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Synthesis of Acyclic, Symmetrical 3,3'-Allyl Dithioethers, from the Alkylation of 3-Mercapto-2-mercaptomethylprop-1-ene in the Presence of Sodium Hydride

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A novel method where 3,3'-allyl dithioethers have been prepared from 3-mercapto-2-mercaptomethylprop-1-ene and two mol equivalent of alkyl halide in the presence of two mol equivalent of sodium hydride has been developed. Using this method, bisepoxide, 2,2'-(2-methylenepropane-1,3-diyl)bis(sulfanediyl)bis(methylene)dioxirane (8) has been synthesized from epichlorohydrin, whereas potassium carbonate was unable to deliver this product. These 3,3'-allyl dithioethers can be utilized either as monomers, or with further chemical reactions transformed into more complex monomers, for photoplastic polymer networks.

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Introduction

Our group has an interest in the field of stimuli responsive polymers,^[1] and is active in the sub-area of photoplastic polymers. Photoplasticity is the phenomenon where the stimulus of radiation (usually UV or visible) can induce shape change, shape creep, or stress relaxation in a crosslinked polymer and this has the advantage in minimizing warpage or internal stresses that can develop in crosslinked polymers as a result of polymerization shrinkage.^[2] Such polymeric materials can be of significant importance for use in, for example, dental applications.^[1] The first photoplastic system that we developed used the thiol-ene reaction to form a crosslinked polymer.^[3] The thiol-ene reaction employs a thiol, in this case pentaerythritol tetrakis(3-mercaptopropionate) (PETMP) (1), to add to an unsaturated compound such as 2-methylenepropane-1,3-di(thioethyl vinyl ether) (MDTVE) 2 (two mol equivalent to one), forming a 3D network 3, schematically shown as 4 (Fig. 1).

It must be noted that the unique photoplastic property of such a cured thiol-ene network **3**, lies within the (2-methylenepropane-1,3-diyl)bis(sulfandiyl) moiety, **5** (Scheme 1). These sub-units have methylene groups which can be attacked by photogenerated carbon radicals, \mathbb{R}^{\bullet} , at the terminal alkene carbon of **5** to form a bond and the simultaneous β -cleavage to regenerate another alkene-group and a sulfanyl radical (Scheme 1).^[4] This radical then is able to attack another alkene in an adjacent polymer chain, causing β -scission and the formation of a new sulfanyl radical. As a result of these processes, the network chains are broken and reformed in new configurations so that

any stress that had been imposed on the chains is relieved. It might be considered that this process could continue without end, but this does not occur because the process of radical combination, and depletion of the photoinitiator concentration, leads to a decrease in the number of radicals. This leads to the cessation of the chain rearrangements thus limiting the extent of shape change and/or stress relaxation.

We were interested in extending the range of monomers which are similar to 2 and we were particularly interested in the bisepoxide monomer (2,2'-[2-methylenepropane-1,3-diyl]bis [sulfanediyl]bis[methylene]dioxirane) (8), based on a thiolepichlorohydrin alkylation (Scheme 2, Table 1).

Reported syntheses of thioethers (sulfides) are numerous and usually involve the alkylation of thiols (mercaptans) with alkyl halides under basic conditions. A recent example is the use of caesium carbonate as a base in DMF as a solvent and tetrabutylammonium iodide (TBAI) as phase transfer catalyst.^[5] It was found that potassium carbonate gave slightly lower yields than caesium carbonate and that iodides gave better yields than bromides although benzyl chloride gave a somewhat higher yield than benzyl bromide.^[5] This shows that the type of halide and alkali-carbonate base (K or Cs) does not have a dramatic effect on product and yield; however, aprotic polar solvents seem to have a more pronounced effect on yield. This was highlighted when benzylmercaptan was alkylated with ethyl iodide, ethyl bromide, and ethyl tosylate in DMF and acetonitrile as solvents, in the presence of tetraethylammonium hydrogencarbonate as a base to obtain benzylethyl sulfide.^[6]





Scheme 1.



Thus in DMF and acetonitrile all yields were around 90-93 % but when diethyl ether was used the yield dropped to 72 % and with dichloromethane the yield was even lower (41 %).^[6] An alternative approach to thioether synthesis is the use of Lewis acid catalysis. Thus, an alcohol and a mercaptan gave the corresponding thioether, using ZrCl4 on dry silica gel as catalyst, with no solvent.^[7] However, this solvent free method did not suit us, because of the restrictions of the amount we would be able to convert into thioethers. Potassium fluoride on alumina in refluxing acetonitrile was used to prepare thioethers, although the substrates used to demonstrate this preparation were fairly simple.^[8] Certain aromatic heterocyclic mercaptans have been alkylated with alkyl halides in the presence of zinc^[9] or KOH,^[10] but these reducing or strong basic conditions impose considerable limitations on the molecules that can be synthesized. None of these synthetic methods investigated thiolalkylations with epichlorohydrin, which we were interested in. Thus, for our work many of these thioether preparations were not applicable to the synthesis of 3,3'-allyl dithioethers, particularly because they are incompatible with the alkene moiety used in the thiol-ene reaction.^[11]

There are only a few examples of the synthesis of allyl thioethers cited in the literature. One example for synthesizing mono allylic thioethers is the iodine-catalyzed alkylation of thiols with allylic alcohols in 1,4-dioxane at room temperature.^[12] The disadvantage of this method is that a four-fold excess of the thiol is required which is a major limitation in our work because the synthesis of MDTVE 2, using this method, would require 2-methylenepropane-1,3-diol, which is very expensive, and 2-mercaptoethyl vinyl ether which is a difficult compound to obtain, and will further undergo a thiol-ene reaction with itself.^[13] Another allylic thioether preparation is the palladium(0)-catalyzed alkylation of allylic carbonates with aromatic thiols,^[14] while $ZrCl_4$ as an acid catalyst on silica can also be used to condense thiols with allylic alcohols.^[7] Evans and Rizzardo have been able to furnish cyclized compounds having the 3,3'-allyl dithioether unit, but this method required the presence of sodium methoxide as a base, highly dilute reaction conditions, and long reaction times to enhance cyclization over generation of the acyclic compound.^[15] Thus we have found that for a great number of our novel acyclic 3,3'-allyl dithioether monomers that we wanted to prepare, we had to

Run	Reactant 1	Reactant 2	Product {by-product}	Yield using NaH [%]	Yield using K ₂ CO ₃ [%]
1	2 × CI	7		60	0
2	OH 2 × HS OH	6	HO S S OH 9	80	48
3	2 × 0. Cl	7		_	85
4	2 × 6	7		76	_
5	2 × HS ~ OH	6	HO S OH	81	93
6		7	$H \xrightarrow{(0, -)_{3}} S \xrightarrow{(-, -0)_{3}} H$ 13	98	_
7	2 × HS (0) H	6	$H \xrightarrow{\left(0 \\ 3 \right)} S \xrightarrow{\left(0 \\ 3 \right)} S \xrightarrow{\left(0 \\ 3 \right)} S \xrightarrow{\left(0 \\ 3 \right)} H$ 13	75	_
8	2 × 7	6	HS $(s) = 1, 5,$	trace	_
9	HS 0 SH 17	2 × 6		56	_
			+ $\begin{bmatrix} CI \\ CI \\ 20 \end{bmatrix}_2^A$	{14}	

