Structural succession at Vysoký kámen in the Czech part of the southern Fichtelgebirge tectonic domain of the Central European Hercynides

Strukturní posloupnost na lokalitě Vysoký kámen v české části jižních Smrčin; centrální evropské hercynidy (Czech summary)

(4 text-figs.)

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A structural succession determined in predominantly competent quartzites and psammitic schists of presumed Cambrian-Ordovician age integrates four phases of translation – slip – transposition with nine phases of folding and represents an extensive history of deformation in cover rocks in the Hercynian orogenic belt. The dominant (composite) low greenschist facies metamorphic fabric is associated with the first two recognized phases of fold formation when many tight to isoclinal folds were developed together with more open folds in fold hinge zones in the most competent units during the second phase. A less penetrative planar mineral alignment associated with the formation of recumbent folds that deform the dominant metamorphic fabric was developed after the first two recognized phases of translation (SW-directed and NE-directed), and after the formation of slip folds. The next structures in the succession represent a brittle response to potential SW-directed overthrusting. The later stages of the deformational history are recorded by at least five sets of upright folds and related weak cleavages and then by potential N-directed translation.
Integration of the phases of translation and folding into the deformational sequence established in less-competent lithologies elsewhere in the southern Fichtelgebirge tectonic domain provides a reference succession of twelve sets of folds and four sets of translation structures. This succession, and the stress systems operative during the development of the successively-formed structures, provide a basis for checking the completeness of the data that have been used in discussions of deformational, metamorphic and igneous history and for erecting dynamic models of lithospheric plate movement during the development of the Hercynian orogenic belt in Central Europe.

Key words: Bohemian Massif, deformational sequence, fold, gash vein, metamorphism, polyphase deformation, relative chronology, Riedel shear, Saxothuringian zone, schistosity, slip

Introduction

Extensive structural successions recording the effects of polyphase deformation and polyphase metamorphism are shown in outcrops throughout the Bohemian Massif in the Czech Republic. In many places, however, these successions represent the effects of more than one orogenic episode with structural and metamorphic features of the late Palaeozoic Hercynian orogeny superimposed on those of the late Precambrian Cadomian orogeny (e.g. Hopgood – Bowes 1987; Bowes – Aftalion 1991; Bowes et al. 1992; Hopgood et al. 1995). Depending on the attitude of pre-existing structures, some of the stress systems operative during the Hercynian episode have no obvious structural expressions (for instance, they simply changed interlimb angles of folds), while others resulted in the development of transposed schistosity that is generally indistinguishable from the earlier-formed planar structure. It is in cover rocks, rather than basement assemblages, that the most complete expressions of successively-operative stress systems can be observed and changes in physical conditions affecting lithospheric segments during the Hercynian episode can be deduced. Such a cover assemblage of lower Palaeozoic sediments occurs in the southern Fichtelgebirge (in the Saxothuringian zone of the Central European Hercynides) of NW Bohemia. There, as in the vicinity of Cheb and southeastwards towards Mariánské Lázně (e.g. Dyleň) and northwards to Oloví and Kraslice (Fig. 1), interbedded pelitic-semipelitic-psammitic rocks which show folded folds, folded schistosities and folded lineations and cross-cutting cleavages record local structural successions (cf. Holubec 1962) that have been integrated into a regionally-applicable deformational sequence into which phases of metamorphic reconstitution and neosome emplacement can be linked (Bowes et al. 1994).

The established deformational sequence which characterizes the southern Fichtelgebirge tectonic domain includes structures that appear to correspond to structures recognized in adjacent parts of Germany, including northwest of Cheb towards Münchberg (Stein 1988, 1992) and at the site of the KTB drill hole (Kohl et al. 1989; O'Brien et al. 1992). While the local structural successions recorded by these authors in the lower Palaeozoic rocks there contain fewer sets of structures than recognized by Bowes et al. (1994) in corresponding rock units in the Czech part of the Fichtelgebirge, and unambiguous correlation of all stages in the deformational sequence is not yet possible, it is clear that the regionally-expressed open, upright ENE-trending Fichtelgebirge anticline and associated structures are the F_3 (B_3) of Stein (1992 figs 3, 11) and the F_{060}^{o} of Bowes et al. (1994, table 3). In the case of the

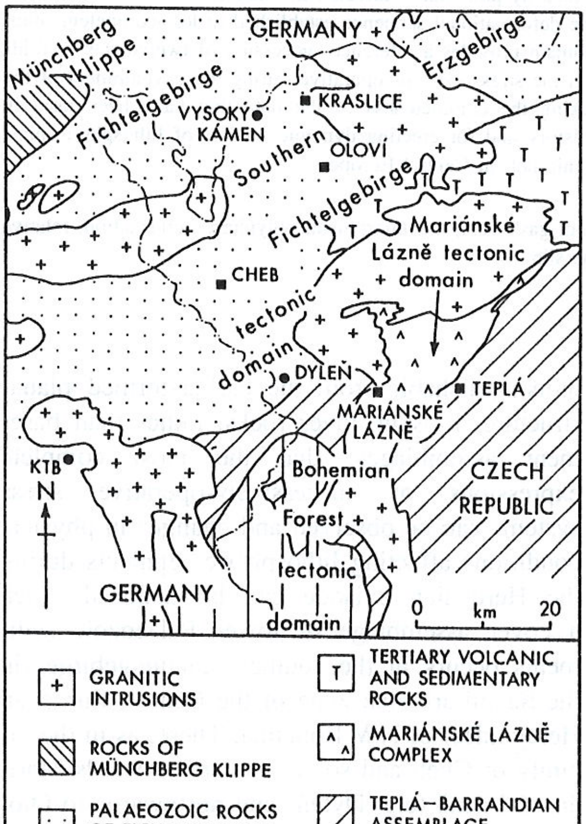

Fig. 1. Outline geological map of part of the Central European Hercynides in the western part of the Czech Republic and the adjacent part of Germany

