Graptolite biostratigraphy of the E1-NC174 core, Rhuddanian (lower Llandovery, Silurian), Murzuq Basin (Libya)

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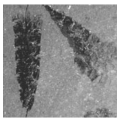

The graptolite biostratigraphy of the Rhuddanian (lower Llandovery, Silurian) of the E1-NC174 core, Murzuq Basin, Libya is described. The generally low diversity graptolite assemblages include both North African endemic taxa and cosmopolitan species. The lower part of the cored interval, below the 'hot' shale, is dominated by *Normalograptus tilokensis*, a species previously considered to be confined to the Upper Ordovician, but which almost certainly ranges into (or perhaps occurs only in) the lower Silurian. As in the BG-14 core, Jordan, the base of the 'hot' shale lies just above the first appearances of *Neodiplograptus africanus* and *Normalograptus rectangularis*. The latter species dominates throughout the mid Rhuddanian 'hot' shale interval, with the highest strata in the core, of late Rhuddanian age, yielding abundant *Neodiplograptus fezzanensis*. • Key words: Silurian, Libya, graptolite, Llandovery, Rhuddanian, hot shale, North Africa, Tanezzuft.

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This paper represents the first published detailed graptolite biostratigraphical study of a 'hot' shale core from North Africa.

The E1-NC174 well (Fig. 1) was drilled in the Murzuq Basin of SW Libya. This large, intracratonic structural basin extends east and south from Libya into western Algeria and northern Niger. Important hydrocarbon source rocks (organic-, and uranium-rich – hence 'hot' – shales) occur within the basin where they overlie glacial deposits (often acting as a reservoir, with the 'hot' shales acting as a seal) of Late Ordovician age. The cored interval is from 7237´ (2205.84 m) to 7294´ (2223.21 m); the core has a diameter of 4˝ (10 cm). Note that feet and inches are used herein as these are the units used on the core storage boxes, in the original core description and in the catalogue of graptolites from the core. Lithologically, there is very little variation throughout the core: it is dominated throughout by hard, dark grey shales, all belonging to the Tanezzuft Formation.

Well logs and the core derived from the E1-NC-174 well have been the subject of considerable previous study. Published work includes that of Lüning *et al.* (2000) who presented maps together with TOC and gamma ray curves demonstrating the presence of a 'hot' shale in the well. More detailed TOC and gamma ray curves were produced by Lüning *et al.* (2003) and supplemented with Rock-Eval pyrolysis data, organic geochemical biomarker analyses, pyrite framboid data and some very limited graptolite biostratigraphy (from four core samples, based on an unpublished 1998 report for LASMO by Loydell).

In November 1999 the opportunity arose to sample the E1-NC174 core more thoroughly, for graptolite biostratigraphical work and palynological studies. Funding from Eni, from 2005–2007, enabled examination of this material. The present paper is based upon study of 82 samples from depths ranging from 7237´ 2˝ (2205.89 m) to 7293´ 10˝ (2223.16 m). Of these, 67 samples yielded graptolites identifiable to species level, with the total number of graptolites examined in excess of 500. In terms of preservation, with the exception of three-dimensional pyrite internal moulds from 7266´ 9˝ and 7267´ ½˝, virtually all specimens are preserved flattened (the few exceptions are preserved in very low relief). There is no tectonic deformation of the rhabdosomes. All figured specimens are housed at the British Geological Survey, Keyworth.

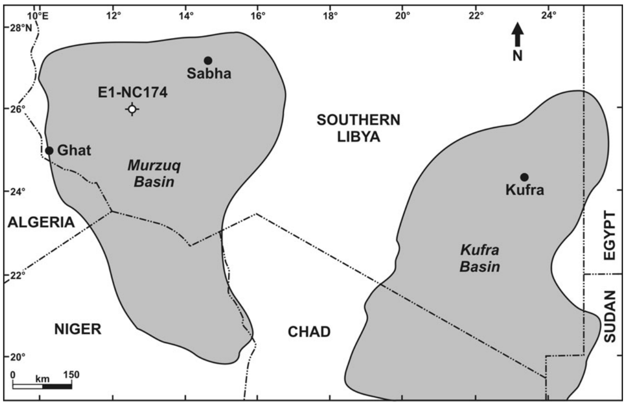

Figure 1. Location of the E1-NC174 well, Libya.

Previous work on Libyan graptolites

There have been several published works which include graptolite data from Libya: the summary of these here is limited to papers with illustrations and/or descriptions; papers with faunal lists only are excluded.

Desio (1940) described 12 graptolite taxa from western Libya. He erected two new species, both of which have subsequently been shown to be common and stratigraphically important: *Climacograptus* (now *Paraclimacograptus*) *libycus* and *Diplograptus* (now *Neodiplograptus*) *fezzanensis*. Some of Desio's material was re-examined by Štorch & Massa (2006) and in some cases assigned to different taxa.

Jaeger (1976) illustrated two specimens from SW Libya as *Climacograptus innotatus brasiliensis* Ruedemann *in* Maury, 1929. Loydell (2007) referred this material to *Paraclimacograptus libycus*.

Parizek *et al.* (1984) illustrated some lower and middle Llandovery graptolites from the Al Qarqaf Arch region.

El-Chair *et al.* (1985) illustrated *C. innotatus brasiliensis* from Tahale, SW Libya: this material also appears to be *P. libycus* (based upon the distinguishing features of this taxon noted by Štorch & Massa 2006). Lüning *et al.* (1999) illustrated *Neodiplograptus fezzanensis* from the Kufra Basin, SE Libya.