Table 1. Synthesis of acyclic allyl thioethers, from the alkylation of 3-mercapto-2-mercaptomethylprop-1-ene (7) (Method A) or 3-chloro 2-chloromethylprop-1-ene (6) (Method B) in the presence of sodium hydride in THF

(Continued)

1085

Run	Reactant 1	Reactant 2	Product {by-product}	Yield using NaH [%]	Yield using K ₂ CO ₃ [%]
10	HS $(-0)^{2}$ SH 18	2 × 6		41	_
			$+ \left[\begin{array}{c} C \\ C \\ 2 \end{array} \right]_{2}^{A}$	{13}	
11	2 mol equiv. $(CH_2O)_n$	7 ^B		99	_

^ABy-product.

adopt a different synthetic strategy. In this paper we have developed a synthetic method (Scheme 2) for bisepoxide **8** and similar compounds that is fast and uses little solvent (Table 1). We also describe the photoplastic properties of **8** cured with PETMP **1**.

Results and Discussion

Application of the method of Evans and Rizzardo was found to be unsuitable for the synthesis of bisepoxide $\mathbf{8}^{[15]}$. The allylic dithiol, 3-mercapto-2-mercaptomethylprop-1-ene (7) (Table 1), with two mol of epichlorohydrin using the strong nucleophilic sodium methoxide as base, produced only a trace amount of the bisepoxide 8 in a glue-like product which was presumably a polymer formed by chain growth anionic polymerization of the epoxide rings. We then investigated other different methods to react epichlorohydrin with the allylic dithiol 7. We found that a Protonsponge^[16] produced no product, while 1,8-diazabicyclo [5.4.0]undec-7-ene (DBU),^[17] gave very impure bisepoxide 8. Thus, we were aiming for conditions that would allow fast deprotonation but have low nucleophilicity. This led us to develop a new synthetic approach whereby 2 mol equivalents of sodium hydride was used to abstract the protons of the thiol groups of 7 but in the presence of two mol equivalents of alkyl halide. The latter condition is important. We have found that in the absence of alkyl halides, sodium hydride does not deprotonate the dimercaptan 7 in THF to the diionic disulfide species, not even at an elevated temperature of 50°C for an extended time of 60 min. Depending on which alkyl halide was used with this method, the liberation of hydrogen varied from being moderate (over 30 min) to fast and exothermic (instantaneous). At this stage we cannot explain this variation. We denote this method, whereby a neat mixture of 7 and two mol of alkyl halide is added to a stirred suspension of two mol of sodium hydride in anhydrous THF at room temperature to produce 3,3'-allyl dithioether, as Method A (Scheme 2). In Method B, a neat mixture of 3-chloro-2-chloromethylprop-1-ene (6) with two mol equivalents of mercaptan (R-SH) is used under the same conditions as for Method A. These two procedures have advantages

and disadvantages. For example, Method A uses the dimercaptan 7, a compound having a severe, long-lasting stench. However, the answer to which of Methods A or B should be used also depends on the availability of either the alkyl mercaptans or halides and which method gives the higher yield. In our first attempt to make the bisepoxide 8, a mixture of 2 mol equivalents of (\pm) -epichlorohydrin and 1 mol equivalent of allyl dithiol 7, was added to a suspension 2 mol equivalents of sodium hydride in THF at room temperature, and after an initial 5 min induction time an extremely exothermic reaction occurred (>50°C) concomitant with the strong evolution of a large volume of hydrogen gas which led to foaming in the reactor. However, bisepoxide 8 was present among the polymeric material. We, therefore, performed the reaction at -20° C, but it was necessary to perform the addition to the sodium hydride suspension as fast as possible - it appears that a localized exotherm is necessary but should be controlled. When the addition was performed too slowly at -20° C the yield of 8 was low. The preparation using Method B was not investigated since the 2,3-epoxypropane-1thiol is difficult to synthesize.^[18] The use of sodium hydride as a base in thioether synthesis is not entirely new: Liu used sodium hydride to alkylate simple alkyl mercaptans, R-SH (R = Me, Et, Pr, Bu) with a 2-chloroethoxynucleoside compound.^[19]

It is noteworthy that when potassium carbonate was used as a base, the reaction between epichlorohydrin and allylic dithiol 7 led to attack on the epoxide and ring-opening gave product 10 exclusively (Scheme 3). Surprisingly, 10 did not transform to 8. The bis(chloropropyl sulfide) 10 may be hazardous, since it resembles β -chloro sulfides, which are powerful vesicants and, therefore, dangerous.^[20] The bisepoxide 8, being a reactive compound, may also be toxic.

We also used a mixture of 2 mol of thioglycerol and allyl dichloride 6 (Method B), and reacted it at room temperature to obtain the allylic disulfide 9 in 80% yield. Note that using potassium carbonate as a base took over 12 h to react and gave a lower yield (48%) (Table 1). We were not able to transform compound 9 satisfactorily into the bisepoxide 8 using the Mitsunobu reaction conditions, also because of the poor solubility of the tetraol 9 in solvents.

^BNo NaH used.

Synthesis of Allylic Dithioether Monomers





Likewise, following either Method A or B compounds 11, 12, and 13 were synthesized (Table 1). Thus, using a four-fold amount of dichloride 6 to 1 equivalent of dimercaptan 7 (Method A), compound 11 was prepared in good yield and purity; in addition, 60 % of the fairly expensive 6 used was recovered. It is important to note that compound 11, in pure form, is prone to decomposition and polymerization in air. Only a cold solution (preferably $<5^{\circ}$ C) of 11 in dichloromethane, under nitrogen, is stable. Last mentioned reactants 6 and 7 were then also used in a reaction with the opposite excess stoichiometry, by adding a mixture of at least 2 mol of dimercaptan 7 and 1 mol of dichloride 6 (Method B) to intentionally form the triple allylic disulfide 14 (Scheme 4, Table 1). However this method gave an impure, uncharacterizable mixture. Repeating the reaction with a greater excess of 7 gave a strong sulfur-odorous mixture that was difficult to purify and a low yield of a product was obtained. This was analyzed as a mixture of oligomers, including 14 (n = 1)and 5) (Table 1). The only characteristic NMR feature of this product was the absence of the CH2-S doublet of the dimercaptan 7 ($\delta_{\rm H}$ at 3.35) and instead a singlet was present ($\delta_{\rm H}$ at 3.35) (Scheme 4). We, therefore, found that when reacting the difunctional compounds of dihalides and dithiols, to use the following approach of employing an approximately six-fold excess of dihalide with one equivalent of dithiol 7 rather than the other way around.