F_4 (B_4) structure of Stein (1992, figs 3, 7, 11), this may represent a number of different late-formed structures possibly corresponding to F_{150}^{o}, F_{120}^{o} and F_{000}^{o} of Bowes et al. (1994).

Additional studies in the German part of the Fichtelgebirge are likely to establish further correlations indicative of a regionally expressed deformational sequence throughout both the southern Fichtelgebirge tectonic domain and its northwestern and western extensions. However there, as in the Czech part, the common presence of incompetent units in which generally flat-lying schistosity was formed during early deformational phases militates against the unequivocal recognition of structures (like thrusts) associated with translation – slip because of the likelihood of the movements being expressed as schistosity transposition.

Accordingly, with major thrusts and associated mylonite zones playing a prominent role in explanations of Hercynian orogenesis in the Saxothuringian zone (Franke 1989; Blümel et al. 1990) and the nearby domains that include the Mariánské Lázně complex (Bowes et al. 1992) and the Moldanubian and Teplá-Barrandian assemblages (Fig. 1), the determination of a structural succession that integrates phases of translation – slip – transposition with phases of folding is an essential part of the data needed to erect a tectonic synthesis of the Central European Hercynides based on observed rather than inferred structures. Such data has been obtained from a study of the competent quartzites and associated somewhat less-competent psammitic schists and minor, generally incompetent semipelitic bands that crop out at Vysoký kámen adjacent to the border of the Czech Republic with Germany, 7.5 km WSW of Kraslice (Fig. 1) There, a number of near-contiguous joint-bounded tors that are up to 25 m high (Fig. 4a) represent exposure that is exceptional in this part of the region. They display a considerable number of both fold and translation structures (Figs 2, 3, 4) whose relative timing, physical conditions of formation and integration with the deformational sequence established for the southern Fichtelgebirge tectonic domain (Bowes et al. 1994) provide a framework for (i) integrating structures commonly referred to in descriptions of different parts of the Central European Hercynides (e.g. nappes, upright folds, thrusts – cf. Franke 1990, fig. 4), (ii) establishing relative timing of phases of medium-pressure, low-pressure and thermal metamorphism variously expressed from place to place and (iii) determining relative times of emplacement of igneous masses, particularly granites. On the basis of the number and variety of structures recognized, and the evidence for their sequential development in a changing P-T stress regime, the structural succession recorded here (Table 1) is considered to represent the most complete one available in this part of the Hercynides. Because of this, it is important for checking the completeness of the data bases that have been used in erecting dynamic models of lithospheric plate movement during the development of the Hercynides in Central Europe.

The quartzite horizons cropping out at Vysoký kámen are not continuous regionally, but the overall rock assemblage has been correlated with fossiliferous assemblages further to the west that are Cambrian – Ordovician in age (Kopecký et al. 1974; cf. Suk et al. 1984, p. 110). Evidence for a number of sets of folds as well as ductile shear zones and boudins, and for the effects of several deformation mechanisms, is given by Schulmann et al. (1988). These authors, and Urban (1982), also provide petrographic data for the low greenschist facies rocks that mainly contain c. 90% quartz (35-40% as deformed clasts that are rarely >1 mm, the remainder as matrix), together with sericitic mica that assists in defining schistosity, ilmenite-hematite and accessory zircon, tourmaline and rutile. No mineralogical expression has been recognized of the low-P metamorphic overprint that is expressed as small randomly-oriented post-F_{060^o} muscovite crystals in micaceous schists 10 km to the SE and is much more prominently expressed a further 30 km to the S.

The near homogenity of composition and texture of the most psammitic rocks, which predominate, makes distinction between sedimentary and tectonic features and between separate sets of tectonic structures difficult. The style of deformation, coupled with the ease with which the psammites fracture parallel to both the bedding and tectonic surfaces (Figs 2a; 3b, f), further complicates the structure (Fig. 3h) and increases the difficulty of interpretation. Additional structural complexity results from factors such as (i) interference between near-coaxial folds of different generations, (ii) slip on near-coplanar surfaces of different generations and (iii) variation in structural expression in different exposures (and even the same exposure) resulting from the differential response to stress (see F_r)

Besides phases of ductile deformation (folding and shearing), the deformational history of the rocks comprising the tors at Vysoký kámen has, from early on, been interspersed with phases of high strain rate when open fractures and discrete shears developed and became infilled with quartz (Figs 2a, b; 3b, c, e; 4a, f) resulting in classic examples of Riedel shear and tension gash associations. This resulted in a vein complex showing more than one relationship although the general pattern seen on some outcrops may superficially appear to be a simple one (Fig. 4a). As well as being rotated to sigmoidal form as they developed, the earlier examples of these veins were folded during subsequent ductile deformation (Fig. 4b, c). Some planar veins have been deformed simply by offset of segments on discrete slip surfaces (Fig. 4f). Late veins remain essentially planar (Figs 2b; 3c, e).