Štorch & Massa (2004) provided a very useful overview of the Llandovery and Wenlock graptolites of Libya. Štorch & Massa (2006) described 23 species from the Aeronian of the Al Qarqaf Arch region; and Štorch & Massa (2007) described three species from the middle Telychian from cores in NW Libya.

Graptolites from neighbouring Algeria have been studied over a long period by Legrand (1969, 1970, 1977, 1978, 1979, 1986a, 1986b, 1995, 1998, 1999, 2000, 2001, 2002, 2003, 2009) whose papers include descriptions of many important species found also in Libya.

Graptolite biostratigraphy of the E1-NC174 core and age of the 'hot' shale

Figure 2 illustrates the stratigraphical ranges of graptolites within the E1-NC174 core, and shows the three biozones recognised. The graptolite assemblages are generally of low diversity and are dominated by biserials: uniserial graptolites were recorded from only four samples. There is a mixture of cosmopolitan taxa and those considered to be endemic to Gondwana and some peri-Gondwanan terranes, the latter exhibiting the high level of intraspecific variation that characterizes graptolites from these regions. There is thus a rather surprising difference in the nature of the assemblages from those from neighbouring Algeria; Philippe Legrand's extensive investigations of the Upper Ordovician and lower Silurian graptolites of Algeria (comprehensively reviewed in Legrand 1999) emphasized the endemicity of the taxa found there. Whilst several of these endemics have also been found in the E1-NC174 core, they occur together with cosmopolitan taxa, notably several species of *Normalograptus*, *Huttagraptus acinaces* (Törnquist, 1899) (Fig. 3O) and *Metaclimacograptus hughesi* (Nicholson, 1869) (Fig. 3R). The presence of these cosmopolitan taxa, together with knowledge gained from work in Jordan (Loydell 2007) where again Gondwanan endemics and cosmopolitan species co-occur, enables more confident integration of North African graptolite biostratigraphy with the 'standard' graptolite biozonation.

Graptolites from the core are illustrated in Fig. 3. Virtually all of the species are well-known and have been described thoroughly by Legrand (1970, 1977, 1986a, 1999, 2001) and/or Loydell (2007); thus only a few comments regarding distinguishing features are made below. A large number of measurements of rhabdosome dorso-ventral width and thecal spacing was made during the identification work. These measurements are included here (Tables 1–7) as they may be of use to workers in the future when identifying, or studying intraspecific variation in, the taxa concerned.

Many, including the lowest, of the samples from the lower part of the core bear monospecific assemblages of *Normalograptus tilokensis* (Legrand, 1986a) (Fig. 3D–H). As noted in the original description (Legrand 1986a), *N. tilokensis* differs from the rather similar *N. rectangularis* in being more robust (most noticeable proximally, although there is some overlap: compare DVW figures in Tables 1 and 3), in having a long, robust virgella and by its distal diminution in width. Legrand (*e.g.* 1986a, 1999, 2003, 2009) used *N. tilokensis* as a biozonal index and assigned the biozone tentatively to the uppermost Hirnantian, having stated (Legrand 1986a) that the North African *tilokensis* and overlying *kiliani* biozones are 'the very approximate equivalent' of the *persculptus* Biozone. Subsequently, Legrand (2009) considered the *tilokensis* Biozone to be equivalent to a Hirnantian post-*persculptus* Biozone