Compound 12 (Table 1) was prepared from the dichloride 6 and 2-thioethanol as described in Method B, since 2-chloroethanol could not easily be purchased, because of its high toxicity, for

use in Method A. As a comparison, potassium carbonate produced a high yield using the dichloride **6** and 2-thioethanol. Product **13** (Table 1) was successfully prepared using either Method A or Method B. It is noteworthy that compounds **9**, **12**, and **13** were chemoselectively produced. Compounds **12** and **13** were further transformed to their respective bisepoxides **15** and **16**, using 2 mol of epichlorohydrin and excess solid sodium hydroxide with 1 mol of water in the presence of benzyltriethyl-ammonium chloride as a phase transfer catalyst in dichloromethane (Scheme 5).^[21] The photoplasticity of these monomers are presently under investigation and the results will be published elsewhere.

We then turned our attention to the synthesis of bis([allylic] dithioether) systems for novel monomer synthesis that would include two 3,3'-allyl dithioether groups for the preparation of enhanced photoplastic polymers. The precursor dithiols 17 and 18 (Table 1) were prepared from their respective dichlorides using aqueous, in situ prepared, sodium trithiocarbonate.^[22] Using Method B, the dithiols 17 and 18 were reacted with a six-fold excess of allyl dichloride 6 to give the desired products 19 and 21 in modest yields of 56 and 41 %, respectively. In addition, chalcogenated trienedichlorides 20 and 22 were also obtained from the reaction mixture in low, yet distinctive amounts, since no further products were isolated (Scheme 6). In both cases, there appears to be a pattern. In addition to the expected symmetric A-B-A pattern of 2 mol of 6 (A) alkylated to 1 mol of thiol (B), the thioglycols 17 and 18 also gave the symmetric A-B-A-B-A pattern of alkylation as a by-product and

1087

C. M. Moorhoff et al.





the combined yield was ~70 %. We were not able to isolate any longer oligomeric compounds or by-products like the symmetric B-A-B and B-A-B-A-B or asymmetric compounds like B-A-B-A. Few examples of dithioether formation by alkylation of a dihalide were found in the literature. For example, the study of the alkylation of thiols with dihaloalkanes X-R-X in the presence of hydrazine and KOH produced overwhelmingly the mono-thioether, R'S-R-X, and only a little of the dithioether, R'S-R-SR', was isolated.^[23] Compounds **19** and **21** are being further investigated for bis([allylic] dithioether) synthesis and the occurrence of trienedichlorides **20** and **22** will be further studied and this research will be reported elsewhere.

Paraformaldehyde and dimercapto compound 7 reacted, without solvent or base, at 130°C within an hour to form the diol **23** as a viscous colourless oil. However, the reaction of diol

23 with epichlorohydrin under the same basic conditions as applied for 12 and 13 was unsuccessful. Instead of the desired bis-epoxide 24, only a crude mixture of impure bisepoxide 8 was found. This suggests that compound 23 had undergone base-promoted release of formaldehyde, followed by subsequent alkylation with epichlorohydrin to form 8 (Scheme 7). Likewise, in our hands, we were unable to alkylate product 12 (Table 1) with 2-chloroethyl vinyl ether in the presence of two mol of NaH. In the last mentioned reaction, an uncharacterizable black tar was produced.

As an example of the importance of monomers containing the bisallylic dithio moiety in the phenomenon of photoplasticity, Fig. 2 shows the stress relaxation behaviour of two specimens during irradiation of bisepoxide **8**. The specimen without benzoin ethyl ether (PhC[=O]CH[OEt]Ph) does not



Fig. 2. Photoinduced stress relaxation of two specimens of the crosslinked network **25** formed from the crosslinking reaction of bisepoxide **8** and a stoichiometric quantity of pentaerythritol tetra(3-mercaptopropionate) (1) using 0.5 wt-% *N*,*N*-dimethylbenzylamine as an anionic catalyst during cure at 80°C for 6 h. One of these specimens also contained 1 wt-% benzoin ethyl ether as a radical source when irradiated with 350 nm UV radiation.

show any significant change in stress during the irradiation period because the crosslinked network structure does not significantly absorb radiation and so no β -scission occurs. In contrast, the sample containing 1 wt-% benzoin ethyl ether shows a sudden loss of stress when the UV lamp is switched on and this stress loss is not significantly recovered when the irradiation is terminated. This behaviour is initiated by the production of carbon radicals from the photolysis of the benzoin ethyl ether. These carbon radicals and the subsequently produced sulfur radicals add to the allylic dithioether group of bisepoxide **8** and cause strand rearrangement as shown in Scheme 1.

Conclusions

A method has been developed whereby novel 3,3'-allyl dithioethers have been prepared from 7 and 2 mol equivalents of alkyl halide in the presence of 2 mol equivalents of sodium hydride. Thus, the sensitive bisepoxide, 2,2'-(2-methylenepropane-1,3diyl)bis(sulfanediyl)bis(methylene)dioxirane 8, has been synthesized and cured with PETMP 1, to form a photoplastic polymer network 25.

Experimental

All reactions were performed under nitrogen. THF was dried over sodium hydride. All purchased chemicals were used as received. Compound **6** (Secant Chemicals Inc., MI, USA) was used for the preparation of **7**, according to the method of Evans and Rizzardo.^[15] Epichlorohydrin, 2-thioethanol, diethylene glycol, and triethylene glycol were purchased from Aldrich, 1-thioglycerol from Fluka, and 2-(2-(2-chloroethoxy)ethoxy) ethanol from Wako Chemicals.

Mass spectrometry experiments were carried out on a Waters Q-TOF II instrument, employing electrospray ionization (ESI) with a 35 eV cone voltage unless otherwise stated and employing lock spray and sodium iodide as a reference sample. Other mass spectra experiments were carried out on a ThermoQuest MAT95XP instrument, employing electron impact (EI) at 70 eV and employing perfluorokerosene (PFK) as a reference sample. NMR spectra were run on Bruker Avance

III 400 (9.4 Tesla magnet) with a 5 mm broadband inverse probe, ¹H at 400.13 MHz, or a Bruker DPX300 (7.05 Tesla magnet) with a 5 mm quad ¹H/¹³Cswitchable probe, ¹H at 300.13 MHz, or a Bruker AV200 (4.7 Tesla magnet) with 5 mm ¹H/¹³C probe with *Z*-gradients at 30 °C in CDCl₃ using the residual chloroform peaks at 7.26 ppm as a reference in proton and 77.16 ppm in carbon spectra.

For the photoplasticity experiments, a specimen 30 mm long, 6 mm wide, and 0.6 mm thick was held between the specimen grips of a dynamic mechanical spectrometer DMTA IV (Rheometrics, USA) and then stretched to 4.5% elongation at 80°C. The stress (force applied by the DMTA to keep the sample stretched, divided by the sample cross-sectional area) was measured as a function of time. After 300 s, the 350 nm UV radiation from a Polilight 400 light source (Rofin, Australia) was used to irradiate the sample for 1200 s with an intensity of 9 mW cm⁻² at room temperature and then the UV source was switched off.