Notwithstanding the foregoing difficulties, detailed study involving over a thousand observations has enabled mutual relationships between the structures observed at Vysoký kámen to be established with a considerable degree of confidence. This has allowed (i) the compilation of a structural succession which, besides folds, includes structures caused by translation (Table 1), (ii) the characterization of the various structures – sets of structures and (iii) the demonstration of the changes in type and orientation of stress systems. The integration of the determined succession with other successions in the southern Fichtelgebirge region forms a basis for establishing a regionally-applicable deformational sequence that characterizes the southern Fichtelgebirge tectonic domain (Bowes et al. 1994; cf. Hopgood 1973; 1980) and permits its distinction from other tectonic domains in the region (viz. Mariánské Lázně and Bohemian Forest tectonic domains – Fig. 1) with their different histories.

The photographs of Figures 3 and 4 show the bases of many of the conclusions drawn while attention is drawn by line drawings to significant features in selected examples (Fig. 2). From these illustrations it can be seen that some of the structural elements and their mutual relationships are of the kind that necessitate close inspection and study because they do not display refolding and cross-cutting relationships in an immediately obvious manner (cf. Hopgood – Bowes 1972, figs 10, 11; Bowes 1979, photos 1-11). They also reinforce the point that the conclusions drawn are based on observed stuctures and not on the basis of hypotheses or models.

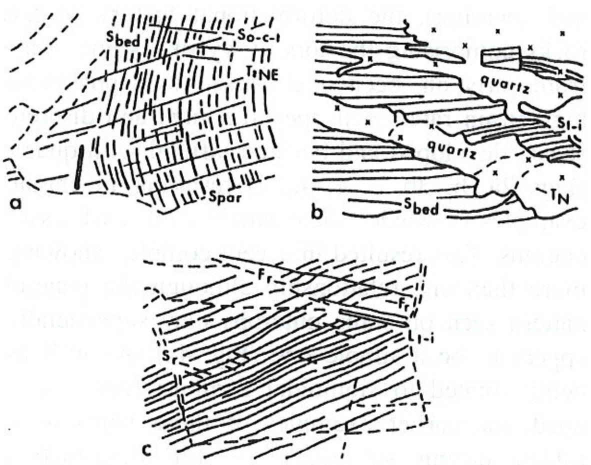

Fig. 2. Examples of significant features shown in photographs (Fig. 3); (a), (b) and (c) correspond to Figure 3b, c and d, respectively

Structures

The structures observed include a number of sets of successively-formed folds arising from ductile deformation as well as "brittle" shears and fractures developed in response to higher strain rates. Although these collectively comprise a unique structural succession, individually they are typical of the structures to be found in the extensive polyphase deformational succession(s) consistently displayed in the metamorphic rocks throughout the Bohemian Massif.

S_{bed} Bedding is shown as mm thick compositional layers that in some outcrops are expressed as a subdued but distinct fine colour banding (Figs 2a; 3b). Only rarely do these layers weather out as discrete surfaces (Figs 2b; 3c). Locally there are compositional pellets with elliptical cross-sections some of which represent a purer quartz sand (Fig. 3e). In one place elongate features (5-6 x 1 cm in cross-section) perpendicular to the bedding and darker in colour than their host are interpreted as neptunian dykes whose margins are now sawtooth-shaped because of a superimposed cleavage (Fig. 3a). Thin quartz segregation veins are parallel to bedding in some places. Also parallel to bedding is a parting (S_{par}; Figs 2a; 3b) which commonly is the most prominent planar structure present (Fig. 3f). This parting varies in spacing from 1-2 mm to 10-20 cm and at some stage(s) in the deformational history of the rocks it was accentuated, probably as a result of slip during flexural-slip folding. As a consequence of the intensity of the deformation which affected this sedimentary succession, and because of the imposition of tectonic planar surfaces (many of them now seen as open fractures – Fig. 3h), original