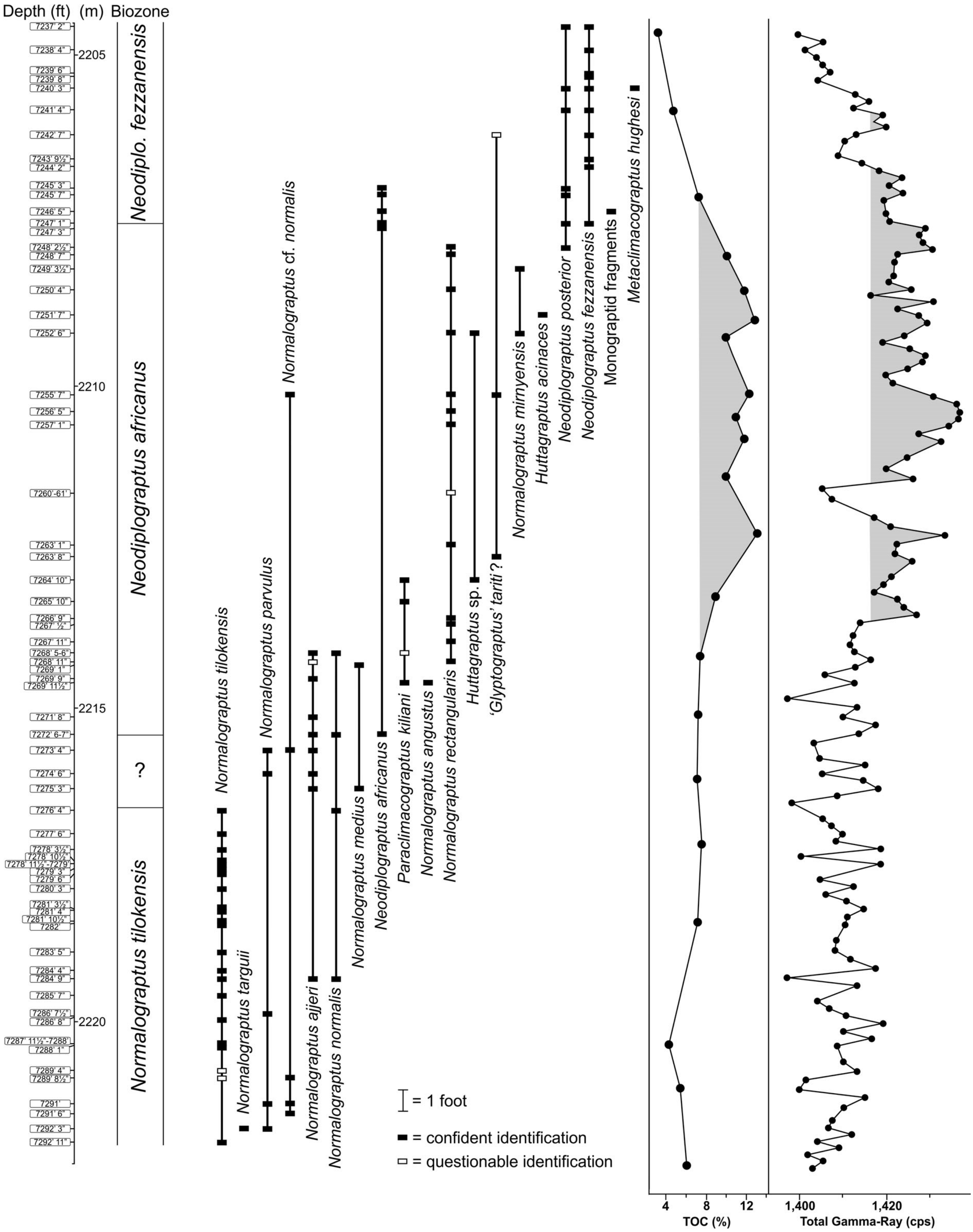

Figure 2. Stratigraphical ranges of graptolites in the E1-NC174 core, Libya. TOC and gamma-ray curves are from Lüning *et al.* (2003); the highest values (the 'hot' shale) are shaded.

'interregnum' such has been recognised in Sweden (Koren' *et al.* 2003) and is present also in China (Chen *et al.* 2005; see Loydell 2007, p. 8). Lüning *et al.* (2000, fig. 11 and 2003, fig. 4) accepted Legrand's (1986a, 1999) proposed correlation of the *tilokensis* Biozone and thus the lower part of the core interval below the hot shale was assigned by them to the Upper Ordovician. Only one sample from the lower part of the core (a sample from 7285´ provided by LASMO) was available at the time of Lüning *et al.*'s work and thus the overall range of *N. tilokensis* in the core was unknown. From the much more detailed sampling undertaken for the current paper, *N. tilokensis* was found to occur from 7292´ 11˝ up to 7276´ 4˝. This LAD poses some problems if *N. tilokensis* is indeed restricted to the upper Hirnantian. *Neodiplograptus africanus* (Legrand, 1970) (Fig. 3S, W) appears at 7272´ 6˝. In Jordan (Loydell 2007) *Ne. africanus* appears close to the *ascensus-acuminatus*/*vesiculosus* Biozone boundary. It has never been recorded at a lower stratigraphical level. Thus the *ascensus-acuminatus* Biozone would need to be less than 4 feet (1.22 m) thick (*i.e*. very condensed) within the E1-NC174 core if *N. tilokensis* is an entirely Ordovician species. In addition, the chitinozoan *Belonechitina postrobusta*, a Rhuddanian chitinozoan biozonal index species (Butcher 2009), is common in samples from the base of the E1-NC174 core and throughout the range of *N. tilokensis* (Anthony Butcher, pers. comm.). It thus appears most likely that the stratigraphical range of the North African endemic graptolite *Normalograptus tilokensis* extends into or perhaps is entirely within the Silurian.

Normalograptus parvulus (Lapworth, 1900) (Fig. 3C) occurs within the core below the hot shale, within the *tilokensis* Biozone and in the unzoned interval below the FAD of *Neodiplograptus africanus*. This well-known and widely recorded species has a range in the 'standard' biozonation from the *persculptus* Biozone up to probably the lower *vesiculosus* Biozone (Loydell 2007).

As noted above, *Neodiplograptus africanus* appears at 7272´ 6˝. It is absent through much of the 'hot' shale interval, and is common at the top of the hot shale. *Ne. africanus* is an important North African biozonal index species (for this reason the biozone is used herein) indicating the middle of the Rhuddanian (Legrand 2003, fig. 2). The upper part of its range in the E1-NC174 core overlaps with the lower parts of the stratigraphical ranges of *Neodiplograptus posterior* (Legrand, 1970) (Fig. 3X, Y), which is uncommon, and the very abundant *Ne. fezzanensis* (Desio, 1940) (Fig. 3T–V), two taxa typical of the upper Rhuddanian, the latter being a North African biozonal index species (Legrand 2003). *Ne. fezzanensis* [none of which in the present collection possesses within its thecae the intriguing tubular structures described by Legrand (1978, 1979, 1986b)], has been recorded also from the Czech Republic (Štorch 1983), from both the upper Rhuddanian *Coronograptus cyphus* Biozone and the lowermost Aeronian *Demirastrites triangulatus* Biozone. The top of the core, assigned to the *fezzanensis* Biozone, is thus of either late Rhuddanian or earliest Aeronian age.