2-(2-(2-Mercaptoethoxy)ethoxy)ethanol

Carbon disulfide (5.00 g, 65.67 mmol) was added to a solution of sodium sulfide nonahydrate (15.00 g, 62.62 mmol) in water (8 mL) at 40°C, and this mixture was stirred for 4 h. 2-(2-(2-Chloroethoxy)ethoxy)ethanol (10.00 g, 59.30 mmol) was then added to this deep orange solution of aqueous sodium trithiocarbonate and was stirred overnight at 60°C. The reaction mixture was cooled to room temperature and diluted with water (40 mL) and extracted with EtOAc (30 mL) to remove unreacted chloroalcohol impurities. The aqueous solution was then slowly acidified with $\sim 6 \text{ M H}_2\text{SO}_4$ until pH ~ 3 . The mixture was then extracted with EtOAc ($2 \times 50 \text{ mL}$) and the organic extract was then treated with 1 g of NaHCO₃ in water (10 mL) and after vigorous extraction resulted in neutralization of the organic extract. The aqueous layer contained orange, unwanted, watersoluble byproducts and was discarded. The organic extract was dried (Na₂SO₄) and filtered and after rotary evaporation gave the mercaptoalcohol (4.35 g, 44%). $\delta_{\rm H}$ (300 MHz, CDCl₃) 3.68– 3.61 (m, 2H, CH₂OH), 3.62 (m, 2H, CH₂O), 3.61 (s, 4H, OCH₂CH₂O), 3.60 (m, 2H, CH₂O), 2.70 (dt, J 8.2, 6.4, 2H, CH₂S), 2.5 (br s, 1H, OH), 1.58 (t, J 8.2, 1H, SH).

1089

2,2'-(2-Methylenepropane-1,3-diyl)bis(sulfanediyl)bis (methylene)dioxirane (**8**)

A 2 mL aliquot of a mixture of 7 (7.00 g, 58.21 mmol, 1 equiv.) and epichlorohydrin (12.60 g, 136.2 mmol, 2.3 equiv.) was added to a stirred, oil-free suspension of sodium hydride (3.00 g, 125.0 mmol, 2.2 equiv.) in THF (75 mL) at -20°C. After a 5 min induction time, a slow evolution of hydrogen gas occurred. The remainder of the mixture was then added cautiously and continuously over 60 min while maintaining the temperature between -10 and -5°C. The pale yellow-white mixture was then allowed to come to room temperature over 20 min. The reaction mixture was diluted with THF (25 mL) and petroleum spirits (100 mL) and filtered over a 5 cm bed of silica gel on a sintered glass funnel to remove polar impurities and NaCl salt. A further mixture of 50 % THF/50 % petroleum spirits (50 mL) was then used to remove most of the product from the filter. The combined clear solution was then rotary evaporated and gave the crude bisepoxide 8 (8.15 g, 60 %). Removal of excess epichlorohydrin and other volatile residues was done at 70°C at 0.5 mmHg. The product was stirred with hexane (10 mL) at room temperature to dissolve residual paraffin oil from the heavier product. The latter was collected and passed though a small Hirsch funnel having a 3 mm layer of silica gel and a 3 mm layer of Celite. The hexane was removed from the filtrate under vacuum to give colourless 8 (5.6 g, 41 %). Rf 0.41 EtOAc 50 %/ petroleum spirits 50%. $\delta_{\rm H}$ (300 MHz, CDCl₃) 5.07 (s, 2H, H₂C=), 3.39 (s, 4H, 2 × SCH₂-allyl), 3.12 (dddd, 2H, *J* 5.7, 5.4, 4.3, 2.6, $2 \times CH^{-0-}CH_2$), 2.80 (dd, 2H, J 4.7, 4.3, $2 \times CH^{-0-}CH_2$), 2.64 (dd, 2H, J 14.1, 5.7, $2 \times SCH_2CH^{-0-}CH_2$), 2.59 (m 2H, $2 \times CH^{-O-}CH_2$), 2.55 (dd, 2H, J 14.1, 5.4, $2 \times$ $SCH_2CH^{-O-}CH_2$). δ_C (50 MHz, CDCl₃) 140.4 (C=), 116.5 $(H_2C=)$, 51.5 $(2 \times CH^{-O-}CH_2)$, 46.7 $(2 \times CH^{-O-}CH_2)$, 35.6 $(2 \times \text{SCH}_2\text{CH}_2\text{CH}_2)$, 33.0 $(2 \times \text{SCH}_2\text{-allyl})$. m/z (EI) 232 (3 %, M⁺), 175 (37), 143 (49), 117 (53); 101 (17), 85 (100), 73 (76), 55 (30). m/z HRMS Anal. Calc. for $C_{10}H_{16}O_2^{32}S_2$: 232.0586. Found: 232.0582.

3,3'-(2-Methylenepropane-1,3-diyl)bis(sulfanediyl) dipropane-1,2-diol (**9**)

A mixture of 6 (1.83 g, 14.64 mmol, 1 equiv.) and 1-thioglycerol (3.60 g, 33.28 mmol, 2.3 equiv.) in THF (1 mL) was added within 10 min to a stirred suspension of sodium hydride (0.78 g, 32.50 mmol, 2.14 equiv.) in THF (30 mL) at 20°C. A slow evolution of hydrogen gas occurred for 30 min. This mixture was then further stirred for 15 h at 20°C. The grey suspension turned white. This mixture was diluted with THF (50 mL) and filtered over a 3 cm bed of silica gel (3 cm diameter). The filter was further eluted with 1:1 dichloromethane:petroleum spirits (100 mL) and the combined filtrate rotary evaporated dry on a hot waterbath (90°C) to give a clear, viscous oil of 9 (3.14 g, 80%) that solidified at room temperature as a waxy solid. $\delta_{\rm H}$ (300 MHz, [D₆]DMSO) 4.99 (s, 2H, H₂C=), 4.72 (d, 2H, J 5.0, 2 × OH), 4.52 (t, 2H, J 5.6, 2 × OH), 3.53 (h, 2H, J 5.3, 2 × CH₂CH[OH]CH₂), 3.35 (d, 2H, J 4.4, 2 × CH), 3.30 (d, 2H, *J* 5.6, 2 × CH), 3.24 (s, 4H, 2 × SCH₂), 2.51 (dd, 2H, *J* 13.2, 5.3, $2 \times CH$), 2.33 (dd, 2H, J 13.2, 6.6, $2 \times CH$). δ_C (75 MHz, [D₆] DMSO) 142.0 (C=), 116.2 (H₂C=), 71.2 (2×OCH), 65.4 $(2 \times \text{OCH}_2)$, 36.9 $(2 \times \text{SCH}_2)$, 35.3 $(2 \times \text{SCH}_2\text{-allyl})$. m/z (EI) 268 (M⁺, 5%), 193 (41), 161 (65), 99 (22), 91 (100), 87 (29), 85 (67), 55 (40). m/z HRMS Calc. for $C_{10}H_{20}O_4^{32}S_2$: 268.0798. Found: 268.0797.

