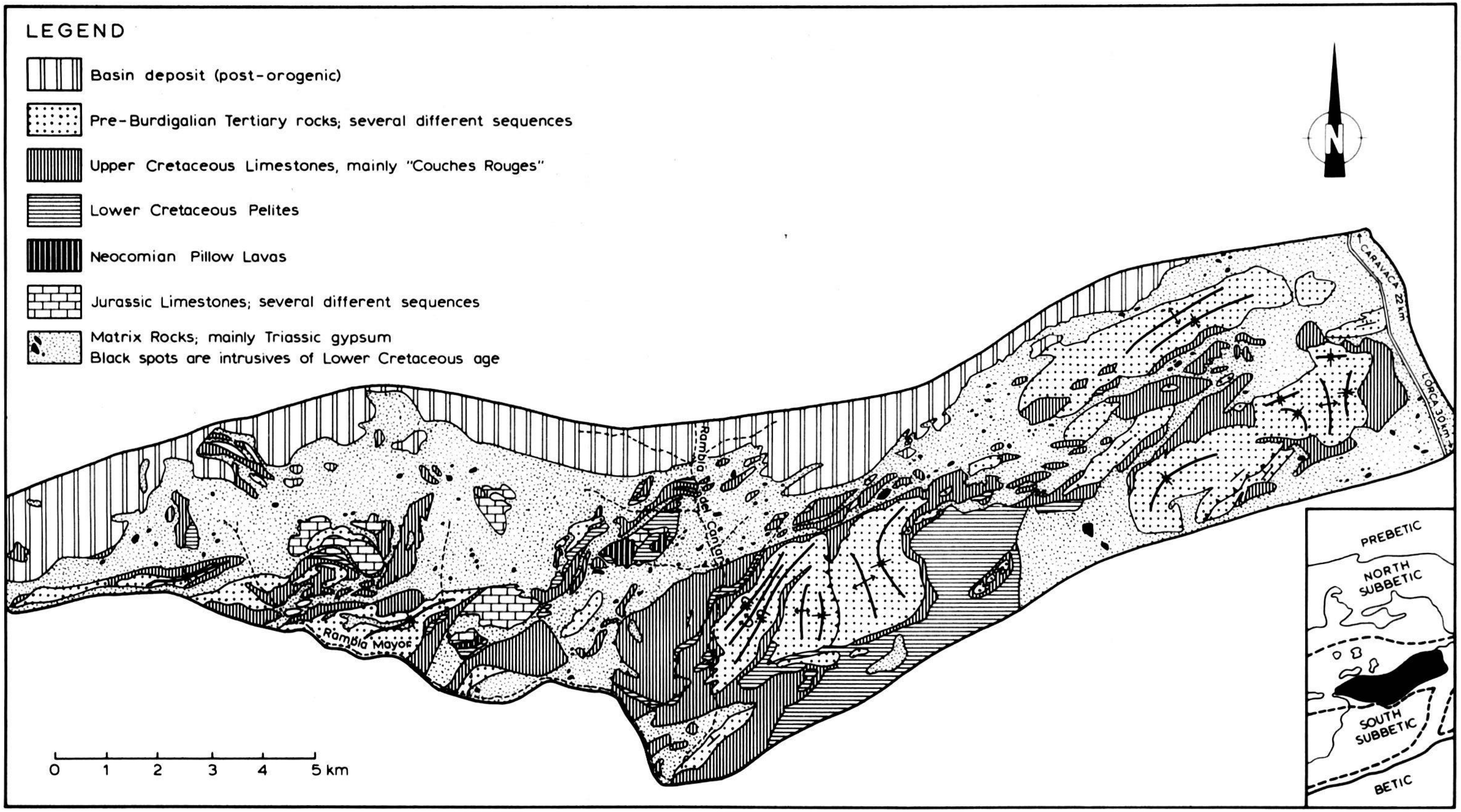

Fig. 3. Simplified geological map of the investigated part of the Crevillente Fault zone, showing a mega-breccia of different stratigraphic sequences within an incompetent matrix of mainly Triassic gypsum. Most contacts between the different rock units are of tectonic nature.

fragments of various other rock types. Blocks of competent Triassic rock, mostly sandstone and dolomite, float within the gypsum like the other blocks of younger material. They cannot be followed over long distances either, but form local masses bounded by anomalous contacts.