Of considerable interest is the stratigraphical range of *Normalograptus rectangularis* (McCoy, 1850) (Fig. 3M, N) within the E1-NC174 core. As noted by Loydell (2007), *N. rectangularis* is a very useful species stratigraphically, as its first appearance is in the upper part of the *ascensus-acuminatus* Biozone. Its range from 7268´ 11˝ to 7248´ 2½˝ is from the base of the 'hot' shale to a level near its top. It is the most abundant species within the 'hot' shale. It never co-occurs with *Ne. africanus* despite its range being entirely within that of the latter species. A similar mutually exclusive relationship was seen in the BG-14 core, Jordan (Loydell 2007), where *N. rectangularis* appears close to the base of the 'hot' shale, 1.5 m above the FAD of *Neodiplograptus africanus*.

Paraclimacograptus kiliani (Legrand, 1977) (Fig. 3Z) occurs immediately below and in the lower part of the 'hot' shale in the E1-NC174 core, in the lower part of the *africanus* Biozone. The species (identified by Loydell 2007 as *Paraclimacograptus* sp.) occurs at a very similar biostratigraphical level in Jordan (Loydell 2007), within the *Cystograptus vesiculosus* Biozone. It occurs also in Mauritania (misidentified as *Pseudorthograptus obuti* by Underwood *et al.* 1998), again at a similar stratigraphical level, equivalent either to the upper *ascensus-acuminatus* Biozone or lower *Cystograptus vesiculosus* Biozone. As noted above, Legrand (1986a) originally considered the *kiliani* Biozone (which is based upon the total stratigraphical range of *Pa. kiliani*) to be probably of late Hirnantian age. However, Legrand (2009) later revised this view and correlated it with the lower part of the lowermost Silurian *Akidograptus ascensus* Biozone. The occurrences in Libya, Mauritania and Jordan referred to above indicate a somewhat higher stratigraphical level for *Pa. kiliani* and also cast doubt on its utility as a biozonal index. In both Jordan and Libya the specimens of *Pa. kiliani* occur above the FADs of *N. rectangularis* and *Ne. africanus*, in the former case demonstrably in the middle Rhuddanian *vesiculosus* Biozone. In Mauritania, the *Pa. kiliani*-bearing level is less than 0.5 m below the FAD of *N. rectangularis* (Underwood *et al.* 1998, fig. 3). There is thus strong evidence that this species occurs in the middle Rhuddanian. In the Oued In Djerane region of south-east Algeria the FAD of *Pa. kiliani* occurs stratigraphically above the LAD of *N. tilokensis* above approximately 20 m of strata which contain neither species (Legrand 2000, fig. 3). A similar relationship (although with a thinner intervening interval lacking both taxa) occurs in the E1-NC174 core. Given the comments above regarding the likely Silurian (rather than Hirnantian) age of the *tilokensis* Biozone, a FAD for *Pa. kiliani* at a stratigraphical level correlating approximately with the