3,3' - (2-Methylenepropane-1,3-diyl)bis(sulfanediyl) dipropane-1,2-diol (**9**): using K₂CO₃

1-Thioglycerol (2.50 g, 23.10 mmol, 2.3 equiv.) and benzyltriethylammonium chloride (BTEAC) (0.08 g) was added to a stirred suspension of potassium carbonate (4.00 g, 28.94 mmol, 2.9 equiv.) and butanone (3 mL), followed by the addition of **6** (1.25 g, 10.0 mmol, 1 equiv.). Within minutes the mixture became hot and was stirred for 18 h at 75°C. The reaction mixture was then diluted with THF (50 mL) and filtered over a 3 cm thick bed of silica gel. The residue was further washed with 1:1 dichloromethane:petroleum ether (100 mL) and the combined filtrate rotary evaporated dry on a hot waterbath (90°C) to give **9** (1.28 g, 48 %).

3,3'-(2-Methylenepropane-1,3-diyl)bis(sulfanediyl)bis(1chloropropan-2-ol) (**10**)

A mixture of 7 (0.70 g, 5.82 mmol, 1 equiv.) and epichlorohydrin (1.20 g, 12.97 mmol, 2.2 equiv.) was added to a suspension of potassium carbonate (1.50 g, 10.85 mmol) and BTEAC (0.03 g) in dichloromethane (2 mL) and stirred overnight at 35°C. The reaction mixture was cooled to 20°C, and then diluted with EtOAc (5 mL) before filtering the suspension over silica gel. The clear solution was then rotary evaporated dry to give a crude, colourless, viscous oil of 10 (1.51 g, 85 %). $\delta_{\rm H}$ (200 MHz, CDCl₃) 5.07 (s, 2H, H₂C=), 3.94 (ddd, 2H, J 7.1, 5.1, 4.8, $2 \times CH_2CH[OH]CH_2$, 3.67 (ddd, 2H, J 12.4, 4.6, 0.6, $2 \times$ ClCH₂CH[OH]), 3.66 (dd, 2H, J 12.4, 5.2, 2 × ClCH₂CH[OH]), 3.33 (s, 4H, $2 \times$ SCH₂-allyl), 2.77 (dd, 2H, J 4.8, 1.5 Hz, $2 \times$ OH), 2.70 (ddd, 2H, J 13.8, 5.1, 1.5, 2 × SCH₂CH[OH]), 2.59 (ddd, 2H, J 13.8, 7.1, 1.3, $2 \times \text{SCH}_2\text{CH[OH]}$). δ_C (50 MHz, $CDCl_3$) 140.1 (1 × C=), 117.1 (1 × H₂C=), 70.0 (2 × CHOH), 48.2 (2 × CH₂Cl), 35.8 and 35.2 (4 × CH₂S). m/z (EI) 304 (5%, M⁺); 211 (51); 179 (100), 161 (10), 129 (13), 117 (17), 109 (18). m/z HRMS Calc. for C₁₀H₁₈O₂³⁵Cl₂³²S₂: 304.0120. Found: 304.0121.

(2-Methylenepropane-1,3-diyl)bis((2-(chloromethyl)allyl) sulfane) (**11**)

A mixture of 6 (21.32 g, 170.6 mmol, 4.2 equiv.) and 7 (4.85 g, 40.34 mmol, 1 equiv.) was added to a suspension sodium hydride (2.40 g, 100.0 mmol, 2.5 equiv.) in THF (60 mL) at 20°C, resulting in a moderate evolution of hydrogen gas. The reaction mixture was stirred for 72 h at 20°C and then diluted with THF (60 mL) and filtered over a 5 cm bed of silica gel. The residue was further eluted with THF (100 mL) and the combined filtrate rotary evaporated dry on a hot waterbath (70°C) to give the crude, colourless oil 11 (11.15 g, 93 %) which solidified as a waxy white material. The waxy solid product was dissolved in ethyl acetate (15 mL) at 50°C. This solution was quickly cooled to room temperature and then put immediately (before crystallizing) on a 100 g silica gel column and chromatographed using 5 % EtOAc/95 % petroleum spirits, increasing to 10 % EtOAc/ 90% petroleum spirits as eluent. After rotary evaporation and high-vacuum removal of solvents, 11 (9.15 g, 76%) was isolated. δ_H (400 MHz, CDCl₃) 5.25 (d, 2H, J 0.8, H₂C=), 5.09 (d, 2H, J 1.2, H₂C=), 5.02 (s, 2H, H₂C=), 4.20 (d, 4H, J 0.8, $2 \times \text{ClCH}_2$), 3.21 (d, 8H, J 1.2, $4 \times \text{SCH}_2$ -allyl). δ_C (100 MHz, CDCl₃) 141.0 (2 × C=), 140.2 (1 × C=), 117.6 (2 × H₂C=), 116.5 $(1 \times H_2C=)$, 46.1 $(2 \times CH_2Cl)$, 34.8 $(2 \times CH_2-allyl)$, 33.8 (2 × CH₂-allyl). Mp 54–58 °C. m/z (ESI, in CHCl₃/MeOH) 319 (100%, $[M + Na]^+$). *m/z* HRMS (ESI) Calc. for $C_{12}H_{18}Cl_2^{32}S_2Na: 319.0125$. Found: 319.0113. Note: the product

was diluted as a 1:1 compound:dichloromethane solution and stored at 10°C to inhibit **11** going off.

2,2'-(2-Methylenepropane-1,3-diyl)bis(sulfanediyl) diethanol (**12**)

A mixture of 6 (7.50 g, 60.00 mmol) and 2-mercaptanethanol (9.60 g, 122.9 mmol) was added neat within 30 min to a suspension of sodium hydride (3.0 g, 125 mmol) in THF (120 mL) at 20°C. After an induction time of 5 to 10 min a slow evolution of hydrogen gas resulted with an increase in reaction temperature to 45°C. This mixture was then further stirred for 24 h at 20°C. This mixture was diluted with THF (50 mL) and filtered over a 4 cm bed of silica gel (5 cm diameter). The filter was further eluted with THF (200 mL) and the combined filtrate rotary evaporated dry to give, after high-vacuum drying at 90°C, a viscous oil of **12** (10.10 g, 81 %). $\delta_{\rm H}$ (300 MHz, CDCl₃) 5.01 $(d, 2H, J 0.6, H_2C=)$ 3.69 $(t, 4H, J 6.0, 2 \times OCH_2)$, 3.29 $(s, 4H, J 6.0, 2 \times OCH_2)$ $2 \times \text{SCH}_2$ -allyl), 2.62 (t, 4H, J 6.0, $2 \times \text{SCH}_2$), 2.5 (br s, $2 \times$ OH). $\delta_{\rm C}$ (75 MHz, CDCl₃) 140.6 (C=), 116.3 (H₂C=), 60.4 $(2 \times \text{OCH}_2)$, 35.1 $(2 \times \text{SCH}_2\text{-allyl})$, 34.1 $(2 \times \text{SCH}_2)$. m/z (EI) 208 (6 %, M⁺); 163 (24), 131 (93), 130 (32), 99 (61), 86 (39), 85 (100), 55 (44). m/z HRMS Calc. for C₈H₁₆O₂³²S₂: 208.0586. Found: 208.0581.