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Fig. 3. Structures and structural relationships, Vysoký kámen
(a) Narrow, irregular ?neptunian dyke (dark – from near top to near bottom at centre of photograph) crossed by horizontal fine S_r cleavage traces; thin tabular quartz veins (qtz) lie parallel to the bedding trace; coin 2 cm in diameter; face on northwestern side of second tor from N.
(b) $F_{o\text{-}c\text{-}t}$ -folded fine bedding (S_{bed} – shown by colour banding), bedding-parallel parting (S_{par} – stained by weathering) and ENE-dipping quartz-filled Riedel shears; widely spaced horizontal dark fractures are parallel to the fold axial plane ($S_{o\text{-}c\text{-}t}$); southern face of northernmost tor.
(c) Folded S_{bed} and fine $S_{t\text{-}i}$ schistosity cut by tapered quartz-filled gash veins of T_N (cf. 3 e); northern face of second tor from S.
(d) Coarse anastomosing intersection $L_{t\text{-}i}$ (S_{bed} – $S_{t\text{-}i}$) folded over F_r and transected by fine (subhorizontal) S_r cleavage; southern end of western side of northermost tor.
(e) Parallel tapered quartz gash veins (T_N) cutting F_{090}o that folds S_{bed} (with compositional pellets – light coloured ellipse lower centre) which is cut by $S_{o\text{-}c\text{-}t}$; locality as 3c.
(f) Recumbent $F_{o\text{-}c\text{-}t}$ folding S_{par} with irregular $S_{o\text{-}c\text{-}t}$ fractures; northern face of northernmost tor.
(g) Quartz vein folded by second generation isoclinal folds showing the typical "irregular" anastomosing form of $F_{o\text{-}c\text{-}t}$ hinges; S_{com} ($S_{t\text{-}i}$ + $S_{o\text{-}c\text{-}t}$) and $L_{o\text{-}c\text{-}t}$ are cut by a fine linear trace parallel to the trace of S_r (subhorizontal here); southern end of eastern side of southernmost tor.
(h) Irregular composite fold forms caused by the interference of parting (S_{par}) parallel to S_{bed} with other fractures, some axial planar to $F_{o\text{-}c\text{-}t}$ and some possibly parallel to axial plane of F_r; northwestern side of northern face of northernmost tor

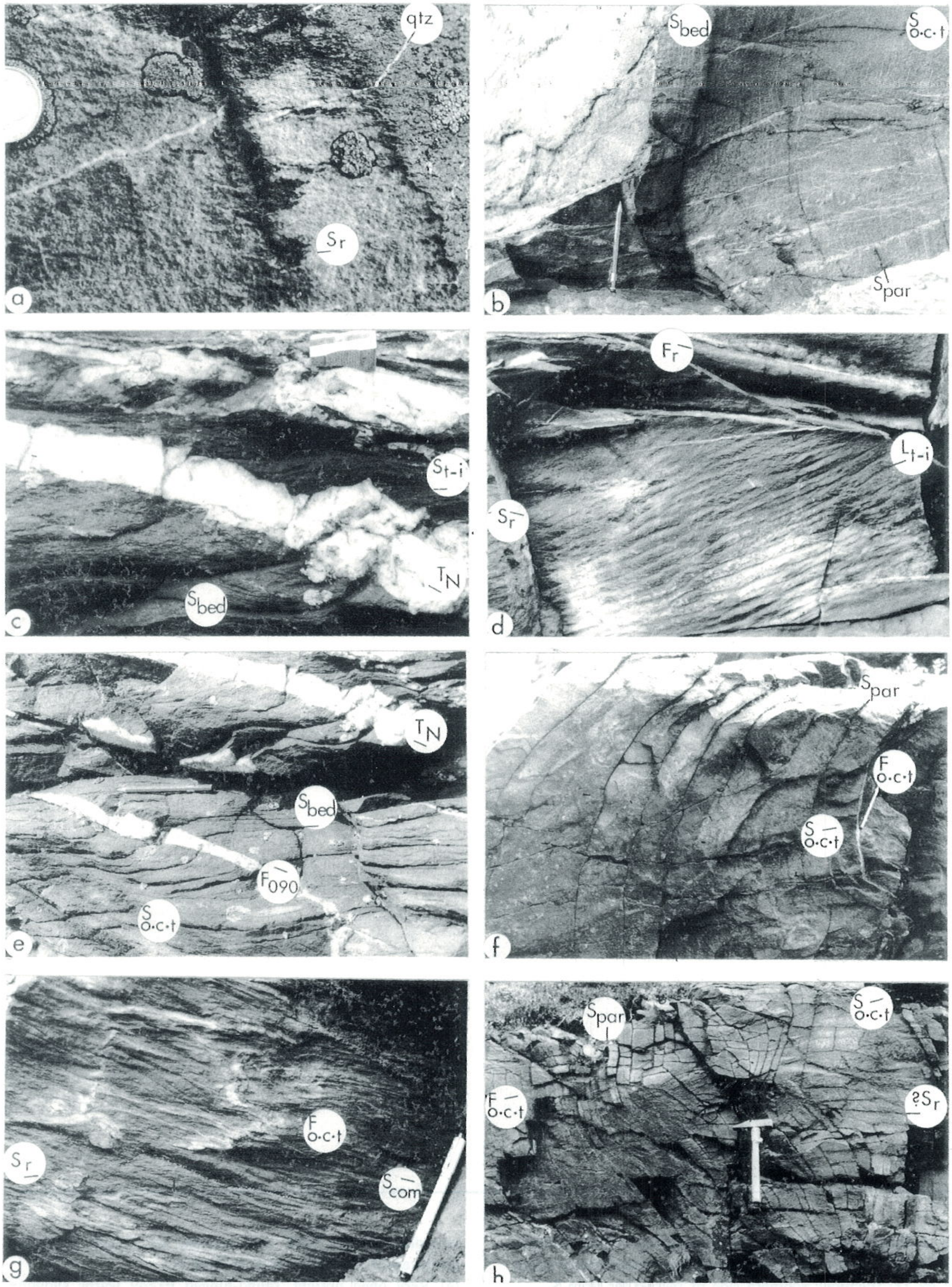
qtz
S_r
a
S_{bed}
$S_{o \cdot c \cdot t}$
S_{par}
b
S_{t-i}
T_N
S_{bed}
c
F_r
L_{t-i}
S_r
d
T_N
S_{bed}
F_{090}
$S_{o \cdot c \cdot t}$
e
S_{par}
$F_{o \cdot c \cdot t}$
$S_{o \cdot c \cdot t}$
f
$F_{o \cdot c \cdot t}$
S_r
S_{com}
g
S_{par}
$S_{o \cdot c \cdot t}$
$F_{o \cdot c \cdot t}$
?S_r
h