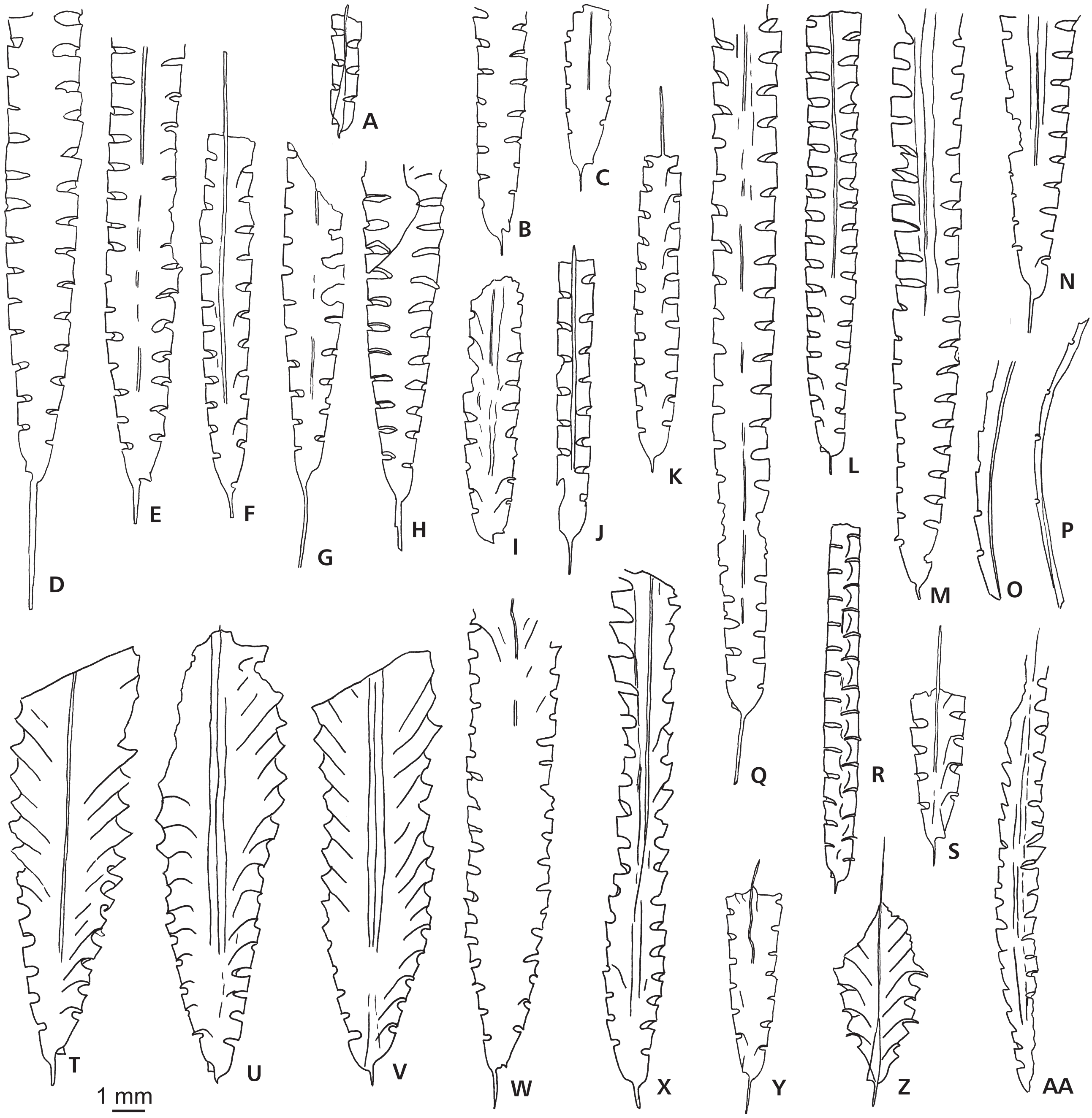

Figure 3. Graptolites from the E1-NC174 core, Murzuq Basin, Libya; core depths are quoted as they are written on the sample labels; all illustrated specimens are diagenetically flattened. • A – *Normalograptus mirnyensis* (Obut & Sobolevskaya *in* Obut *et al.*, 1967): BGS FOR 5570, 7249´ 3½˝. • B – *Normalograptus targuii* Legrand, 2001: BGS FOR 5563, 7292´ 3˝. • C – *Normalograptus parvulus* (H. Lapworth, 1900): BGS FOR 5564, 7292´ 3˝. • D–H – *Normalograptus tilokensis* (Legrand, 1986a): D – BGS FOR 5565, 7278´ 3½˝; E – BGS FOR 5566, 7278´ 10½˝; F – BGS FOR 5567, 7282´ ; G – BGS FOR 5568, 7278´ 11½˝–7279´ ; H – BGS FOR 5569, 7278´ 10½˝. • I – *Normalograptus* cf. *normalis sensu* Loydell, 2007: BGS FOR 5571, 7291´ . • J – *Normalograptus angustus* (Perner, 1895): BGS FOR 5572, 7269´ 11½˝. • K – *Normalograptus ajjeri* (Legrand, 1977): BGS FOR 5573, 7268´ 5˝–7268´ 6˝. • L – *Normalograptus medius* (Törnquist, 1897): BGS FOR 5574, 7275´ 3˝. • M, N – *Normalograptus rectangularis* (McCoy, 1850): M – BGS FOR 5575, N – BGS FOR 5576, 7256´ 5˝. • O – *Huttagraptus acinaces* (Törnquist, 1899): BGS FOR 5577, 7251´ 7˝. • P – *Huttagraptus* sp.: BGS FOR 5578, 7264´ 10˝. • Q – *Normalograptus normalis* (Lapworth, 1877): BGS FOR 5579, 7268´ 5˝–7268´ 6˝. • R – *Metaclimacograptus hughesi* (Nicholson, 1869): BGS FOR 5580, 7240´ 3˝. • S, W – *Neodiplograptus africanus* (Legrand, 1970): S – BGS FOR 5581, 7272´ 6˝–7272´ 7˝; W – BGS FOR 5582, 7245´ 3˝. • T–V – *Neodiplograptus fezzanensis* (Desio, 1940): T – BGS FOR 5583, 7239´ 8˝; U – BGS FOR 5584, 7243´ 9½˝; V – BGS FOR 5585, 7237´ 2˝. • X, Y – *Neodiplograptus posterior* (Legrand, 1970): X – BGS FOR 5586, 7243´ 9½˝; Y – BGS FOR 5587, 7245´ 3˝. • Z – *Paraclimacograptus kiliani* (Legrand, 1977): BGS FOR 5588, 7264´ 10˝. • AA – "*Glyptograptus*" *tariti* Legrand, 1970?: BGS FOR 5589, 7263´ 8˝.

ascensus-acuminatus/*Cystograptus vesiculosus* Biozone boundary is consistent with all of the existing biostratigraphical data, most particularly the co-occurrence of *Pa. kiliani* with *Huttagraptus* in both Libya and Jordan. The main anomaly between the stratigraphical ranges in Libya and Jordan when compared with Algeria is that the FAD of *Ne. africanus* is below that of *Pa. kiliani* in the E1-NC174 core and in the BG-14 core, Jordan (Loydell 2007), whereas in the Oued In Djerane region the LAD of *Pa. kiliani* is more than 70 m below the FAD of *Ne. africanus* (Legrand 2000, fig. 3). One might perhaps argue that the Libyan and Jordanian specimens of *Ne. africanus* are misidentified, but if so what could they be? In the case of the lowermost E1-NC174 core specimen, it could be *Ne. incommodus* Legrand, 2009, the proximal end of which is similar to that of narrow specimens of *Ne. africanus*. But *Ne. incommodus* also has its FAD significantly (approximately 55 m) above the LAD of *Pa. kiliani*. The Jordanian BG-14 core specimen of *Ne. africanus* occurring below *Pa. kiliani* is clearly not *Ne. incommodus*, however: its supragenicular walls are at a higher angle than those of the latter species and assignment to *Ne. africanus* seems reasonable. The most likely explanation of this apparent stratigraphical anomaly is that *Ne. africanus* has a longer overall stratigraphical range than indicated by Legrand (2000), that it is uncommon in the lower part of its stratigraphical range (this is supported by data from both Jordan and Libya) and that its absence from pre-*Pa. kiliani*-bearing strata in Algeria may simply reflect collection failure here.