A most striking feature of the northern fault zone is the variety of post-Triassic sedimentary sequences encountered in the blocks. They vary in sedimentary facies, thickness and stratigraphic ranges. There are also differences in the gaps occurring in the stratigraphic columns of the various blocks. A few examples serve to illustrate the differences. The Lower to Middle Eocene sediments sometimes comprise poorly bedded red and white chalky limestones (Eocene "Couches Rouges"). A few sandy turbidites are intercalated, being of rather uniform composition. They are thin and brown, and contain a small percentage of larger Foraminifera. In other blocks, however, sediments of the same age consist of yellow-green pelites (Lower Green Pelite formation). They contain some turbidites too, here however of varying composition and thickness. In another block the Lower and Middle Eocene is formed by a third formation, the Melgoso Turbidite formation (HERMES 1978a, p. 24) which is built up of a well-bedded sequence of alternating bluish limestones, yellow and bluish pelites, and yellow larger foraminiferal turbidites; some conglomerates are intercalated. The turbidites show many flute casts and other sedimentary structures and the content of quartz sand is high, up to 40%. Locally the formation has the character of an olisthostrome. The sedimentological nature of the entire sequence is much more proximal than that of deposits of the same age in both the North Subbetic and the South Subbetic. For this reason the block containing this formation is considered to be "exotic".

Another block that is considered to be exotic, contains the Pinosa Turbidite formation, which is of Early Miocene age. It consists of sandy turbidites alternating with silexite bearing marls. The fossil content is very poor. It is the time-equivalent of the Upper Green Pelite formation of the South Subbetic (HERMES 1978a), which also occurs in some blocks within the fault zone. Turbidites are almost absent in this latter formation and the fossil content is higher than in the Pinosa Turbidite formation.

One other "exotic" lithology deserves special attention. This is a sequence of pillow lavas of Neocomian age which forms an important part of two blocks within the fault zone (BEUNK et al., in prep.; VAN DE FLIERT et al., in prep.). Pillow lavas of the same age are found near Huelma, 125 km to the WSW in the Median Subbetic zone of the western part of the Betic Cordilleras (personal communication Prof. Dr. J.M. Fonboté). The easterly end of more or less continuous exposures of this Median Subbetic zone is to be found approximately 100 km west of the present area.

Some other aspects of the variety in the sedimentary sequences concern differences in the time-stratigraphic range represented in different blocks and by the gaps occurring in the successions. Blocks consisting only of Jurassic, or Cretaceous or Tertiary rocks are found along with blocks with a more comprehensive succession (for instance Liassic through to Burdigalian). Gaps in the successions may comprise the entire Cretaceous and Lower Tertiary in one block while in another just the Paleocene may be absent. We cannot exclude a tectonic origin for at least part of these gaps.

A more detailed description of the stratigraphic anomalies encountered in the investigated part of the Crevillente Fault zone will be presented in another paper by GRAVEN & DE SMET. The examples mentioned here illustrate the great variation of stratigraphic sequences. In addition, the blocks show very varied dimensions and styles of internal tectonics and there is an anomalous role for Triassic gypsum. All of these factors typify the stratigraphically and structurally chaotic appearance of this fault zone.

Another interesting feature within the fault zone is that a number of subvertical faults running parallel to the main Betic direction (N 70° E) become inclined faults when they turn away from this trend. Looking only at the outcrops of the subvertical part of such a curved fault, one is at first sight inclined to interpret the tectonic contact as diapiric; the contact usually being between rigid rock on one side and more plastically behaving rock, like gypsum, clay or marl on the other. Outcrops of the NE–N trending parts of such faults, however, show a low angle eastward overthrusting. On a relatively small scale, these structures appear similar to larger ones found along bends of a major transcurrent fault zone, where parts with a pure strike-slip movement turn into parts where crustal blocks converge and overthrusting develops.

The boundaries of the northern fault zone cannot be located exactly. The contact with the North Subbetic is masked by post-Burdigalian deposits of the Barranda-Royos basin, a northeastern offshoot of the Guadix-Baza basin, which covers an approximately 20 km wide, E–W running zone, north of the investigated area. These young deposits are hardly deformed in the central part of the basin. Along their southern boundary the strata are inclined, sometimes to a vertical position. They often are disrupted by steep straight faults, which cause an abrupt tectonic contact with the gypsum and other rocks of the fault zone. Along the extensions of some of the larger faults into the post-tectonic basins, gypsum crops out, probably as a result of diapiric intrusion into extension fissures. In a few instances even fault blocks have been formed of these younger rocks. They are completely separated from neighbouring rock by sheets of gypsum. The formation of these blocks can be considered as a late stage of the fault-tectonic development. The boundary with the South Subbetic is better exposed but by no means always clear and distinct. Triassic gypsum locally protrudes several kilometres further south than elsewhere, and the Southern Subbetic itself displays some quite abrupt stratigraphic changes.