Fig. 3

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Fig. 4. Structures and structural relationships, Vysoký kámen
(a) Tapered en échelon T_{NE} quartz veins (folded below label) cut by T_N fractures; southern side of second tor from S.
(b) Thin quartz gash veins slip-folded (F_{slip}) on S_{slip}; eastern end of southern face of southernmost tor.
(c) Recumbent folded (F_r) tapered quartz gash veins; southeastern corner of southern face of southernmost tor.
(d) Upright F_{090^o} fold showing characteristic round hinge and near-planar limb habit and crossed by S_{150^o} cleavage; northwestern part of second tor from N.
(e) Very open upright, round-hinged F_{150^o} warps showing a tendency towards planar-limbed habit; northern part of second tor from N.
(f) Dextral offset of quartz gash vein segments dipping 40° towards 060° (T_{NE}) on discrete, subhorizontal slip surfaces parallel to the open fractures (T_N); southern face of second tor from S

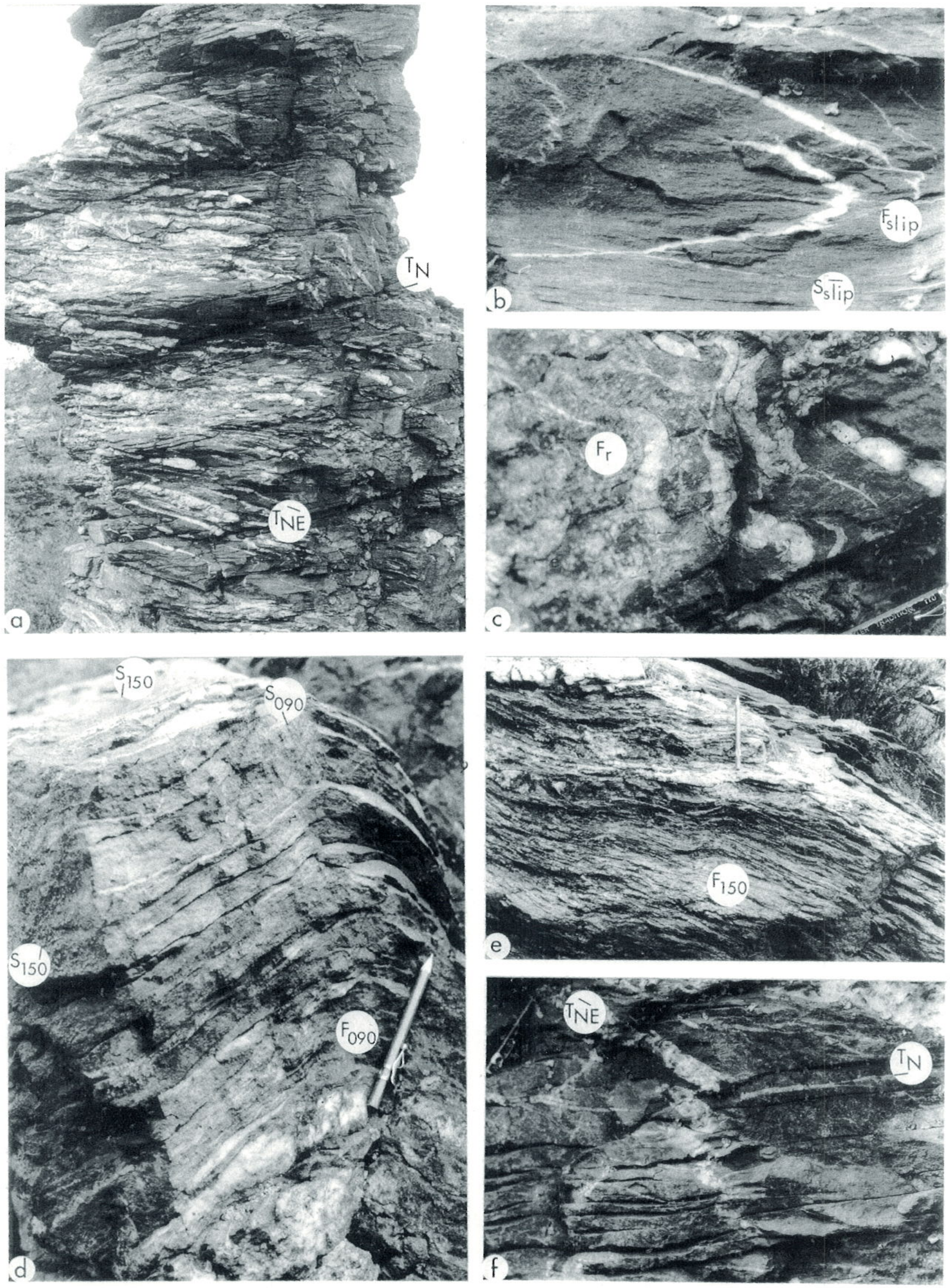

Fig. 4

bedding is difficult to discern in many outcrops. Distinction of the bedding-parallel parting (S_{par}) from later tectonic surfaces is facilitated where staining by weathering highlights the bedding surfaces (Figs 2a; 3b). This parting imparts a flagginess to the psammites while in less siliceous lithologies it can superficially resemble schistosity. Thus on the limbs of isoclinal folds, where it lies parallel to the fold axial plane, it can be difficult to distinguish from axial-planar schistosity.