Species not recorded from the E1-NC174 core are the 'standard' biozonal indices *Akidograptus ascensus* Davies, 1929 and *Parakidograptus acuminatus* (Nicholson, 1867), neither of which has been recorded from either Libya or Algeria, and *Cystograptus vesiculosus* Nicholson, 1868, which has been recorded from the Ghadāmis Basin of NE Libya by Štorch & Massa (2004). The absence of these species, and several others typical of Rhuddanian sections elsewhere in the world, is presumably due to environmental factors: temperature, salinity, oxygen level or some other factor associated with proximity to the palaeo-shoreline.

Based on the graptolites present in the E1-NC174 core and the TOC and gamma-ray curves, it is clear that the 'hot' shale in the core is of mid Rhuddanian age, occurring within the *Neodiplograptus africanus* Biozone. It would thus appear that this 'hot' shale is the stratigraphical equivalent of that in the Ghat-3 section, SW Libya studied by Fello *et al.* (2006) and in the BG-14 core in Jordan studied by Lüning *et al.* (2005) and Loydell *et al.* (2009).

Conclusions

The graptolite assemblages of the Rhuddanian of the E1-NC174 core are of low diversity and contain both endemic North African and cosmopolitan taxa. Three taxa are numerically dominant: *Normalograptus tilokensis* below, *N. rectangularis* within, and *Neodiplograptus fezzanensis* above the 'hot' shale. The 'hot' shale is of the same mid Rhuddanian age as 'hot' shales studied previously in the Ghat area, Libya and in southern Jordan.

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Table 1. Measurements of rhabdosome dorso-ventral width (DVW) and two thecae repeat distance (2TRD) in *Normalograptus tilokensis* (Legrand, 1986a) from the E1-NC174 core.

Depth		Th1[1]	Th2[1]	Th3[1]	Th5[1]	Th10[1]	Th15[1]
7276´ 4˝	DVW	1.0	1.2	1.45	1.75		
	2TRD		1.6	1.7	1.8		
7276´ 4˝	DVW	0.9	1.2	1.4	1.75		
	2TRD		1.6	1.6	1.85		
7276´ 4˝	DVW	0.9	1.1	1.35	–	1.6	1.5
	2TRD		1.7	1.7	–	1.85	1.95
7278´ 3½˝	DVW	–	1.2	1.4	1.85	2.3	
	2TRD		1.75	1.9	1.8	2.05	
7278´ 3½˝	DVW	1.0	1.3	1.5	2.0	2.1	2.25
	2TRD		1.7	1.65	1.65	1.65	1.6
7278´ 10½˝	DVW	0.95	1.2	1.5	2.0	2.65	
	2TRD		1.9	1.7	1.8	1.7	
7278´ 10½˝	DVW	1.15	1.45	1.65	2.05	2.25	
	2TRD		1.6	1.6	1.7	1.75	
7278´ 11½˝	DVW	0.9	1.1	1.3	1.75		
	2TRD		1.8	1.9	2.0		
7282´	DVW	0.95	1.2	1.3	1.5		
	2TRD		1.6	1.6	1.6		
7284´ 4˝	DVW	1.1	1.4	1.65	1.8		
	2TRD		1.65	1.75	1.65		
7288´ 1˝	DVW	0.9	1.2	1.4	1.5	1.65	1.7
	2TRD		1.45	1.55	1.55	1.75	1.75
7292´ 11˝	DVW	0.95	1.1	1.35	1.7	1.8	
	2TRD		1.65	1.65	1.75	1.85	

Table 2. Measurements of rhabdosome dorso-ventral width (DVW) and two thecae repeat distance (2TRD) in *Normalograptus rectangularis* (McCoy, 1850) from the E1-NC174 core.

Depth		Th1[1]	Th2[1]	Th3[1]	Th5[1]	Th10[1]	Th15[1]	Th20[1]
7248´ 2½˝	DVW	0.85	0.95	1.15	1.4	1.75	1.9	
	2TRD		1.7	1.7	1.7	1.8	1.6	
7250´ 4˝	DVW	0.8	1.0	1.2	1.55			
	2TRD		1.5	1.55				
7252´ 6˝	DVW	0.8	0.95	1.0	1.25			
	2TRD		1.6	1.65	1.4			
7252´ 6˝	DVW	0.75	0.9	–	1.2			
	2TRD		1.5	1.45	1.5			
7255´ 7˝	DVW	0.8	0.85	1.05	1.45	2.0		
	2TRD		1.4	1.35	1.6			
7256´ 5˝	DVW	0.9	1.2	1.35	1.65	2.2		
	2TRD		1.5	1.45	1.55	1.65		
7256´ 5˝	DVW	0.95	1.25	1.4	1.6	2.0	2.05	1.95
	2TRD		–	1.55	1.55	1.65	1.65	1.65
7256´ 5˝	DVW	0.85	1.15	1.25	1.6	2.15	2.35	2.4
	2TRD		1.7	1.55	1.4	–	1.4	1.5
7257´ 1˝	DVW	0.95	1.25	1.45	1.9	2.5	3.1	2.75
	2TRD		1.6	1.6	–	–	1.5	1.6
7263´ 1˝	DVW	0.9	1.0	1.1	1.25			
	2TRD		1.5	1.6	1.7			
7266´ 9˝	DVW	0.9	1.15	–	1.5			
	2TRD		1.7	1.7	1.8			
7267´ 11˝	DVW	0.9	1.15	1.3	1.6			
	2TRD		1.6	1.6	1.6			
7267´ 11˝	DVW	0.85	1.0	1.1	1.3	1.55		
	2TRD		1.7	1.7	1.7	1.85		
7268´ 11˝	DVW	0.85	1.0	1.15	1.35	1.5		
	2TRD		1.5	–	–	1.8		