It is beyond the scope of the present paper to describe all the stratigraphic anomalies and related structures in detail. The examples mentioned illustrate our conclusion that the rock sequences of the individual blocks cannot be assembled into one, or even a few stratigraphically and paleogeographically coherent units. The large number of stratigraphic anomalies is characteristic of the zone. We are not dealing with a single occurrence of aberrant stratigraphy for which one might offer a casual explanation. We feel therefore that an interpretation of the stratigraphic anomalies as a result of tectonic disintegration of an intermediate zone between North Subbetic and South Subbetic is unjustified at the present time. Furthermore, the stratigraphic and structural characteristics are not in agreement with what one would expect from large scale diapirism, simple under- or overthrusting, or a combination of the two.

The structural phenomena and relationships, some of which have been referred to, are in good agreement with the model of major (right-lateral) transcurrent faulting. In this, the observed stratigraphic anomalies could be explained by fracturing and differential horizontal displacement along the zone. The gypsiferous Triassic sediments have acted as a buffer and a lubricant, facilitating internal differential movement.

2.3 *The southern fault zone and the area between the two fault zones*

We shall make a few remarks on the southern fault zone (Vélez Rubio Corridor) and the South Subbetic area between the northern and the southern fault zones. The occurrence of two types of exotic blocks will be mentioned in the present context, for more detailed information, however, see HERMES (1978a).

One type of exotic block has a very characteristic mature sandstone of the Aljibe flysch, a rock unit known from the western Betic Cordilleras and, under the name of Numidian sandstones (Grès numidiens) from North Africa, Sicily and southern Italy. In the present area outcrops have been reported from the Vélez Rubio Corridor (GEEL 1973) and from the Zarcilla - Fuensanta depression (HERMES 1978a, p. 39).

A second type of exotic block also occurs in the Zarcilla - Fuensanta depression. It is characterized by a strongly fossiliferous Late Sinemurian to Early Pliensbachian sequence (TURNŠEK et al. 1975). Elsewhere in the South Subbetic this sequence consists of grey dolomites and dolomitic limestones in which only stromatolites have been found hitherto. Concerning the South Subbetic between the Crevillente fault zone and the Vélez Rubio Corridor, HERMES (1978a) has pointed out that it possibly consists of a number of very large allochthonous blocks transported a considerable distance along the fault system. Considerations leading to this hypothesis are:

- The stratigraphy is similar to that of the Penibetic zone and to some of the flysch units of the Campo de Gibraltar and thus of the internal (= African) zone.
- Tectonically the area is aberrant with a predominance of southward verging folds and southwards overthrusting. Although of minor occurrence in view of the broad exposures in the bordering fault zones, Triassic rocks crop out at a few places where steep tectonic contacts between different blocks are suspected. Small scale folding along subvertical axes has been encountered locally near these and other steep faults.

HERMES (1978b) has suggested that the entire Betic Cordilleras, from the Hercynian Meseta and the Iberian Chain in the north to the Alboran sea in the south, might represent one large shear zone, similar to that of the northern part of the island of New Guinea, which we discuss below.

3. The Sorong Fault zone of Irian Jaya (Western New Guinea)

The Sorong Fault zone runs along the north coast of Djazirah Doberai, the northern peninsula of the western part of the island, which was formerly called

"Vogelkop" (Fig. 4). The fault zone and the geology of the area is described in detail, by VISSER & HERMES (1962) and HERMES (1968, 1974).

The Sorong Fault zone forms the boundary between a zone of characteristic eugeosynclinal deposits (pelagite-ophiolite association) in the north and miogeosynclinal deposits (shallow water clastics and carbonates) in the south. A sinistral displacement along the fault amounting to 360 km has been recorded (HERMES 1974). The width of the fault zone so far established is of the order of 4–10 km but locally it may be much larger.