$\mathbf{F_{t\text{-}i}}$ The first discernible tectonic structures are the hinges of folds, ranging from tight to isoclinal, that deform the bedding and the bedding-parallel parting. In some of the finer-grained lithologies there is an associated axial-planar schistosity generally at a low angle to bedding ($S_{t\text{-}i}$; Figs 2b; 3c). A linear "fluting" ($L_{t\text{-}i}$), mostly 0.25-1 cm across, but sometimes as wide as 2 cm, that superficially resembles ripple marks, is locally developed where the bedding and axial-planar schistosity intersect, especially near the fold hinges (Figs 2c; 3d).

$\mathbf{F_{o\text{-}c\text{-}t}}$ The second set of discernible tectonic structures is represented by open to close to tight folds ($F_{o\text{-}c\text{-}t}$) and rarely, in incompetent lithologies, by isoclinal folds (Fig. 3g). These deform the bedding-parallel parting (Fig. 3f, h), quartz segregation veins (Fig. 3g) and F-S-$L_{t\text{-}i}$. The open folds that are so commonly seen to deform the bedding-parallel parting in the more competent units (Fig. 3f, h) are likely to represent the hinges of close to tight folds. Crude axial planar fractures are seen (Figs 2a; 3b, f, h; $S_{o\text{-}c\text{-}t}$), but in less competent units there is an axial-planar cleavage – schistosity (Fig. 3e; $S_{o\text{-}c\text{-}t}$), which merges into composite schistosity (Fig. 3g; $S_{com} = S_{t\text{-}i} + S_{o\text{-}c\text{-}t}$) on the limbs of isoclinal folds. There coarse (c. 1 cm spaced) intersection lineation ($L_{o\text{-}c\text{-}t}$) is also strongly developed.

$\mathbf{T_{SW}}$ At several places there are SW-dipping, sigmoidal quartz gash veins and Riedel shears. They are now strongly deformed and irregular and cut isoclinal folds. Their attitude indicates potential or actual translation accompanying overthrusting in what is now a southwesterly sense. This movement sense is also indicated by the presence of SW-verging monoclines affecting the schistosity.

$\mathbf{T_{NE}}$ The SW-verging monoclines are cut by more regular, locally abundant, later sigmoidal, en échelon quartz tension gashes with an overthrust sense to the NE (Fig. 4a).

$\mathbf{F_{slip}}$ Gently plunging slip folds resulting from deformation of the quartz veins and their host lithologies developed during (continued) T_{NE} translation. Their axes have been variously reorientated and now trend W-NW. These folds have an associated fine axial-planar schistosity (S_{slip}) producing an intersection lineation oblique to earlier-formed linear structures, such as $L_{t\text{-}i}$ (Fig. 4b).

$\mathbf{F_r}$ Recumbent folds deform earlier-formed schistosity ($S_{t\text{-}i}$, $S_{o\text{-}c\text{-}t}$) and sigmoidal gash veins (e.g. T_{SW}; Fig. 4c) and reorient earlier-formed linear structures (e.g. $L_{t\text{-}i}$) which twist across F_r. The folds have hinges that plunge gently (5°-30°) towards 300° on the southernmost tor, and to between 270° and 325° on the northernmost tor (Figs 2c; 3d). Flexural slip folding was associated with the development of axial-planar fractures (5-10 cm spacing) in the most competent units where they add further complexity to the pattern of fractures resulting from the presence of (bedding-parallel) S_{par} and $S_{o\text{-}c\text{-}t}$ (axial planar to $F_{o\text{-}c\text{-}t}$; Fig. 3h). In less competent units a fine but penetrative cleavage is seen in many places (S_r; Figs 2c; 3a, d, g), and occasional crenulation cleavage is present in the least competent units (cf. Schulmann et al., 1988, tab. II.2). Potential WSW-directed translation is indicated by the asymmetry of some structures which now verge towards 240°. The existence of folds of this set in proximity to areas of intense deformation associated with F_{slip} is consistent with their post-F_{slip} development.

The following features related to F-S_r illustrate aspects of the complexity of the structure at Vysoký kámen. (i) Interference is shown between sigmoidal fold forms with 300°/15° plunges in quartz gash veins associated with potential shear and Fr with similarly-plunging (300°/20°) axes. (ii) There is similarity in the expression of folds affecting planar quartz veins and schistosities resulting from slip on both S_r and the subparallel S_{slip}. (iii) There has been differential response to stress and differences in the intensity of expression of cleavages and fractures as is shown on the northernmost part of the northernmost tor – at the top subhorizontal S_r axial-planar cleavage is the dominant planar structure whereas a metre or so below, bedding-parallel fractures (S_{par}) dominate, and crudely outline F_r. (iv) Movement in response to late stress causing opening up and reactivation of S_{par} and S_r resulted in the development of complex fold forms in which second generation folds ($F_{o\text{-}c\text{-}t}$) merge into the later recumbent structures (F_r).