Table 3. Measurements of rhabdosome dorso-ventral width (DVW) and two thecae repeat distance (2TRD) in *Neodiplograptus posterior* (Legrand, 1970) from the E1-NC174 core.

Depth		Th1^1	Th2^1	Th3^1	Th5^1	Th10^1	Th15^1
7237´ 2˝	DVW	1.0	1.3	1.5	1.75		
	2TRD		1.7	1.8	1.75		
7241´ 4˝	DVW	1.0	1.35	1.6	1.85	2.0	1.9
	2TRD		1.6	–	1.55	1.75	1.8
7243´ 9½˝	DVW	1.05	1.45	1.4	1.75	1.5	1.8
	2TRD		1.5	1.35	1.45	1.8	2.15
7245´ 3˝	DVW	0.85	1.05	1.35	1.45		
	2TRD		1.55	1.6	1.45		
7248´ 2½˝	DVW	0.95	1.1	1.25	1.5		
	2TRD		1.5	1.5	1.5		

Table 4. Measurements of rhabdosome dorso-ventral width (DVW) and two thecae repeat distance (2TRD) in various graptolite species from the E1-NC174 core.

Species	Depth		Th1^1	Th2^1	Th3^1	Th5^1	Th10^1	Th15^1
Me. hughesi	7240´ 3˝	DVW	0.8	0.9	1.0	1.05	1.05	
		2TRD		1.25	1.4	1.5	1.5	
Paracl. kiliani	7264´ 10˝	DVW	1.15	1.7	2.4			
		2TRD		1.45	1.45			
Paracl. kiliani	7269´ 11½˝	DVW	0.9	1.5	1.8	2.3		
		2TRD		1.5	1.5	1.55		
"*G.*" *tariti*?	7263´ 8˝	DVW	–	0.9	1.1	1.3	1.4	
		2TRD		–	1.45	1.5		
"*G.*" *tariti*?	7263´ 8˝	DVW	–	–	–	1.1	1.4	1.5
		2TRD		1.2	1.2	1.35	1.25	1.35

Table 5. Measurements of rhabdosome dorso-ventral width (DVW) and two thecae repeat distance (2TRD) in *Neodiplograptus africanus* (Legrand, 1970) from the E1-NC174 core.

Depth		Th1^1	Th2^1	Th3^1	Th5^1	Th10^1	Th15^1
7240´ 3˝	DVW	1.0	1.1	1.4	1.85	2.35	2.7
	2TRD		1.65	1.65	1.75	1.65	
7245´ 3˝	DVW	1.0	1.4	1.7	2.15	2.5	2.5
	2TRD		1.45	1.4	1.4	1.4	1.45
7245´ 3˝	DVW	1.05	1.4	1.65	2.0		
	2TRD		1.5	1.3	1.5		
7246´ 5˝	DVW	0.95	1.25	1.6	1.95	–	
	2TRD		1.3	1.3	1.4	1.35	
7247´ 3˝	DVW	1.0	1.25	1.6	2.05	2.35	
	2TRD		1.6	1.6	1.4	1.4	
7247´ 3˝	DVW	0.9	1.35	1.65	1.9		
	2TRD		1.45	1.45			
7272´ 6˝	DVW	0.95	1.3	1.5			
	2TRD		1.7	1.6			

Table 6. Measurements of rhabdosome dorso-ventral width (DVW) and two thecae repeat distance (2TRD) in *Neodiplograptus fezzanensis* (Desio, 1940) from the E1-NC174 core.