2,2'-(2-Methylenepropane-1,3-diyl)bis(sulfanediyl) diethanol (**12**): K₂CO₃ method

2-Mercaptoethanol (2.00 g, 25.60 mmol) in butanone (3 mL) was added to potassium carbonate (4.45 g, 32.20 mmol) and BTEAC (0.06 g) as a phase transfer catalyst. Compound **6** (1.27 g, 10.16 mmol) was then added to the stirred reaction mixture upon which the reaction mixture became warm. This mixture was further stirred for 18 h at 75°C. The reaction mixture was then diluted with EtOAc (12 mL) and filtered over a 2 cm bed of silica gel (3 cm diameter). The filter was further eluted with EtOAc (100 mL) and the clear combined filtrate rotary evaporated dry on a hot waterbath (90°C) to give a clear, viscous oil of **12** (1.97 g, 93%).

11-Methylene-3,6,16,19-tetraoxa-9,13-dithiahenicosane-1,21-diol (**13**) using Compound **6**

A mixture of 6 (1.50 g, 12.0 mmol, 1 equiv.) and crude 2-(2-(2mercaptoethoxy)ethoxy)ethanol (4.10 g, 24.66 mmol, 2.1 equiv.) was added neat in 5 min to a suspension of sodium hydride (0.60 g, 25.00 mmol, 2.1 equiv.) in THF (20 mL). An immediate, very rapid evolution of hydrogen gas occurred, foaming up into the overflow bulb and the reaction was exothermic (>50°C). The now yellowish-white reaction mixture was stirred overnight at 20°C and then diluted with THF (30 mL) and filtered over a 3 cm bed of silica gel (3 cm diameter). The filter was further eluted with THF (30 mL) and the filtrate rotary evaporated dry on a hot waterbath (70°C) to give a viscous oil of **13** (4.52 g, 98%). $\delta_{\rm H}$ (200 MHz, CDCl₃) 5.00 (s, 2H, H₂C=), 3.7–3.55 $(2 \times m, 12H, 6 \times OCH_2)$, 3.60 (s, 8H, $2 \times$ OCH_2CH_2O), 3.30 (s, 4H, 2 × SCH₂-allyl), 2.60 (t, J 6.8, 4H, $2 \times CH_2S$), 2.6 (br s, 2H, $2 \times OH$). δ_C (100 MHz, CDCl₃) 140.9 (C=), 116.0 (H₂C=), 72.5, 70.6, 70.4, 70.3 (8 × CH₂O), 61.7 $(2 \times CH_2OH)$, 35.7 $(2 \times SCH_2-allyl)$, 30.4 $(2 \times CH_2S)$. m/z(ESI, in MeOH, 100 eV cone voltage) $407 (100\%, [M + Na]^+)$. m/z HRMS (ESI) Calc. for C₁₆H₃₂O₆³²S₂Na: 407.1538. Found: 407.1534.

11-Methylene-3,6,16,19-tetraoxa-9,13-dithiahenicosane-1,21-diol (**13**) using Compound **7**

A mixture of 7 (1.20 g, 10.0 mmol, 1 equiv.) and 2-(2-(2-chloroethoxy)ethoxy)ethanol (3.50 g, 20.76 mmol, 2.1 equiv.) was added neat within 2 min to a suspension of sodium hydride (0.51 g, 21.25 mmol, 2.1 equiv.) in THF (20 mL) at 20°C. An immediate evolution of hydrogen gas occurred and the reaction was exothermic (50° C) and was cooled in a waterbath. This now yellowish-white reaction mixture was stirred for 24 h and was diluted with THF (30 mL) and filtered over a 3 cm bed of silica gel (3 cm diameter). The filter was further eluted with THF (30 mL) and the filtrate rotary evaporated dry on a hot waterbath (70° C) to give the crude product **13** (2.71 g, 71 %).

2,2'-(7-Methylene-2,12-dioxa-5,9-dithiatridecane-1, 13-diyl)dioxirane (**15**)

Crude 12 (2.90 g, 13.94 mmol, 1 equiv.) was added within 5 min to a mixture of NaOH (7.00 g, 175 mmol, 12 equiv.), BTEAC (0.60 g, 3.00 mmol), water (0.60 g, 16.7 mmol, 1.2 equiv.), and epichlorohydrin (16.00 g, 173.9 mmol, 13 equiv.) and stirred for 40 min at 40°C. The reaction mixture was then cooled to 20°C and the solid paste was washed twice with CH₂Cl₂ (50 mL) to dissolve all organic material. The combined CH₂Cl₂ layer was washed with water (50 mL) and the organic layer dried over sodium sulfate. This solution was then treated with petroleum spirits (50 mL) and filtered over silica gel and the silica gel was eluted with 50% ethyl acetate/50% petroleum spirits. Rotary evaporation of the filtrate on a hot waterbath (90°C) gave a crude oil of **15** (2.15 g, 48 %). δ_H (300 MHz, CDCl₃) 4.96 (s, 2H, H₂C=), 3.71 (dd, 2H, *J* 11.6, 3.0, 2 × OC*H*₂CH^{-O-}CH₂), 3.63 (dd, 2H, J 9.6, 6.6, 2 × OCH₂CH₂S), 3.56 (dd, 2H, J 9.6, 6.6, $2 \times OCH_2CH_2S$), 3.33 (dd, 2H, J 11.6, 5.7, $2 \times OCH_2CH_2^{-O-}$ CH₂), 3.27 (s, 4H, $2 \times$ SCH₂-allyl), 3.08 (m, 2H, $2 \times$ CH^{-O-} CH₂), 2.73 (dd, 2H, J 5.1, 4.8, 2 × CH^{-O-}CH₂), 2.55 (dd, 4H, J 6.9, 6.9, $2 \times \text{SCH}_2$), 2.54 (m, 2H, $2 \times \text{CH}^{-O}$ -CH₂). δ_{C} $(75 \text{ MHz}, \text{CDCl}_3) 140.8 \text{ (C=)}, 115.9 \text{ (H}_2\text{C=)}, 71.5 \text{ (}2 \times \text{OCH}_2\text{)},$ 70.6 (2 × OCH₂), 50.7 (2 × $CH^{-O-}CH_2$), 44.0 (2 × $CH^{-O-}CH_2$), 35.6 (2 × SCH₂-allyl), 30.4 (2 × SCH₂CH₂O). m/z (EI) 320 (4%, M⁺), 219 (29), 187 (100), 117 (20), 113 (22), 99 (17), 87 (20), 86 (38), 85 (43), 61 (20), 57 (49), 55 (14). m/z HRMS Calc. for C₁₄H₂₄O₄³²S₂: 320.1111. Found: 320.1103.