T_{SW} SW-dipping quartz gash veins which cut across F_r indicate a brittle response to potential SW overthrusting. Thus while the vergence sense remained the same, there was a change from ductile (F_r) to brittle (T_{SW}) deformation.

F_{090^o} Generally upright, open to close folds (F_{090^o}) deform S_r schistosity and earlier-formed structures (Fig. 4d). These folds possess a fine, steeply-dipping (>60°) axial-planar schistosity, and their axes show variable but generally low angle plunges, depending on the prior attitudes of the folded surfaces.

F_{030^o}, $F_{050\text{-}060^o}$, F_{120^o}, F_{150^o} F_{090^o} folds were succeeded by four sets of upright, open (to close) folds, all accompanied by fine axial-planar cleavage, whose order is yet to be determined. S_{030^o} and S_{150^o} cleavages have been observed cutting across F_{090^o} folds (Fig. 4d) and while F_{150^o} folds are commonly expressed as open warps, in closely layered, more competent rocks the hinges are more angular, and separated by long unfolded intervals (Fig. 4e).

T_N Potential N-directed translation is indicated by N-dipping (080°/20-25°N) undeformed tapered quartz (Riedel shear) veins that have been observed to cut F_{090^o} (Figs 2b; 3c, e).

Deformational history

The structural succession determined at Vysoký kámen records the successive development of folds during at least nine phases of deformation and the development of subhorizontal movement planes (thrusts) during four phases of deformation (Table 1). The main low greenschist metamorphic fabric is composite and was formed during the first two phases of fold formation when tight to isoclinal folds were developed ($F_{t\text{-}i}$, $F_{o\text{-}c\text{-}t}$). It is best expressed in the less competent units. The open to close folds of the second phase that are so prominently expressed in more competent units probably represent hinge zones of much tighter folds whose disposition at the time of formation was grossly recumbent. A marked, but less penetrative, planar mineral alignment (S_r) associated with the development of recumbent folds (F_r) that deform the dominant (composite) metamorphic fabric was developed after the first two recognized phases of translation – slip – transposition (T_{SW}; T_{NE}) and after the local formation of slip folds (F_{slip}) with which there is also an associated axial planar fabric (S_{slip}). The asymmetry of some of the F_r is indicative of associated potential WSW translation and the deformation, like that in the preceding phases of fold formation, was ductile. The next-formed structures (T_{SW}) represent a brittle response to potential SW overthrusting so that while the vergence sense remained the same, the deformation changed from being ductile (F_r) to being brittle (T_{SW}). This indicates not only change in crustal setting but also the likely "continuous" nature of the overall deformational history whose stages of development have been determined from refolding and cross-cutting relationships.

Table 1. Structural succession at Vysoký kámen and structures and order of succession based on correlation (*in italics*)

Sets of essentially vertical joints
T_N N-dipping (080°/20-25°N) quartz shear veins
(Upright, open folds F_{000^o})
(Upright, open folds F_{090^o})
(Upright, open folds F_{120^o})
(Upright, open folds F_{150^o})
F_{030^o}, $F_{050\text{-}060^o}$, F_{120^o}, F_{150^o} Upright, open (to close) folds (order not determined).
F_{030^o}
Low-P metamorphism
Upright, open folds F_{060^o}
F_{090^o} Generally upright, open to close folds that reorientate early-formed lineations and axes and axial-planar cleavage of F_r.
T_{SW} 220°-dipping quartz gash veins.
Recumbent, angular-hinged folds F_{ra}
F_r Recumbent folds that reorientate earlier-formed linear structures (vergence now towards 240°); axial-planar cleavage – fracture (S_r); occasional crenulation cleavage.
Recumbent, round-hinged folds F_{rr}
F_{slip} Slip-folded quartz veins (F_{slip} axes now c. 265°/05°) with axial-planar fabric (S_{slip}).
T_{NE} *c.* 50° N-dipping (now 355° after later reorientation) en échelon quartz veins.
T_{SW} Southwesterly-verging irregular, sigmoidally-folded quartz gash veins.
$F_{o\text{-}c\text{-}t}$ Open (in competent units) – close – tight (- isoclinal in incompetent units) folds that deform bedding, bedding-parallel parting and $S_{t\text{-}i}$ schistosity – fracture; axial-planar fracture – cleavage – schistosity ($S_{o\text{-}c\text{-}t}$); coarse (c. 1 cm spacing) intersection lineation ($L_{o\text{-}c\text{-}t}$).
$F_{t\text{-}i}$ Tight to isoclinal folds that deform bedding and bedding-parallel parting; axial planar schistosity ($S_{t\text{-}i}$) and (?later) parallel, open fractures; linear "fluting"($L_{t\text{-}i}$) mostly 0.25-1 cm across (superficially resembling ripple marks) at bedding – schistosity intersection.
Quartz segregation veins (qtz) parallel to bedding.
S_{bed} Sedimentary layered fine – medium, even-grained siliceous silts and sands with quartz clasts, compositional pellets and possibly neptunian dykes; parting (S_{par}) parallel to bedding.