In the fault zone, brecciated and fragmented rocks are found of very varied size and lithology. Their diameters range from sand-size to blocks of the order of kilometres. For example, there occurs a block of granite, more than 10 km long, near Sorong (VISSER & HERMES 1962; HERMES 1968, 1974). An inventory of the components of this gigantic breccia in the area around the village of Sorong on the northwest point of the peninsula may be found in VISSER & HERMES (1962). Most of the elements could be identified with rocks cropping out in the immediate surroundings. However, a small number of lithologic types remained which were only known from rock units cropping out near the fault zone at a considerable distance (of the order of hundreds of kilometres) from their present position in the fault breccia.

Of particular interest is that in the area east of Sorong, in the Tamrau Mountains north of the fault, there is a block (or possibly a number of blocks) with Mesozoic formations representing the only known occurrence of miogeosynclinal deposits

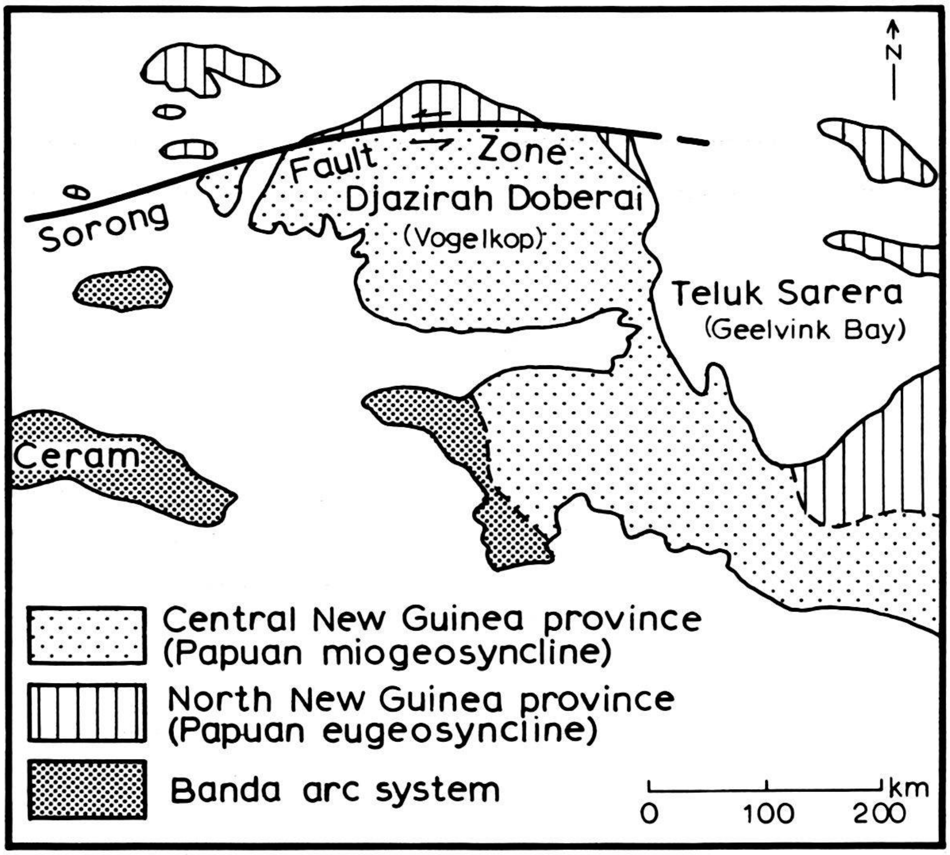

Fig. 4. Location of the Sorong Fault zone (New Guinea).

occurring north of the fault zone (VISSER & HERMES 1962, encl. 2). This evidence suggests that the width of the faulted zone could be much larger than of the Sorong Fault zone sensu stricto and thus that the Sorong Fault zone forms part of a more comprehensive fault system.

The Sorong Fault zone terminates in the Manokwari area at the northeastern tip of Djazirah Doberai. This is suggested by the presence of an eastward directed overthrust zone accompanied by a strong negative gravity anomaly along the entire western shore of Teluk Sarera (formerly called Geelvink Bay). The fault system, however, continues along the north coast of New Guinea across Teluk Sarera. Apart from topographical features favouring this hypothesis, numerous records of sinistral transcurrent faulting have been reported from areas more to the east (CAREY 1938, 1976; ROBINSON & RATMAN 1978; DOW 1977 and many others). Of particular interest for our present purpose is CAREY's thesis (1938) which relates the structure of New Guinea with the Melanesian Shear System.