2,2'-(13-Methylene-2,5,8,18,21,24-hexaoxa-11,15dithiapentacosane-1,25-diyl)dioxirane (**16**)

Crude 13 (5.40 g, 14.04 mmol, 1 equiv.) was rapidly added within 5 min to a mixture of NaOH (7.00 g, 175 mmol, 12 equiv.), BTEAC (0.60 g, 3.00 mmol), water (0.60 g, 16.70 mmol, 1.2 equiv.), epichlorohydrin (16.00 g, 173.9 mmol, 13 equiv.), and stirred for 40 min at 40°C. The reaction mixture was then cooled to 20°C and the solid paste was washed twice with CH₂Cl₂ (50 mL) to dissolve all organic material. The combined CH₂Cl₂ layer was washed with water (50 mL) and the organic layer dried over sodium sulfate. This solution was then treated with 50 mL of petroleum spirits and filtered over silica gel and the silica gel was eluted with 50 % ethyl acetate/50 % petroleum spirits. Rotary evaporation of the filtrate on a hot waterbath (90°C) gave a crude oil of 16 (3.85 g, 55%). $\delta_{\rm H}$ (400 MHz, CDCl₃) 5.00 (s, 2H, H₂C=), 3.72 (dd, 2H, J 11.7, 3.2, $2 \times$ $OCH_2CH^{-O-}CH_2$, 3.7–3.6 (m, 12H, 6 × OCH₂), 3.60 (s, 8H, CH₂), 3.31 (s, 4H, $2 \times$ SCH₂-allyl), 3.14 (m, 2H, $2 \times$ CH^{-O-} CH_2), 2.78 (dd, 2H, J 4.8, 4.8, 2 × $CH^{-O-}CH_2$), 2.61 (t, J 6.4, 4H, 2 × SCH₂), 2.60 (m, 2H, 2 × OCH₂CH^{-O-}CH₂). $\delta_{\rm C}$ (100 MHz, CDCl₃) 140.9 (C=), 116.0 (H₂C=), 72.0 (2 × OCH₂), 70.8 (2 × OCH₂), 70.7 (6 × OCH₂), 70.4 (2 × OCH₂), 50.8 (2 × CH^{-O-}CH₂), 44.3 (2 × CH^{-O-}CH₂), 35.7 (2 × SCH₂-allyl), 30.4 (2 × SCH₂CH₂O). *m/z* (EI) 496 (4 %, M⁺): 307 (76); 275 (100), 144 (25), 117 (72), 115 (97), 113 (28), 101 (43), 87 (43), 86 (32), 85 (29), 57 (57). *m/z* (HRMS) Anal. Calc. for C₂₂H₄₀O₈³²S₂: 496.2159. Found: 496.2166.

2,2'-Oxybis(ethane-2,1-diyl)bis((2-(chloromethyl)allyl) sulfane) (**19**) and 2,22-Bis(chloromethyl)-12-methylene-7,17-dioxa-4,10,14,20-tetrathiatricosa-1,22-diene (**20**)

A mixture of **6** (7.50 g, 60.0 mmol, 6 equiv.) and 2,2'oxydiethanethiol (17) (1.37 g, 9.91 mmol, 1 equiv.) was added neat in one addition to a suspension of sodium hydride (0.60 g, 25.00 mmol, 2.5 equiv.) in THF (30 mL) under nitrogen. After the addition, the reaction mixture reacted very slowly, evolving hydrogen gas, and was stirred overnight. NMR analysis showed that only about half of the reaction mixture had reacted. The grey suspension mixture was then treated with anhydrous methanol (0.5 mL) which resulted in an immediate evolution of hydrogen gas and the grey mixture become light-yellow. The reaction mixture was stirred at 20°C for 48 h. This mixture was then diluted with THF (30 mL) and filtered over a 3 cm bed of silica gel (3 cm diameter). The filter was further eluted with THF (20 mL) and the filtrate rotary evaporated dry on a hot waterbath (70°C) to give the crude product as a slightly pale-yellow oil (2.95 g). Excess 6 (1.69 g, 33.7 %) was also recovered. This crude product was then chromatographed on 50 g of silica gel (30 cm column) and eluted with 5 % EtOAc/95 % petroleum spirits to give **19** (1.65 g, 56%) $\delta_{\rm H}$ (400 MHz, CDCl₃) 5.24 (dt, 2H, J0.8, 0.8, H₂C=), 5.11 (dt, 2H, J0.8, 0.8, H₂C=), 4.20 (d, 4H, J 0.8, $2 \times ClCH_2$), 3.60 (t, 4H, J 6.8, $2 \times OCH_2$), 3.34 (d, 4H, J 0.8, 2 × SCH₂-allyl), 2.61 (t, 4H, J 6.8, 2 × SCH₂). $\delta_{\rm C}$ $(100 \text{ MHz}, \text{ CDCl}_3)$ 141.3 $(2 \times \text{C}=)$, 117.5 $(2 \times \text{H}_2\text{C}=)$, 70.6 $(2 \times \text{OCH}_2)$, 45.9 $(2 \times \text{ClCH}_2)$, 35.3 $(2 \times \text{SCH}_2\text{-allyl})$, 30.8 $(2 \times CH_2S)$. m/z (EI) 314 (2%, M⁺), 227 (42), 225 (100), 151 (36), 149 (97), 121 (71), 120 (33), 113 (85), 89 (56), 85 (41), 61 (25). m/z HRMS Calc. for $C_{12}H_{20}O^{35}Cl_2^{32}S_2$: 314.0327. Found: 314.0317. Further elution with 90% hexanes/10% EtOAc gave 20 (0.35 g, 14%). $\delta_{\rm H}$ (300 MHz, CDCl₃) 5.22 $(d, 2H, J0.9, H_2C=), 5.09 (dt, 2H, J0.9, 0.9, H_2C=), 4.99 (s, 2H, J0.9, L_2C=), 4.99 (s, 2H, L_2C=), 4.99 (s,$ $H_2C=$), 4.18 (d, 4H, J 0.9, 2 × ClCH₂), 3.58 (t, 4H, J 6.6, 2 × OCH₂), 3.57 (t, 4H, J 6.6, 2 × OCH₂), 3.32 (d, 4H, J 0.9, 2 × SCH₂-allyl), 3.30 (s, 4H, 2 × SCH₂-allyl), 2.59 (t, 4H, J 6.6, $2 \times \text{SCH}_2$), 2.58 (t, 4H, J 6.6, $2 \times \text{SCH}_2$). δ_C (75 MHz, CDCl₃) 141.2 (2 × C=), 140.9 (C=), 117.5 (2 × H_2C =), 116.0 (H_2C =), 70.5 $(2 \times \text{OCH}_2)$, 70.4 $(2 \times \text{OCH}_2)$, 45.8 $(2 \times \text{ClCH}_2)$, 35.8 $(2 \times \text{SCH}_2\text{-allyl}), 35.2 (2 \times \text{SCH}_2\text{-allyl}), 30.6 (4 \times \text{CH}_2\text{S}). m/z$ (ESI, in MeOH) 527 (91 %, [M + Na]⁺), 403 (100), 337 (67). m/z HRMS (ESI) Calc. for C₂₀H₃₄O₂³⁵Cl₂³²S₄Na: 527.0697. Found: 527.0716.