Depth		Th1^1	Th2^1	Th3^1	Th5^1	Th10^1	Th15^1
7237´ 2˝	DVW	1.1	1.7	2.1	2.8	3.6	
	2TRD		1.45	1.5	1.35		
7237´ 2˝	DVW	1.25	1.65	2.1	2.9	3.1	
	2TRD		1.3	1.4	1.35	1.6	
7238´ 4˝	DVW	1.05	1.6	1.95	2.75		
	2TRD		1.45	1.45	1.45		
7238´ 4˝	DVW	1.05	1.55	–	2.25		
	2TRD		1.4	1.45	1.5		
7239´ 6˝	DVW	1.0	1.3	–	2.25		
	2TRD		1.55	1.5	1.5		
7239´ 8˝	DVW	1.0	1.55	1.8	2.5	3.65	
	2TRD		1.6	1.75	1.5		
7239´ 8˝	DVW	1.1	1.75	2.25	2.5		
	2TRD		1.5	1.45	1.15		
7239´ 8˝	DVW	1.0	1.75	2.35	2.9	–	3.5
	2TRD		1.7	1.7	1.65	–	
7240´ 3˝	DVW	1.0	1.3	1.65	2.05	3.0	3.55
	2TRD		1.6	1.7	1.6	1.65	
7240´ 3˝	DVW	0.95	1.25	1.45	2.4		
	2TRD		1.85	1.8	–		
7240´ 3˝	DVW	1.0	1.45	1.9	2.6	–	
	2TRD		1.5	1.45	1.45	1.65	
7240´ 3˝	DVW	1.1	1.5	1.75	2.3	3.4	
	2TRD		1.4	1.4	1.5	1.5	
7240´ 3˝	DVW	0.95	1.25	1.5	2.0		
	2TRD		1.75	1.85	1.55		
7240´ 3˝	DVW	1.0	1.25	1.65	2.1	3.0	
	2TRD		1.65	1.75	1.8		
7240´ 3˝	DVW	0.9	1.2	–	2.4	3.0	3.15
	2TRD		1.75	1.6	1.7	–	1.6
7240´ 3˝	DVW	1.05	1.45	1.85	2.3	2.9	
	2TRD		1.6	1.6	1.45	–	
7240´ 3˝	DVW	1.05	1.55	2.0	2.45		
	2TRD		1.65	1.65	1.7		
7240´ 3˝	DVW	1.1	1.5	1.75	2.5	2.9	
	2TRD		1.6	1.6	–		
7240´ 3˝	DVW	1.0	1.25	1.75	2.1		
	2TRD		1.65	1.55	1.65		
7241´ 4˝	DVW	1.1	1.65	2.0	2.9	3.65	
	2TRD		1.75	1.5	1.4	1.4	
7242´ 7˝	DVW	0.95	1.35	1.55	2.2	–	–
	2TRD		1.45	1.45	1.55	–	1.4
7243´ 9½˝	DVW	1.0	1.5	1.9	2.35	3.5	
	2TRD		1.5	1.35	1.45	–	

Table 7. Measurements of rhabdosome dorso-ventral width (DVW) and two thecae repeat distance (2TRD) in various *Normalograptus* species from the E1-NC174 core.

Species	Depth		Th1[1]	Th2[1]	Th3[1]	Th5[1]	Th10[1]	Th15[1]	Th20[1]
N. ajjeri	7268´ 5˝	DVW	0.9	1.1	1.15	1.4	1.4		
		2TRD		1.3	1.35	1.45	1.55		
N. ajjeri	7268´ 5˝	DVW	0.85	1.0	1.0	1.25			
		2TRD		–	1.55	1.65			
N. ajjeri	7271´ 8˝	DVW	0.9	1.05	1.1	1.1			
		2TRD		1.65	–	–			
N. ajjeri	7274´ 6˝	DVW	1.0	1.3	1.5	1.6	1.55	1.6	
		2TRD		1.65	1.65	1.8	1.7	1.9	
N. ajjeri	7275´ 3˝	DVW	1.0	1.15	1.25	–	1.4	1.35	
		2TRD		1.4	1.3	1.4	1.6		
N. ajjeri	7284´ 9˝	DVW	1.05	1.25	1.35	1.5	1.55	1.4	1.45
		2TRD		1.5	1.6	1.7	1.7	1.85	1.95
N. angustus	7269´ 11½˝	DVW	–	–	0.95	1.0	1.0		
		2TRD		–	–	1.9			
N. medius	7269´ 1˝	DVW	0.9	1.05	1.15	1.5	1.6	1.85	
		2TRD		1.5	–	–	1.8		
N. medius	7275´ 3˝	DVW	0.9	1.15	1.3	1.5	1.65	1.7	
		2TRD		1.4	1.45	1.45	1.55	1.6	
N. normalis	7268´ 5˝	DVW	0.95	1.05	1.2	1.45	1.55	1.8	1.85
		2TRD		1.7	–	–	–	1.95	1.9
N. normalis	7276´ 4˝	DVW	0.95	–	–	1.55			
		2TRD		1.55	1.6	1.75			
N. normalis	7284´ 9˝	DVW	1.05	1.35	1.5	1.8	2.0		
		2TRD		1.5	1.45	1.6			
N. normalis	7284´ 9˝	DVW	1.15	1.4	1.55	1.75	2.05		
		2TRD		1.55	1.6	1.6	1.9		
N. cf. *normalis*	7255´ 7˝	DVW	0.95	1.1	1.25	1.4	1.1		
		2TRD		1.55	1.5	1.55	1.6		
N. cf. *normalis*	7272´ 6˝	DVW	1.0	1.25	1.4	1.75	1.7		
		2TRD		1.7	1.7	1.6	1.7		
N. cf. *normalis*	7291´	DVW	1.25	1.4	1.55	1.75	1.75		
		2TRD		1.5	1.5	1.55(5[2])			
N. parvulus	7273´ 4˝	DVW	0.95	1.1	1.2	1.25			
		2TRD		1.25(2[2])	1.3(3[2])				
N. parvulus	7274´ 6˝	DVW	1.05	1.3	1.4				
		2TRD		1.5					
N. parvulus	7286´ 7½˝	DVW	0.95	1.15	1.2	1.3	1.5	1.5	1.5
		2TRD		1.25	1.35	1.6	–	1.6	
N. parvulus	7292´ 3˝	DVW	1.0	1.25	1.35	1.4			
		2TRD		1.4	1.35				
N. targuii	7292´ 3˝	DVW	–	1.2	1.35	1.45			
		2TRD		–	1.55	1.9			