In his description of the "master shears" CAREY (1938, p. 67) mentions that they are always accompanied by very wide (200 or 300 feet) "pug and shear" zones in which it is "surprisingly common ... to find large blocks of foreign material, frequently old basement rocks, as fault erratics in the stream beds in the vicinity of these large shear zones. Sometimes the shear zones are literally packed with these foreign materials ... metamorphics, crystallines, diorite, or perhaps Eocene or Lower Miocene limestones belonging to a much lower part of the stratigraphic column than the outcropping strata. Some of these fault-erratics are quite large for they not infrequently exceed ten feet or more in diameter."

4. Comparable features in other orogens

Transcurrent fault zones subparallel to the strike are a well-known feature of most orogens, as emphasized for instance by ERNST (1971, 1977). There is, however, still uncertainty or controversy over the amount of lateral displacement, and the presence of "exotic" blocks is only occasionally mentioned in relation to transcurrent faulting. The following examples may serve to illustrate that the phenomena reported from the Betic and New Guinea orogens could be of more general occurrence.

4.1 *The Great Glen Fault System*

The Great Glen Fault shows a minimum net sinistral displacement of about 150 km, although there has been some dispute about this in recent years (see JOHNSON & FROST 1977).

In his memorable description of this well-known fault KENNEDY (1947) mentions that "at the surface the line of disruption is marked by a broad belt of crushed, sheared and mylonitized rock, up to a mile in width". The main movement is stated to be post-Middle Old Red Sandstone (Late Devonian - Early Carboniferous).

EYLES & MCGREGOR (1952) record the existence of "schistose beds of unusual character" that "did not recall those of any Scottish formation with which I (EYLES) was familiar". They state, moreover, that the Great Glen belongs to a fault system, with some other faults running slightly oblique to it. In fact the system includes at least eight other major subparallel, sinistral, strike-slip faults. These have measurable sinistral displacements of 1-10 km along strike (e.g. the Ericht-Laidon Fault, 4 km; Loch Gruinart Fault, 9 km: see BORRADAILE 1973; WESTBROOK & BORRADAILE 1978). These faults occasionally bound rhomb-shaped blocks of country rock of several square kilometres in area. Reconstruction of fault displacements along slightly sinuous faults shows that lozenge-shaped fault blocks (perhaps the forerunners of exotic blocks) must be formed as a consequence of the fault geometry (personal communication Dr. G. Borradaile).

In their description of the Leannan fault zone of northern Ireland, (the supposed southwestern continuation of the Great Glen Fault or at least one of its splays taking up most of its displacement), PITCHER et al. (1964) mention the occurrence of "lenticular slices, exotic in various degrees" within the fault zone. They also emphasize that "... the fault line is in many places a composite structure, being made up of a number of closely spaced faults each with its own crush zone".

Obviously the Great Glen is also an example of a transcurrent fault system of considerable width, subparallel to the strike of the Caledonian fold belt and characterized by a crush zone containing exotic blocks. Movements went on well into the Devonian, when the Old Red Sandstone "Molasse" was deposited.

4.2 *The San Andreas Fault System*

The San Andreas Fault belongs to a system, which is generally estimated to be at least 100 km wide. MOODY & HILL (1956) even suggest a width of 250-350 km.

According to ANDERSON (1971) the whole system is composed of a number of blocks, the faults separating these blocks being themselves fault zones of a finite width. SHARP (1967) mentions that a crush zone, several hundred feet wide, marks the San Jacinto Fault.

SAUL (1967) asserted that many important faults of the San Andreas Fault System actually represent fault zones that are several kilometres wide and include fault slices and folded rocks.

The importance of the differential block-movement in the San Andreas Fault System is clearly demonstrated by the sediments of young Tertiary-Pleistocene basins. They contain debris that never could have been supplied by the mountains presently adjoining the area (ANDERSON 1971).

Blocks of controversial provenance are also reported from the San Andreas Fault System. EHLIG (1968) mentions the presence of the Pelona, Rand and Orocopia schists in the southern part of the San Andreas Fault, near the junction with the Garlock Fault. The area from which these schists originate is not known with certainty.