The later stages of the deformational history are recorded by (i) at least five sets of upright, open folds with related weak cleavages, (ii) quartz veins and subhorizontal surfaces indicative of potential N-directed translation (T_N), and (iii) sets of essentially vertical joints that played a major role in the development of the outcrop as vertically-sided tors in which many of the lithological units and structural features are flatly disposed. The generally weak expression of the upright folds in the mainly competent lithologies largely preclude determination of order of development, but these structures were formed relatively high in the crust during a period when there were changes in the orientation of the stress field.

The importance of the integration of phases of translation – slip and phases of folding at Vysoký kámen in establishing the overall deformational history of the Central European Hercynides is shown when the structural succession there is compared with those present in much less competent lithological assemblages elsewhere in the southern Fichtelgebirge region (e.g. at Dyleň, Cheb and Kraslice – Oloví – cf. Bowes et al. 1994). There is clearly overall comparability in the fold successions, the orientations of the axes of later-formed folds and in both the development of the dominant metamorphic fabric early in the succession and the change from ductile to brittle deformation relatively late in the succession. However it is only at Vysoký kámen that it has been possible, so far, to establish the relative order in a structural succession, and directions of movement, of four sets of potential or actual thrusts operative during the deformational history of this part of the Hercynides.

While the structural succession at Vysoký kámen (Table 1) is the most complete succession yet established at a single set of outcrops in the region, a second set of recumbent folds (in addition to F_r), seen elsewhere, was not observed. Apparently not expressed, presumably because of the dominance of competent rocks, are very late upright folds – cleavages (F-$S_{090°}$; F-$S_{000°}$) immediately preceding T_N, and the low-P metamorphic overprint that is so prominent in some other parts (Bowes et al. 1994; cf. Hopgood et al. 1995). In addition, elsewhere in the regionally-applicable deformational sequence of the southern Fichtelgebirge tectonic domain, (i) $F_{090°}$ (cf. Fig. 4d) is followed by $F_{060°}$ (expressed as large open folds – cf. Schulmann et al. 1988, fig. 9), (ii) $F_{060°}$ is followed by low-P metamorphism, and (iii) a provisional sequence of development of the other late upright folds is $F_{030°}$, $F_{150°}$, $F_{120°}$, $F_{090°}$ and $F_{000°}$. Addition of these to the structural succession determined at Vysoký kámen (*shown in italics* in Table 1) provides a reference succession (with twelve sets of folds and four sets of translation – slip structures in sequence) against which can be checked the completeness of the data bases that have been used elsewhere in discussions of deformational, metamorphic and igneous history, and for erecting dynamic models of lithospheric plate movement, during the development of the Hercynian orogenic belt in Central Europe.

Comparison of structural successions from different parts of the Bohemian Massif leading to correlation of tectonic domains with a common deformational history, and discrimination from domains with either different, or only partially comparable histories, provides a way of determining relative times of juxtaposition of different structural segments, including cover and basement units (cf. Hopgood – Bowes 1987; Bowes et al. 1992; Hopgood et al. 1995). Conversion of the determined *relative* chronology to an *absolute* chronology, allowing comparison between the timing of events in the polydeformational and polymetamorphic histories and of phases of multiple igneous intrusion in other parts of the orogen with those in the southern Fichtelgebirge (e.g. at Vysoký kámen), is dependent on the integration of isotopic data with structural data such as that done by van Breemen et al. (1982), Bowes and Aftalion (1991) and Košler et al. (1993) elsewhere in the Czech Republic.

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Strukturní posloupnost na lokalitě Vysoký kámen v české části jižních Smrčin; centrální evropské hercynidy

V kvarcitech a fylitech, které odpovídají patrně kambricko-ordovickému stáří, byla stanovena základní strukturní sukcese. V horninách lze zjistit 4 fáze střižných pohybů a 9 fází vrásnění, které představují deformační historii v metamorfovaných horninách hercynské orogenetické zóny.

Dominantní metamorfní stavba hornin facie zelených břidlic je spojena s prvními dvěma fázemi vrásnění, kdy vznikly sevřené až izoklinální vrásy společně s otevřenými vrásami v zámkových zónách kompetentních hornin, ty náležejí k druhé fázi. Nevýrazné planární uspořádání minerálů, spojené se vznikem překocených vrás, které deformují dominantní metamorfní stavbu, vzniklo po prvních dvou translačních fázích (jz. a sv. směru) a po vzniku kluzných (střižných) vrás.

Další struktury v sukcesi představují odezvu na možný, jz. směrem orientovaný přesun (příkrov). Pozdější fáze deformační historie jsou zaznamenány v posledních 5 souborech přímých vrás, které mají vztah k nevýrazné břidličnatosti a možnému přesunu k S.

Soubor střižných fází a vrásnění v deformační posloupnosti stanovené v méně kompetentních horninách (svory, fylity) v j. části smrčinského tektonického bloku vykazuje 12 souborů vrás a 4 soubory střižných struktur.

Tato posloupnost a systém napětí působící na vznikající struktury poskytují základní informace pro kontrolu úplnosti dat, které byly použity v diskusi o deformační, metamorfní a magmatické historii a pro budovaný model pohybu litosférických desek během vzniku hercynské orogenetické zóny ve střední Evropě.