2,15-Bis(chloromethyl)-7,10-dioxa-4,13-dithiahexadeca-1,15-diene (**21**) and 2,28-Bis(chloromethyl)-15-methylene-7,10,20,23-tetraoxa-4,13,17,26-tetrathianonacosa-1,28-diene (**22**)

A mixture of **6** (7.00 g, 56.00 mmol, 6 equiv.) and distilled **18** (1.65 g, 9.05 mmol, 1 equiv.) was added neat in one addition to a stirring grey suspension of sodium hydride (0.45 g, 18.75 mmol, 2.04 equiv.) in THF (30 mL) at 20°C. An immediate, very rapid evolution of hydrogen gas occurred and the reaction was

exothermic (50°C). This now yellowish-white reaction mixture was then stirred overnight at 20°C and then diluted with THF (30 mL) and filtered over a 3 cm bed of silica gel (3 cm diameter). The filter was further eluted with THF (30 mL) and the combined filtrate rotary evaporated dry on a hot waterbath (70°C) to give 4.9 g of crude product as an opaque oil. Chromatography of the crude product on 90 g of silica gel (30 cm column) started with slow elution with 5% EtOAc/95% hexanes and after 100 mL of eluent increased to 10 % EtOAc/ 90 % hexanes and then to 15 % EtOAc/85 % hexanes to give 21 (1.33 g, 41 %). δ_{H} (300 MHz, CDCl₃) 5.24 (d, 2H, J1.0, H₂C=), 5.11 (dt, 2H, J 1.0, 1.0, H₂C=), 4.20 (d, 4H, J 1.0, 2 × CH₂Cl), 3.63 (t, 4H, J 6.6, $2 \times CH_2O$), 3.60 (s, 4H, $2 \times CH_2O$), 3.34 (d, 4H, J 1.0, 2 × SCH₂-allyl), 2.62 (t, 4H, J 6.6, 2 × CH₂S). $\delta_{\rm C}$ (75 MHz, CDCl₃) 141.3 (2 × C=), 117.5 (2 × H₂C=), 70.9 $(2 \times \text{OCH}_2)$, 70.5 $(2 \times \text{OCH}_2)$, 45.9 $(2 \times \text{ClCH}_2\text{-allyl})$, 35.2 $(2 \times \text{SCH}_2\text{-allyl})$, 30.6 $(2 \times \text{CH}_2\text{S})$. m/z (ESI) 381 (100%, $[M + Na]^+$; *m/z* HRMS (ESI) Calc. for $C_{14}H_{24}O_2^{35}Cl_2^{32}S_2Na$: 381.0492. Found: 381.0500. Further elution with 20 % EtOAc/ 80 % hexanes gave 22 (0.35 g, 13 %). $\delta_{\rm H}$ (300 MHz, CDCl₃) 5.24 (d, 2H, J0.9, H₂C=), 5.11 (d, 2H, J0.9, H₂C=), 5.01 (s, 2H, H₂C=), 4.20 (d, 4H, J 0.9, 2 × CH₂Cl), 3.63 (t, 4H, J 6.9, 2 × CH_2O), 3.62 (t, 4H, *J* 6.9, 2 × CH_2O), 3.61 (s, 8H, 4 × CH_2O); 3.34 (d, 4H, J0.9, $2 \times$ SCH₂-allyl), 3.32 (s, 4H, $2 \times$ SCH₂-allyl), 2.62 (t, 8H, J 6.9 Hz, $4 \times CH_2S$). δ_C (75 MHz, CDCl₃) 141.2 $(2 \times C=)$, 141.0 (C=), 117.5 $(2 \times H_2C=)$, 116.1 (H₂C=), 70.9 $(2 \times \text{OCH}_2)$, 70.8 $(2 \times \text{OCH}_2)$, 70.5 $(2 \times \text{OCH}_2)$, 70.4 $(2 \times$ OCH_2), 45.9 (2 × ClCH₂-allyl), 35.8 (2 × SCH₂-allyl), 35.2 $(2 \times \text{SCH}_2\text{-allyl}), 30.6 (2 \times \text{CH}_2\text{S}), 30.5 (2 \times \text{CH}_2\text{S}). m/z$ (ESI) $615 (79\%, [M + Na]^+), 529 (26), 419 (29), 437 (28), 319 (100).$ m/z HRMS (ESI) Calc. for C₂₄H₄₂O₄³⁵Cl₂³²S₄Na: 615.1241. Found: 615.1240.

(2-Methylenepropane-1,3-diyl)bis(sulfanediyl) dimethanol (23)

Paraformaldehyde (1.20 g, 39.96 mmol) and 7 (2.40 g, 19.96 mmol) were mixed to a paste and stirred and heated at 130°C. After 1 h the paste had become a translucent gel and was cooled to 20°C. This mixture was dissolved in acetone, the opaque solution filtered over Celite, and evaporated to give a clear oil of **23** (3.60 g, 99%). $\delta_{\rm H}$ (200 MHz, CDCl₃) 5.13 (s, 2H, H₂C=), 4.68 (s, 4H, 2 × SCH₂OH), 3.45 (s, 4H, 2 × SCH₂-allyl), 2.6 (br s, 2H, 2 × OH). $\delta_{\rm H}$ (200 MHz, [D₆]DMSO) 5.56 (t, 2H, *J* 7.0, 2 × OH), 5.04 (s, 2H, H₂C=), 4.54 (d, 4H, *J* 7.0, 2 × SCH₂OH), 3.33 (s, 4H, 2 × SCH₂-allyl). $\delta_{\rm C}$ (50 MHz, CDCl₃) 141.2 (C=), 116.6 (H₂C=), 65.2 (2 × OCH₂), 34.0 (2 × SCH₂-allyl).

Attempted Reaction of **23** with Epichlorohydrin Under Strong Basic Conditions

Crude **23** (2.60 g, 14.42 mmol, 1 equiv.) was rapidly added within 5 min to a mixture of NaOH (3.50 g, 87.5 mmol, 6.1 equiv.), BTEAC (0.30 g, 1.50 mmol), water (0.30 g, 16.67 mmol, 1.2 equiv.), epichlorohydrin (8.00 g, 88.35 mmol, 6.1 equiv.), and stirred for 40 min at 40°C. The reaction mixture was then cooled to 20°C and the solid paste was washed twice with CH₂Cl₂ (30 mL) to dissolve all organic material. The combined CH₂Cl₂ layer was washed with water (20 mL) and the organic layer dried over sodium sulfate. This solution was then treated with petroleum spirits (10 mL) and filtered over silica gel and the silica gel was eluted with 50 % ethyl acetate/ 50 % petroleum spirits. Rotary evaporation of the filtrate on a hot waterbath (90°C) gave a crude oil of **8** (2.05 g, 61 %).

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