4.3 *Mélanges*

In addition some attention should be paid to the still largely enigmatic complexes, known as "mélanges" (and partly also wildflysch?). They are described from many orogens. GREENLY (1919) introduced the term "mélange" (autoclastic mélange) in his description of a complicated tectonic mixture in the Precambrian Mona complex of Anglesey, Wales. GANSSER (1974) used the term "ophiolitic mélange" in view of the occurrence of components of ophiolitic origin in such mixtures in other orogens. In his review of examples from the Middle East and the Himalayas, he defines ophiolitic mélange as "an olistostromal and tectonic mixture of ophiolitic material and sediments of oceanic origin with exotic blocks, reflecting areas which have subsequently disappeared". From the eleven factual and genetic characteristics enumerated by GANSSER (1974, p. 483) we quote the following which deserve emphasis:

- ... a mixture of rocks of the ophiolitic suite with non-ophiolitic rocks often of unknown origin (exotic blocks).
- The matrix of the mélange could be ophiolitic (frequently tectonically sheared serpentines) or sedimentary, the latter mostly of a flyschoid facies.
- The base of a mélange is always a tectonic contact; ...
- The ophiolitic mélange results from a sedimentary (olistostromal) and tectonic mixture. (I would like to stress that such a mélange cannot have only a tectonic origin. This could not explain the intimate mixture of exotic blocks of very varies composition. See also GRACIANSKY, in press.)
- The ophiolitic mélange is restricted to ophiolitic belts and outlines zones of major structural significance (plate boundaries).
- The final emplacement of a mélange body can be by diapiric protrusion and then the original connections to members of the ophiolitic suite become completely disrupted.
- It thus can occur also when the classical ophiolitic suite is incomplete or totally missing and may outline geotectonic belts in the same way as an ophiolite zone would do.
- The ophiolitic mélange must be distinguished from normal olistostromes (ELTER & TREVISAN 1973), the latter being interbedded in a normal sedimentary sequence.

This description obviously has much in common with the description of our transcurrent fault breccias. It describes a mixture of rocks, in which exotic blocks occur and in which incompetent rocks form the matrix; furthermore there is a coincidence with zones of major structural significance (plate boundaries).

GANSSER's rejection of a purely tectonic origin of the ophiolitic mélange (because it could not explain the intimate mixture of exotic blocks of very varied composition), results in our opinion from the fact that brecciation and mixing of lithologies, during displacements along major transcurrent faults, had not been envisaged.

5. Concluding remarks

Comparison of a few examples of major transcurrent fault systems leads to the conclusion that they have the following characteristics in common:

- geologically and morphologically they are marked by rectilinear elements extending over long distances, up to hundreds of kilometres;
- structurally they are composed of a number of subparallel, often anastomosing faults or fault zones;
- the fault systems run subparallel to the orogen;
- individual fault zones have a finite width, within which large scale breccias often occur. These are characterized by a large number of stratigraphic anomalies and often by exotic elements;
- important movements of the fault system continue until a rather late stage of orogenic development (tardigeosynclinal molasse stage).

In the present paper we particularly emphasized the characteristics of the mega-breccia occurring within the Betic Fault System. We argued that transcurrent movement is the dominant mode of large scale, late tectonic deformation in the Subbetic area. It is, however, not our intention to suggest that it is the exclusive mode of deformation. Within the framework of plate tectonic models, we may not always expect the direction of subduction or crustal shortening to be exactly perpendicular to the axis of the oceanic trough or the edge of the continental crust. On the contrary, an oblique convergent subduction movement is more to be expected. In such instances differential movement subparallel to the plate boundary will develop as well as subduction or crustal shortening perpendicular to it. The ratio and amount of both components of displacement will be largely dependent on the angle between the direction of subduction movement and the azimuth of the subduction zone.

We suggest that transcurrent faulting is a more common phenomenon in orogens than previously recognized. Stratigraphic anomalies and exotic blocks occurring along zones of major tectonic significance subparallel to the general strike of orogens, are often interpreted as a result of differential movement perpendicular to that general strike. Attempts are made to explain them within the framework of a nappe model or, on local scale, in terms of a diapir model. Such stratigraphic discrepancies and the occurrence of allochthonous elements are, however, characteristic phenomena within the macroscopic to megascopic breccia which may develop in a major transcurrent fault system. Working in the field it is difficult to recognize major lateral movement. Structures with a vertical component of deformation, as caused by overthrusting, diapirism or gravitational tectonics, are more striking phenomena on a local scale and may appear to be the dominant mode of deformation. They may, however, also be the more local manifestations in the complicated picture resulting from major transcurrent faulting.

Finally we want to stress our opinion that rocks which behave plastically, such as the strongly gypsiferous sediments of the Germano-Andaluzian facies in the Subbetic area, may play as major a role in transcurrent faulting as they are generally accepted to do in thrusting and nappe formation.

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